NEUVis: Comparing Affective and Effective Visualisation

Phillip Gough

Design Lab: Faculty of Architecture, Design and Planning
The University of Sydney

2016

A thesis submitted in partial fulfilment of requirements
for the degree of Doctor of Philosophy

Abstract

Data visualisations are useful for providing insight from complex scientific data. However, even with visualisation, scientific research is difficult for non-scientists to comprehend. When developed by designers in collaboration with scientists, data visualisation can be used to articulate scientific data in a way that non-experts can understand. Creating human-centred visualisations is a unique challenge, and there are no frameworks to support their design.

In response, this thesis presents a practice-led study investigating design methods that can be used to develop Non-Expert User Visualisations (NEUVis), data visualisations for a general public, and the response that people have to different kinds of NEUVis.

For this research, two groups of ten users participated in quantitative studies, informed by Yvonna Lincoln and Egon Guba's method of Naturalistic Inquiry, which asked non-scientists to express their cognitive and emotional response to NEUVis using different media. The three different types of visualisations were infographics, 3D animations and an interactive installation. The installation used in the study, entitled 18S rDNA, was developed and evaluated as part of this research using John Zimmerman's Research Through Design methodology. 18S rDNA embodies the knowledge and design methods that were developed for this research, and provided an opportunity for explication of the entire NEUVis design process.

The research findings indicate that developing visualisations for the non-expert audience requires a new process, different to the way scientists visualise data. The result of this research describes how creative practitioners collaborate with primary researchers and presents a new human-centred design thinking model for NEUVis. This model includes two design tools. The first tool helps designers merge user needs with data they wish to visualise. The second tool helps designers take that merged information and begin an iterative, user-centred design process.

Keywords

Non-expert user visualisation, NEUVis, data visualisation, user-centred design, design thinking, design methodology, research through design, naturalistic inquiry, wicked problems, artistic visualisation, scientific visualisation, information visualisation, infoVis, visual analytics, science communication, human-computer interaction, user interface design, museum installations.

Contents

List of Figures

List of Tables

Statement of Original Authorship

This is to certify that to the best of my knowledge, the content of this thesis is my own work. This thesis has not been submitted for any degree or other purposes.

I certify that the intellectual content of this thesis is the product of my own work and that all the assistance received in preparing this thesis and sources have been acknowledged.

The research documented in this thesis was conducted with ethical approval from the Human Research Ethics Committees of The University of Sydney.

Signature: ――――――――――――――――――――――――――――
Name: Phillip Gough
Date: 16th September, 2016.

Attribution of published material included as part of the body of this thesis

In addition to the statement above, in cases where I am not the corresponding author of a published item, permission to include the published material has been granted by the corresponding author

Signature: ――――――――――――――――――――――――――――
Name: Phillip Gough
Date: 16th September, 2016.

As supervisor for the candidature upon which this thesis is based, I can confirm that the authorship attribution statements in this thesis are correct.

Signature: ――――――――――――――――――――――――――――
Name: Dr Caitilin de Bérigny
Date: 16th September, 2016.

Acknowledgements

Chapter 1

Introduction

Preamble

This chapter is based on a paper I presented at IEEE Pacific Visualization Symposium 2014, in Yokohama, Japan, March 4 -7, 2014 [85]. The paper was peer-reviewed and published in the conference proceedings by The Institute of Electrical and Electronics Engineers (IEEE). My contribution to this paper has been substantially expanded and updated for inclusion in this thesis.

Gough, P., Wall, C. de B., & Bednarz, T. (2014). Affective and Effective Visualisation: Communicating Science to Non-expert Users. In *2014 IEEE Pacific Visualization Symposium* (pp. 335–339). Yokohama: IEEE. doi:10.1109/PacificVis.2014.39.

The rate of progress is so rapid that what one learns at school or university is always a bit out of date. Only a few people can keep up with the rapidly advancing frontier of knowledge, and they have to devote their whole time to it and specialize in a small area. The rest of the population has little idea of the advances that are being made or the excitement they are generating. Seventy years ago, if Eddington is to be believed, only two people understood the general theory of relativity. Nowadays tens of thousands of university graduates do, and many millions of people are at least familiar with the idea.

—Stephen Hawking, in *A Brief History of Time*.

Science is the key to our future, and if you don't believe in science, then you're holding everybody back. And it's fine if you as an adult want to run around pretending or claiming that you don't believe in evolution, but if we educate a generation of people who don't believe in science, that's a recipe for disaster.

—Bill Nye in an interview with *Popular Mechanics*

1.1   Science and the General Public

On the morning of September 24th, 2013, the Climate Council was officially launched in Australia. Its launch followed a federal election which saw a change in government, and dissolution of the Australian Climate Commission. The Climate Council, a new, independent organisation, was formed to carry on the same work as the Climate Commission: provide accurate, authoritative, apolitical, and easy-to-understand information to the Australian public about climate change. However, the Climate Council relied on crowdfunding, that is, many small donations from the public [92].

By mid-afternoon of their first day, the Climate Council raised $165,000, just over one tenth of the annual funding that was previously provided to the government body, mostly by small donations from individuals [155]. In less than two weeks, more than $1 million had been raised from over 20,000 donations, averaging about $50 each [5]. The Climate Council's website claims that this was Australia's biggest crowdfunding campaign [40].

The public understands the need to engage with scientific information, and the Climate Council is just one example [44, 210]. On the morning of the campaign launch, Professor Tim Flannery, Chief Commissioner of the Climate Commission and leader of the new Climate Council, made a statement:

"An informed public is crucial to a functioning democracy." [92]

Informing the population about science isn't a new problem; in 1985 Alan McGowan, President of the Scientists' Institute for Public Information published a paper titled *Science and the Media: The Vital Connection*. McGowan highlights how:

Figure 1.1: A still image from *The Hungry Microbiome* (2014). Animation and narration by Christopher Hammang. Published by CSIRO under Creative Commons Attribution Licence.

> In one sense, it has all been said before. That is, that the electorate must be educated in science and technology in order for it to make informed decisions. The scientific community has even been criticized for not doing enough. [134, p. 353]

The case of the Climate Council shows how important it is that scientific research be digested from research findings into a form which is meaningful, honest, objective, and consumable by the general public. It should not simply be expected that the general public has the time, effort, access, and understanding of science to interpret scientific papers, even if there is a desire for the knowledge. This desire creates a space and a need for creative practice to engage with the problem: not to change scientific processes or publishing, but to act as a bridge between the scientific community and the general public. The creative output of art and design act as this bridge. The work of creative practitioners, such as designers, artists, animators or programmers [86], centralises the work necessary to bridge this gap. The benefit of this centralisation is the distribution of understanding.

This can be done by visualising scientific information for the non-expert audience. Visualisations take effort to produce, as well as investment in time and, probably, money.

Consider a 3D animation, such as *The Hungry Microbiome*, produced in 2014 by CSIRO and funded by a grant from Inspiring Australia, a strategy from the Australian Government to increase engagement with science (see figure 1.1). A superficial look at what goes into producing this visualisation shows that the animator needs to:

- Have an interesting subject, in this case, determined by a brief from the funding body and scientific stakeholders.

- Develop the scientific literacy required to understand the specific research relating to the subject. The animator of *The Hungry Microbiome*, Chris Hammang, has prior experience studying medical science and cell biology in addition to animation.

- Discern what information from the research will be interesting to the intended audience.

- Compose a script and storyboard to communicate the information.

- Use specialised skills, time and resources to develop the animation.

A project like this could take weeks, or even months to produce. It may require teams of people with specialised and diverse skills in a range of disciplines. Different visualisation methods, such as infographics, could be less time-consuming, or easier for the creative practitioner to understand. However, any visualisation requires some kind of resource investment. Even though decreasing video production costs may reduce the investment in resources, there is an abundance of high-quality video available to the user [59]. This ultimately means that the production quality must increase, in order to stand out among the competition. This ultimately may require increase the required investment of time and effort. The return on centralising that effort is that it allows many people to benefit from the understanding that the animator has to develop in order to produce the video. The right visualisation can leverage the ubiquity and familiarity of social media and modern media consumption; a video can be shared thousands of times, and be available to the general public for years[1]. The total investment of resources for one animator is much less than an equivalent investment of thousands of potential viewers. To centralise the understanding of science and distribute it in an accessible way is to democratise scientific understanding. Rather than distributed workload, it distributes benefit; rather than isolating knowledge, it empowers with it.

Communicating science to the general public also benefits the scientific community. Effective science communication can encourage favourable attitudes towards publicly funded science research, supporting the scientific community [206]. Voters and policy makers will develop informed attitudes to not only the content of science, but the importance of funding. It has been suggested that a general public who is ignorant of science may resist investment in science, though no link has been shown. Informing the public about science is the reason for communicating science, not acquiring public funding [88]

The public is interested in, and can see the benefit of visualising scientific research. Of the many approaches possible to this challenge, this thesis addresses the following questions:

- What is the nature of this challenge: can, and should it be addressed by designers?

- How do audiences compare different approaches that designers may take?

---

[1]At the time of writing, *The Hungry Microbiome* had over 130,000 views on youtube. Available at `https://youtu.be/NI3KtR3LoqM`

If communicating science to non-scientists is an appropriate problem for the practice of design, it should be able to framed as a *Wicked Problem*.

1.2   Wicked Problems

Nigel Cross, emeritus Professor of Design Studies at the Open University, UK, describes wicked problems as

> Fundamentally un-amenable to the techniques of science and engineering [50, 49].

Scientific method addresses *tame* problems. This is not to say that tame problems are simple problems; many tame problems are very complex. Likewise wicked problems may be simple, but the nature of the problem is different. If the challenge of designing visualisations for the general public is wicked, it should show the characteristics of wicked problems, rather than tame ones.

The term "wicked problems" was first used by Horst Rittel [166], he describes them as:

> Social system problems which are ill-formulated, where the information is confusing, where there are many clients and decision makers with conflicting values, and where the ramifications in the whole system are thoroughly confusing. [38, 21]

The term was expanded (and popularised) by Richard Buchanan in his seminal work *Wicked Problems in Design Thinking* [21]. Buchanan reframed wicked problems from a description of planning issues to include design thinking: [21, p.16]

1. Wicked problems have no definitive formulation, but every formulation of a wicked problem corresponds to the formulation of a solution.

2. Wicked problems have no stopping rules.

3. Solutions to wicked problems cannot be true or false, only good or bad.

4. In solving wicked problems there is no exhaustive list of admissible operations.

5. For every wicked problem there is always more than one possible explanation, with explanations depending on the [intellectual perspective] of the designer.

6. Every wicked problem is a symptom of another "higher level" problem.

7. No formulation and solution of a wicked problem has a definitive test.

8. Solving a wicked problem is a "one shot" operation, with no room for trial and error.

9. Every wicked problem is unique.

10. The wicked problem solver has no right to be wrong-they are fully responsible for their actions.

This list was summarised by Jeff Conklin in [41, p.8] as:

1. You don't understand the problem until you have developed a solution.

2. Wicked problems have no stopping rules.

3. Solutions to wicked problems are not right or wrong.

4. Every wicked problem is essentially unique and novel.

5. Every solution to a wicked problem is a one-shot operation.

6. Wicked problems have no given alternative solutions.

These outlines provide a guide for determining whether it is suitable to approach visualisation of science for non-scientists using design methods.

Every wicked problem is a symptom of another "higher level" problem

The high-level problem is often difficult to solve in the short-term, though its symptoms need to be addressed immediately.

The underlying issue is not how to best design visualisations for the general public, rather, it is that there is a need for a deeper understanding of science among the general public. Visualising scientific research will help increase the level of understanding for people who engage with the content, but it is not a solution to the higher problem.

You don't understand the problem until you have developed a solution

The problem is ill-structured, or ill-defined. Proposed solutions expose new aspects of the problem, which requires adjustment of the solution. Problems require a solution in order to be understood.

Balancing the specific context of the audience and the constraints of the designer requires testing and iteration. Developing potential solutions into testable prototypes will allow the designer to gauge the response of the intended audience of the visualisation.

Wicked problems have no stopping rule

Since it is not possible to definitively state the problem, it is also difficult to definitively state the solution. Wicked problems are solved by solutions that are *adequate* rather than *correct*.

A visualisation aimed at the general population may be endlessly tweaked, refined and improved. It may be the case that the most adequate solution is selected when funds, time or energy run out. There is no definitive way of knowing when the final design has been reached. However, it is possible to find the best solution, within the problem space.

Solutions to wicked problems are not right or wrong

Just as the selected answer is *adequate* rather than *correct*, one answer may be *better* or *worse* than another, instead of *right* or *wrong*, *true* or *false*.

There are many ways to visualise information. Often one piece of information can be expressed by several different types of charts, which could be represented as an image, animation, or interactive presentation. Outside of a specific brief from a client, there may be little to guide the designer for choosing between these alternatives; except perhaps expertise, funds, time and energy. Therefore, a published visualisation may not be *correct*, but a *better* design, given the considerations that the designer has to make.

Every wicked problem is essentially unique and novel

With the constraints, considerations, requirements of a client, as well as the expertise of the designer, among many other conditions of the intended audience, the problem that faces the designer is that every wicked problem is essentially different. Experience can guide a designer, but, as Conklin states: "one is always a beginner in the specifics of a new wicked problem" [41, p.8].

There are many tools that a designer can use to create visualisations for the general public. One example is D3.js, a JavaScript library for creating data-driven websites (D3 stands for Data Driven Documents), including interactive data visualisations through manipulation of HTML, CSS and SVG elements based on data [17]. There is a large number of visualisation types that are predefined in D3.js, which allow the designer to experiment with different representations. When using a framework like D3.js, the designer leverages the experience of previous similar visualisation designs, and is able to focus their creative efforts on satisfying the unique details that are required by a particular client, with a particular set of information, for a particular audience.

Every solution to a wicked problem is a one-shot operation

Every solution to a wicked problem is expensive, has lasting consequences, and has the potential to expose a new set of wicked problems. As Rittel said "One cannot build a freeway to see how it works."[166, p. 163]

Though it is unlikely that designing a visualisation is going to have the same impact as Rittel's example, it is still expensive to develop solutions to a visualisation problem. The time and funding constraints of developing the best solution means that investigating dead-end solutions may have lasting effects on the quality of the solution ultimately published. Also, it is unlikely that new data sets can be simply uploaded to a visualisation that has been designed to show a specific dataset to a unique audience, with unique needs. Elements of visualisations are transferrable, but the particulars of any one visualisation for non-expert user audience are unique.

Wicked problems have no given alternative solutions

Conklin states that it requires *creativity* and *judgement* to solve a wicked problem [41, p.9]. There may be many potential solutions, or none. The formulation of solutions requires creativity, choosing which solution to develop requires judgement.

Tools, like D3.js, are a useful starting point for visualising information for the general public, but they are just building blocks, with which the designer constructs an entire experience for their audience. The creativity of the designer is central to the design process, and the final product [48].

If three designers are given one problem, they may each use the same process, and still come up with ten unique answers between them. Judgement on the part of the designer is required to choose which one of the answers is the best to be deployed to the audience.

Nigel Cross describes this as the *designerly* ways of knowing, thinking and acting [50]. The use of synthesis to solve problems, rather than analysis, is what makes designers suitable to address wicked problems [48]. Unlike wicked visualisation problems, tame visualisation problems can be addressed using automated and standardised methods, like those used for data visualisation for expert audiences.

1.3   Expert Visualisation

McGowan points out that the scientific community has been criticised for not doing enough to help the general population understand scientific research [134], but this may be unfair. If the nature of the problem is wicked, rather than tame, it is not a good fit for the practice that scientists usually employ. Of course this is not to say that scientists should not be involved, or that they are unable to develop new ways to communicate to an audience using designerly thinking and design methods. Rather, communicating with the non-scientific community is a good opportunity for collaboration between primary researchers (such as scientists) and creative practitioners (such as designers, artists and animators). Visualisation is a useful tool for science, and is not a novel concept for the scientific community. Scientific visualisation (sciVis) addresses the problem of gaining insight from the results of numerical simulations, computations, measurements or other real-world processes. Scientific visualisation often involves series of complex data processing operations to eventually produce an image, plot or animated sequences. This approach answers a well-defined question, reveals a fact that was not known before, or aids cognition of data through reduction and the mapping of information to spatial variables [128][2].

Scientific visualisation focuses on 3-dimensional phenomena [78], describing the physical world through realistic renderings of features such as volumes, surfaces and light sources [198]. One example is a visualisation of bone lesions described in research by CSIRO [159] (see figure 1.2). The researchers were provided with CT scans of bone, affected by myeloma (a type of bone marrow cancer) and automated the process of quantifying bone lesions—holes in the bone—through the use of complex image processing algorithms. The research involved automating and optimising the visualisation, and producing an interactive interface for exploring the data.

---

[2]In [128] Manovich describes information visualisation (infoVis) in this way. However, the principle also applies to scientific visualisation.
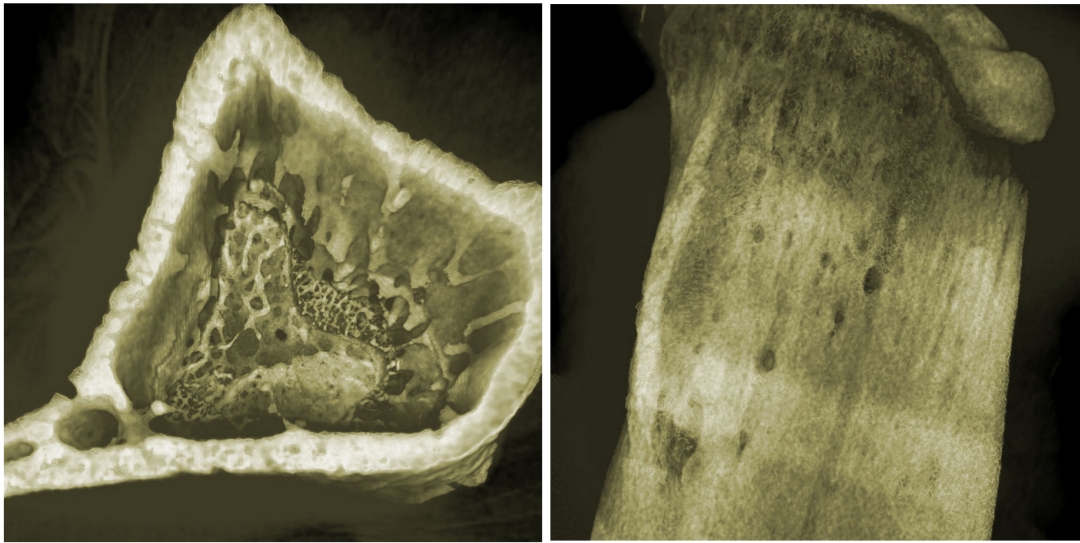
Figure 1.2: Real-time rendering of bone lesions caused by myeloma. [159]

Phenomena of the physical world is the domain of sciVis, and data that does not have a spatial variable, but already has a structure, is the domain of information visualisation (infoVis). Data of this type includes relational graphs (such as networks), tables, time series, documents, personal data and much more [198]. Relational data, without only abstract or mathematical structure, can be understood with much less difficulty by visualising the data. One example from The University of Sydney is an inspiration network (see figure 1.3) of ideas or topics that inspired games developed at the Global Game Jam, 2014 which was produced by Xavier Ho [101]. This data has no spatial variables, but positions of the inspirations (nodes) are assigned to highlight relationships with other games' inspirations.

Visualising abstract data requires that spatial arrangement (such as size and position of objects) be assigned to the most significant variables, with other variables being assigned to visual dimensions (such as colour) [128]. Visual analytics, a third visualisation field has emerged to leverage the practices used in sciVis and infoVis with data-mining to support analytical reasoning for various fields, such as business, medicine and transport: any field where decision making can be supported by an understanding of data [198]. The "information overload" described by Daniel Keim in [111], one of the defining papers in the field, is an opportunity for automated systems to be designed which support analytical reasoning. This objective of visual analytics is what primarily differentiates it from infoVis. This is expressed in the way that infoVis used the "Visual Information-Seeking Mantra"

Overview first, Filter and zoom, Details on demand, [179]

which was updated for a visual analytics approach:

Figure 1.3: Global Game Jam 2014 Inspiration Network Visualisation. Image by Xavier Ho.

> Analyze first, Show the Important, Zoom, filter and analyse further, Details on demand. [111]

It is often stated that the objective of visualisation—sciVis, infoVis and visual analytics—is to provide "insight" [33, 221, 111, 161]. Some research argues that since "gaining insight" is difficult to define and measure (how much insight? how deep was the insight?), and is not always the objective of a visualisation, that the real, tangible benefit of visualisation is saving time [37]. In addition to the difficulty of testing what insight is achieved, it is also possible to argue that insight can be gained without any visualisation, but it would take more time. However, the current research environment generates unprecedented amounts of data, which is referred to as the data deluge [37, 46, 76], a data tsunami [14], information overload [111], or simply as "big data". The downside of saying that visualisation is really about saving time is that with such large data sets, it may simply be beyond human cognitive abilities to ever gain insight from data without visualisation. Science uses visualisation to make big data an opportunity, and to remove the bottleneck in the scientific process caused my managing data that exponentially increases in volume. The rapidly expanding computational landscape has fuelled the need for visualisation algorithms to aid analysis of scientific data [14].

One other shared factor of these fields is that there is a focus on producing visualisations for a user group that already has an understanding of the domain of the data. Scientists visualise data from their own research, visual analytics practitioners visualise data to support expert decision-making in areas such as businesses or medicine. These are important research applications, but their ability to help the general public is limited.

1.4 Non-Expert Visualisation

> The non-mathematician is seized by a mysterious shuddering when he hears of "four-dimensional" things, by a feeling not unlike that awakened by thoughts of the occult.
> - Albert Einstein, in *Relativity* [66, p. 56]

Though tongue-in-cheek, Einstein's comment is still relevant after a century. The mysteries of science and technology may still astound the layperson—which is not a fault. But, seemingly esoteric knowledge can be made clear through visualisation if it is done effectively and affectively. By appealing to the emotional response to the non-expert user, data can be engaging, as well as enlightening.

Visualisation for domain experts is focused on data, and the optimal way to display it. However, when visualising science for the non-expert audience, there are a greater number of stakeholders, such that a single, unified theory of visualisation may be impossible [163]. Designing a visualisation for a broad, novice audience requires consideration about:

- How meaning is extracted from the visual stimuli (pyschophysics)[62].

- What people understand from the visualisation (cognition)[62].

- The relationship between images and meaning (semiotics)[62].

- The social and cultural context[62].

- The dynamic story underlying the data [173].

- Spectrum of experience in the population [161].

- Usage patterns (a momentary glance as part of a daily routine or contemplation of artistic re-imaginations of data) [161].

- Types of data used [161].

- Types of insight expected to be gained [161].

- The analytical power of a visualisation, or the capacity for a visualisation to communicate specific information and provide insight, and how this is effected by the chosen format of the visualisation [143].

- The point of engagement with the visualisation. [151]

- The most useful methods to employ in order that engagement with the visualisation is sustained [151], such as *gamification* [54], social motivations [151], aesthetics [157] or artistic interpretations. [216]

- The way in which a user will disengage and can reengage with the visualisation [151].

The comparison produced for this thesis in table 1.1 outlines the elementary differences between domain-expert and non-expert approaches to visualisation. The literature review in the next chapter describes the nature of both the domain expert user visualisation, and non-expert user visualisation in detail. This table shows an overview of some the additional needs of the non-expert user. The differences between these two approaches are entirely dependent on the knowledge that the audience has of the domain of the data and the different goals that data professionals and the general public have when using a visualisation. An interactive exhibition, such as the *Dino Zoo* (see figure 1.4) at Queensland University of Technology (QUT) [165] exemplifies these considerations and the differences between domain expert and non-expert visualisation. For example, the types of data used may be similar if the same message was to be used in a scientific visualisation, but it is important to develop an engaging story to entice users to uncover the data—something which is not necessary with an interested party, such as a research scientist. *Dino Zoo* also attracted a broad spectrum of guests, particularly school children, with limited experience of dinosaurs and the science about them. The type of insight to be gained is also different, *Dino Zoo* gives insight into process of removing a fossil from dig site, the way it is protected for transport, and then examined by the scientist. Obviously, this is not necessary for the scientists to be shown in a visualisation, but it informs the non-expert audience about the process and culture of science. The intuitive design of *Dino Zoo* is supported by high quality 3D scans using medical MRI technology, which are also used by scientists to investigate ancient dinosaur fossils [102, 99]. Exploring these data sets in a public context has to be natural

Table 1.1: A comparison of the attributes of domain expert and non-expert visualisation.

Domain-Expert Visualisation	Non-Expert Visualisation
sciVis, infoVis, visual analytics.	Science communication, museum installations, data art, infographics, animation (and more).
Free exploration of data through interactive displays.	Exploration of data requires some guidance into meaning and implication of data and how it relates to the user.
Cognitive aid: for creating insight about data and supporting analytical decision making.	Cognitive aid with an affective appeal: for creating insight and meaning to support function as a member of society.
Tame, well defined problems. Suitable for automation and predictable, repeatable processes.	Wicked, ill-defined problems. Suitable for iterative development using designerly approaches.
Primarily data-centric approach to representations.	Data-centred and user-centred considerations are equally important.

Figure 1.4: *Dino Zoo*. Digital installation at QUT Gardens Point Campus, Brisbane. Image by Tomasz Bednarz, used with permission.

and familiar, which also gives the user an understanding of what they are interacting with, and its social and physical affordances [20] and can be used as a site for collaborative learning [98]. A user visiting the installation at QUT will not have the same incentive to learn a complex interface, or scientific software, which may give extra information to a scientist specialising in this field. The aura of the large scale, interactive installation—the presence of huge virtual of dinosaurs in a digital, but unique here-and-now [13]—fits a usage pattern of a museum, rather than a tool for domain experts. Finally, visualising these data is a complex, wicked problem: it has no stopping rule; there is no right or wrong design; it is a unique and novel mix of context, content and technology; it is not easily adaptable to other displays or designs; and has no given solution, but requires collaboration between scientists and expert video game developers.

This chapter has described two approaches to visualisation. First, for the domain expert user through sciVis, infoVis, and visual analytics. These approaches address tame problems: well-defined challenges that can be understood at the start, and can be automated, producing predictable, consistent and reliable results. The second approach addresses a context where the audience has no specific knowledge of the domain of the data. Determining the most effective way to visualise data for the non-expert audience is difficult. If visualisation is to support the general population in decision making on important issues, climate change for example, it needs to address the cognitive and emotional response of the audience, as moods and emotions profoundly effect the way people make decisions [174]. These complex, wicked problems can be a good opportunity for collaboration. Combining intellectual and embodied experiences using multiple modalities, such as sight, sound and touch, creates new and accessible points of engagement with scientific research [103, 86]. Evocative visu-

alisation creates memorable experiences, and through transdisciplinary collaboration the uninitiated audience can engage with the complex and beautiful world of science. There is a lot more than just beautification and public outreach that creative practitioners, of all background, can offer art and science research [75]. Art, design and animation can have much to offer scientific visualisation, which will be discussed in this thesis.

The aim of thesis is to address two main questions through qualitative methods: what is the nature of NEUVis, and what are different approaches to NEUVis? Zimmerman's theoretical model of research through design provided a framework for evaluation of a designed artefact [226]. This artefact, as described in detail in chapter 5, was evaluated using Zimmerman's method, and also compared to other types of visualisation in two experiments, described in chapter 3. The experiments were conducted using qualitative methods of naturalistic inquiry [124]. The main contributions from this research are described in chapter 4. They are include: a description of the nature of collaboration between primary researchers and creative practitioners described in terms of boundary objects [27]; recommendations for engaging users with content in NEUVis contexts; and two design method tools for creating NEUVis. The thesis is organised such that a literature review, chapter 2 on page 29, follows this introduction, chapter 3 on page 61 describes the experiment and chapter 4 on page 73 describes the results from the experiments, and the main contributions listed above. Following these results, chapter 5 on page 89 describes the development of the designed artefact, and is listed after the contributions of the research, as the design tools developed after the experiment were applied to the final iteration of the design of the artefact. Finally, chapter 6 on page 113 includes a discussion of the results and conclusion.

Chapter 2

Literature Review

Preamble

This chapter is based on a peer-reviewed article I wrote for *Leonardo* journal, and accepted for publication in November 2014. It has been published on the *Leonardo* "just accepted" website before being assigned to a journal issue. The article has been substantially developed for inclusion in this chapter.

Gough, P. (Accepted November 2014). From the Analytical to Artistic: A Review of Literature on Information Visualization. *Leonardo*. doi:10.1162/LEON_a_00959

In section 2.3.3 are excerpts I contributed to a peer-reveiwed conference paper presented at *VINCI* 2014, which was also adapted into a journal article for the *International Journal of Software and Informatics*.

Gough, P., De Berigny Wall, C., & Bednarz, T. (2014). Affective and Effective Visualisation: Communicating Science to Non-expert Users. In *2014 IEEE Pacific Visualization Symposium* (pp. 335–339). Yokohama: IEEE. http://doi.org/10.1109/PacificVis.2014.39

Gough, P., Dunn, K., Bednarz, T., & Ho, X. (2015). Art and Chartjunk: A Guide for NEUVis. *International Journal of Software and Informatics*, 9(1), 61–72.

A book is made from a tree. It is an assemblage of flat, flexible parts (still called 'leaves') imprinted with dark pigmented squiggles. One glance at it and you hear the voice of another person - perhaps someone dead for thousands of years. Across the millennia, the author is speaking, clearly and silently, inside your head, directly to you. Writing is perhaps the greatest of human inventions, binding together people, citizens of distant epochs, who never knew one another. Books break the shackles of time, proof that humans can work magic.

—Carl Sagan in *Cosmos*.

If I have seen further it is by standing on ye shoulders of Giants.

—Isaac Newton in a letter to Robert Hooke, February 1675.

2.1   Introduction

Visualisation is effective because of the powerful visual processing systems in the human brain [218]. To visualise something is to make it seeable, or to make a mental image. Visualisation can be meaningful and insightful if it helps the user create a metal image of data, its structure and the relationships between individual points of data [128]. Visualisation helps the user overcome the limitations of human working memory to achieve its primary functions: saving time and facilitating insight. Comparing points of data on a graph requires much less mental agility than comparing the numbers by themselves [23]. Anscombe's Quartet is a good example of how visualisation does this: the four sets of numbers in table 2.1 are almost statistically identical, but their differences are obvious once visualised in figure 2.1.

Mathematicians, statisticians, journalists, designers, academics, science communicators, computer programmers, and many more, have published work about visualisation. This chapter will divide the body of literature into 4 sections and present some examples of visualisations which use artistic methods to communicate science to non-scientific audiences for a variety of purposes. 2.2 Visualisation Research focuses on academic investigations into visualisation. 2.3 Visualisation Practice will present literature that is aimed at the practice of creating visualisations. 2.4 Science Communication discusses some of the literature from the field of science communication that can inform creative practice. Finally, 2.5 Artistic Visualisation will present artistic research and visualisation as art.

2.2   Visualisation Research

Much of the academic literature relating to visualisation is published within the fields of scientific visualisation (sciVis), information visualisation (infoVis) and visual analytics. There is very little research that has been conducted from a design perspective, but there are many books for designers that outline best visualisation practices. These practices draw on design knowledge, but also from fields as diverse as also perceptual psychology, statistical graphics and computer science. Within this literature there is a lot of information that can contribute to a design-led approach to NEUVis.

Table 2.1: Anscombe's Quartet. Each set of numbers is almost statistically identical.

I		II		III		IV	
x	y	x	y	x	y	x	y
10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76
13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50
12.0	10.84	12.0	9.13	12.0	8.15	8.0	5.56
7.0	4.82	7.0	7.26	7.0	6.42	8.0	7.91
5.0	5.68	5.0	4.74	5.0	5.73	8.0	6.89
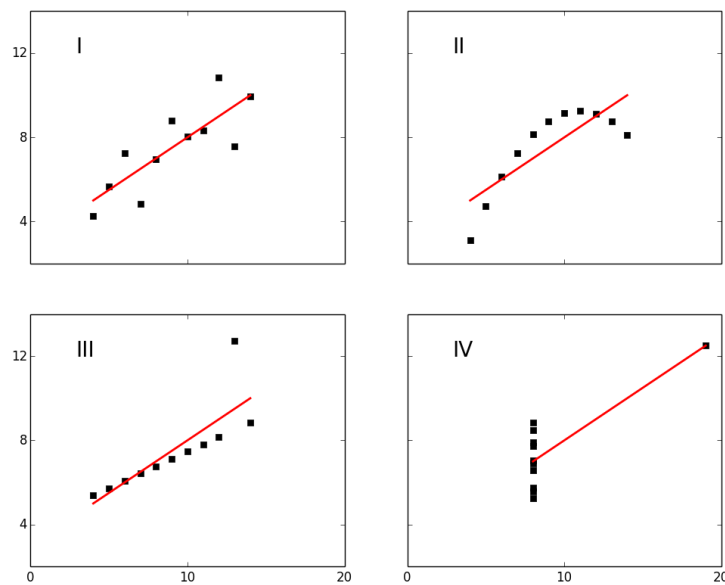
Figure 2.1: Anscombe's Quartet: Points plotted with a line to show the linear regression for each graph. The differences between each set becomes obvious only when visualised.

2.2.1   Evaluating Visualisations

Four out of five papers on the theme of 'evaluation' published at IEEE InfoVis 2014 conference [169] used two performance metrics to evaluate visualisation techniques: time and accuracy. Evaluation is a major question in infoVis, sciVis and visual analytics: *how do we evaluate visualisations?* Though IEEE InfoVis is not the only visualisation conference, [169] suggests that time spent reading a visualisation and accuracy is a major topic. Evaluation methods have been addressed many times by researchers [28, 106, 141, 169, 186, 160, 203], and is applicable to empirical research in the field of Human-Computer Interaction (HCI), perceptual psychology and cognitive research [28]. Evaluation is important to visualisation, because it can expose faults and inefficient mapping of data to graphics, showing where the visualisation can be improved, or be more effective [186].

 In 2004, Catherine Plaisant, Director of Research the University of Maryland Human-Computer Interaction Lab, published a paper which summarised the most common methods of evaluation in the maturing discipline of infoVis [160]. She includes the following:

1. *Controlled experiments that compare design elements*, such as a new interface element, or mapping between data and graphical elements.

2. *Usability evaluation of a tool*, often outlining problems which users encounter and how the designers resolved the issue.

3. *Controlled experiments, evaluating two or more tools*, which compare a novel design to the state-of-the art.

4. *Case studies of visualisation tools in realistic situations.*

Plaisant discusses how three implicit features of visualisation are not addressed by these research methods.

1. Insight, or discovery may not be instantaneous, and may require the user to look at the data from different perspectives over a long period of time.

2. Visualisation can answer questions you didn't know you had. This is inherently difficult to evaluate.

3. The benefits of visualisation may not be traced back to the visualisation itself: visualisation may be one of tools that increase the productivity of a user in the real-world, daily work context. The benefit of visualisation may not always be in the big discovery.

Empirical research into visualisation also leaves little room for evaluating qualitative insights, partly from the nature of many empirical research methods [150]. These methods often give users specific tasks, which require simple, definitive answers to questions. Researchers use this approach to measure accuracy and precision. These may be pertinent issues for infoVis and sciVis, but specific accuracies are not as relevant to NEUVis. The message or implications of scientific research may be more important than pinpoint accuracy of specific datum.

Another approach to evaluating visualisations is an expert review, such as a heuristic evaluation[1] [203]. Heuristic evaluations are common, particularly in HCI, and allow an expert to conduct an evaluation of a system against a predefined set of criteria [145], such as Jakob Nielsen's Usability Heuristics [146]. Though they should not be the exclusive method for evaluation, heuristic and other expert reviews can provide quick insight into problems with usability of visualisations, and highlight different problems than those found in user testing [203]. Usability testing and heuristic evaluation is as useful for NEUVis as it is to infoVis, sciVis and visual analytics. Interactive NEUVis systems, particularly those which use video-game elements (a practice known as 'gamification' [55]) should be evaluated using both expert evaluation and user testing. Interactive art and gamification may deliberately break the 'normal' rules of interactivity to engage the user, but the user's experience with NEUVis should be considered. Particularly if the goal is for users to gain some new knowledge or understanding of science.

Sheelagh Carpendale, director of the Innovations in Visualization Laboratory at the University of Calgary, published a review of research and evaluation methods for visualisation in 2008 [28]. This paper outlines challenges for quantitative methods in visualisation research. However, Carpendale adds:

> Quantitative evaluation is naturally precision-oriented, but a shift from high precision to high fidelity may be made with the addition of qualitative evaluations. [28, p.40]

While Carpendale acknowledges the importance of qualitative research, she notes that these methods are generally under-used and under-reported in visualisation literature, going on to note a sign that was reported to hang in Albert Einstein's office:

> *Everything that can be counted does not necessarily count; everything that counts cannot necessarily be counted.*

This is a salient point for NEUVis reserach. InfoVis and SciVis have not substantially invested in qualitative research methods, or developed similar qualitative evaluation models for visualisation.

More recent models of evaluating visualisations have included two approaches which may be useful for evaluating NEUVis. John Stasko, from the School of Interactive Computing at the Georgia Institute of Technology, published a value-driven model of evaluating visualisations in 2014 [186]. Stasko presents this evaluation of visualisation as a descriptive aid, rather than a prescriptive model. The sum of four elements create the value of visualisation:

The ability of the visualisation to answer a wide variety of questions about the data in the smallest amount of time. As discussed in section §1.3, saving time is a primary function of visualisation, but this description extends beyond most evaluations in visualisation research. Rather than asking specific questions and measuring narrow results, such as in HCI user studies, this approach specifies that visualisations should have more utility than is often measured in some studies.

---

[1]This is where an expert in interaction (such as a designer) evaluates the quality of a design according to a predefined set of rules or guidelines.
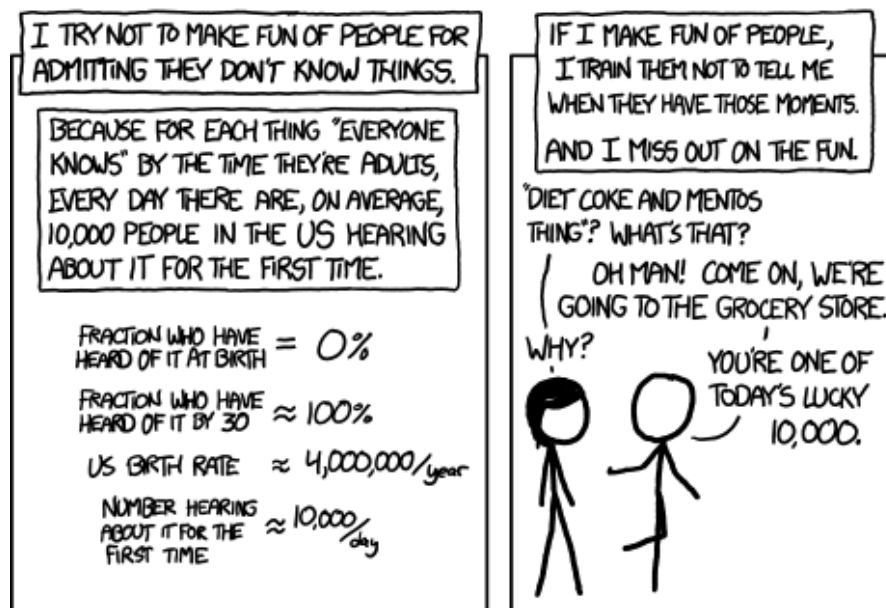
Figure 2.2: *Ten Thousand* by Randall Munroe on his webcomic xkcd. Published under a Creative Commons Attribution-NonCommercial 2.5 License. [140]

The ability of the visualisation to prompt or encourage insight, and insightful questions about the data.   Taking away questions, and a deeper interest in the content is a valuable outcome for visualisations. This is particularly true for NEUVis, where a single, effective presentation has the potential to spark a lifelong passion with the audience, inspiring an excitement for science.

The ability of the visualisation to communicate not just specific data, but an overview, an essence, or take-away sense of data.   An overview, or take-away message may be essential for some NEUVis. Exceptions to this may be argued, particularly for artistic data visualisations. But it should be considered that the overall message of the data be implicit to the design of NEUVis, and made explicit in its final presentation. This is important for many reasons. One of which is that any NEUVis for the general population will inevitably be accessible for someone who is hearing about domain of the information for the first time. This point is illustrated by Randall Munroe (see 2.2), a robotics expert (turned comic artist) who often uses his webcomic, *xkcd,* and several books to communicate science, mathematics and programming. He says in the title of this image on xkcd.com:

> Saying "what kind of an idiot doesn't know about the Yellowstone supervolcano" is so much more boring than telling someone about the Yellowstone supervolcano for the first time.

The ability of the visualisation to generate knowledge, as well as confidence and trust about the data, its domain and context. If a visualisation does not generate confidence in the data, within its broader domain and context, then what value can it have? If it minimised time to questions about the data, but does not make the user feel confident that the answer is reliable, then what value can the visualisation have? This may not be a significant issue for infoVis or sciVis, where the audience and the primary researchers may be the same people. However, in NEUVis, a context where the visualisation may be the only link between primary research and potential audience, it is not difficult to imagine that a visualisation which inspires no confidence or trust may easily have an effect opposite to what was intended. This may be an interesting area for further, specific research.

Instead of using accuracy and time as metrics for evaluation, a model presented at Eurographics 2015 uses enjoyment to validate a visualisation [169]. This model used the concept of flow, from renowned psychologist Mihaly Csikszentmihalyi, to augment an existing model of visualisation. Flow is a mental state that is brought about by engaging in any task that is challenging, but the user has a high skill level in the task[2]. It is an effortless, spontaneous feeling experienced by a user totally engaging with an activity, so that they completely lose themselves, and feel ecstasy [51, 52]. The paper connects this concept of flow to Munzner's popular nested model of visualisation design and validation [142]. This nested model uses validation rather than evaluation, because the validation is used throughout the design process. It outlines 4 threats to validity that a visualisation developer must face[3]:

1. Addressing a problem that does not actually relate to users,

2. Showing the user the wrong thing, or using wrong abstractions,

3. Using the wrong encoding (mapping of data to visuals) or interaction, or

4. Using the wrong algorithm, their code being too slow.

A connection is made through comparing enjoyment factors of Csikszentmihalyi's flow to the levels of Munzner's model (see table 2.2).

Flow and enjoyment in visualisation is an area of research that can extend to NEUVis, particularly if it is possible to create an evaluation model that helps determine whether the user achieves a state of flow.

Though it has not yet been widely investigated, the concept of presence may benefit immersive scientific visualisation, infoVis or visual analytics, and also NEUVis. Presence relates to mediated experiences with technology: an experience with technology creates a sense of presence by being natural and real, giving the illusion that the experience with the technology is not mediated at all [126]. This aesthetic experience is relevant to immersive experiences such as Virtual Reality. As this technology becomes more ubiquitous, it will become more important for NEUVis to effectively

---

[2]Flow is what is also described as being "in the zone" by athletes, or in "the green room" by some musicians.

[3]It should be noted that Munzner uses the term "designer" rather than developer, which I have not done. Designers address wicked problems, as outlined in Chapter 1, but Munzner's descriptions of challenges do not fit with this way of thinking, so for clarity, I use "developer".

Table 2.2: Saket's connection between flow and a nested model for visualisation [169]. An X indicates where the development interacts with enjoyment of the visualisation.

Enjoyment Factor	Why? problem or domain	What? data	How? encoding or interaction	How fast? algorithm
Challenge		X	X	
Focus			X	
Clarity	X	X		
Feedback				X
Control			X	
Immersion			X	

provide a sense of presence to the audience. It is easy to imagine how further research into presence has the potential to benefit novel NEUVis applications such as museum installations and virtual or augmented reality.

2.2.2 Comprehending Visualisation

Another topic of infoVis research is how users comprehend visualisation. This has been approached from different perspectives. Colin Ware, Director of the Data Visualization Research Lab at the Center for Coastal and Ocean Mapping at the University of New Hampshire, is a leading author in this area. He approaches visualisation with a focus on visual perception (perceptual psychology), outlining ways in which the visual processes of the human brain can be exploited [218]. His research has been extended to areas of visual analytics for business [68, Chapter 3] and information design [135]. Ware's research is exceptionally useful to NEUVis, but he points out that:

> For the visualization designer, training in art and design is at least as useful as training in perceptual psychology. [218, p. 17]

The understanding that creative practitioners have about the use of colour, form, mass and other visual design principles is valuable to visualisation. Perceptual psychology is useful, but not the only source of knowledge for effective visualisation.

Ambient visualisation is one approach that does not rely heavily on perceptual psychology[4]. There are three levels to comprehension in ambient visualisation: *that* something has been visualised; *what* kind of information is being visualised; *how* the information has been visualised [105]. Visualisation research usually begins with the 3rd step, but users must navigate through all three in order to actually

---

[4]According to [183], ambient visualisations reside in the user's environment, rather than on a computer screen, much like a painting. They can display dynamic information which a user in the space my need; much like a clock or a bus timetable.

use the visualisation. This is trivial in domain-expert visualisation, but, as outlined in [105], it is important to ambient visualisation. This understanding could also be significant for NEUVis.

Human visual perception is what allows visualisation to identify trends, patterns and unusual occurrences within datasets. Perception is what drives the user's ability to gain insight. A paper from 2008, [221], presents previous research on how people achieve insight, as opposed to what insight is. This paper also asks if an understanding of insight can lead to insight-oriented visualisations. This would prove difficult, as 'insight' is a concept that is now understood well. The authors adopt a definition of insight (from biology) as "an individual observation about the data by the participant, a unit of discovery," which sparks a critical breakthrough, leading to discovery; seeing something previously unnoticed, bringing to light something familiar [221, p.1]. The authors also outline different types of insight. *Complex* insights are about large amounts of data in context, rather than the nature of individual points. *Deep* insights develop over time, often developing further questions. *Qualitative* insights are subjective, rather than exact and have multiple levels of resolution. *Unexpected*, or unpredictable, serendipitous insights and *relevant* insights are the result of the context of the data and its presentation [221, p.2]. Coming to insight may be the end result of a number of different user experiences. Providing an overview of data and adjusting or filtering data may be useful in producing perspectives that lead to insight, particularly when something that was passed over is brought to light. Exposing something unnoticed can also be done by exposing patterns in the data. All of this can bring about insight by solidifying the user's mental model of the data.

2.2.3 Other Approaches to Visualisation

Visualisation research shows a bias towards factors that are influenced by perceptual psychology. This is understandable, as it is easier to test than whether a visualisation can engage the user in a state of flow or whether the user has a qualitative insight. But, as visualisation, which uses colour and patterns to solve problems, begins to address increasingly complex problems, research must inform how visualisation should be designed to aid increasingly complex cognitive tasks. Caroline Ziemkiewicz, of Brown University Visualisation Research Lab, suggests that these fundamental principles address how people see, rather than how people think [224]. In order to fully understand how visualisations work, the way that the users think must also be understood. Visualisation uses visual processing to overcome the limitations of working memory in the human brain, but working memory varies between different people. So does spatial and verbal cognition, and all of these may effect the way a user can use a visualisation to perform a task. At this point, there is no usable decomposition of visualisation design that takes these factors into account[224].

Non-expert users represent a much broader group than domain-expert visualisation would address, making these differences greater. One important paper outlines four types of visualisation which is aimed at the non-expert audience: *Ambient*, *Social*, *Artistic* and *Casual* infoVis [161]. The authors assert that these four areas of infoVis challenge two standard assumptions in infoVis. The first assumption is that users are only interested in rational processing of information. The second is that visualisation is for work. The four groups are outlined in the paper: *Ambient* infoVis are abstract depictions of data that communicate from a peripheral location; *Social* infoVis represents networks and

social processes and situations; *Artistic* infoVis includes data-driven artworks; *Casual* infoVis represents things that do not fit into the other categories:

> We define: Casual InfoVis is the use of computer mediated tools to depict personally meaningful information in visual ways that support everyday users in both everyday work and non-work situations. [161, p.1149]

InfoVis is defined as providing computer-supported, interactive visualisations of abstract data to amplify cognition to a small but skilled population of knowledge workers [26, p.7]. The goal of casual infoVis is to provide opportunity for non-analytical insight into data that is personally relevant and meaningful to a wide audience in contexts inside and outside work [161]. However, it will always be on the 'edges' of infoVis, as it doesn't conform with the traditional assumptions of infoVis. NEUVis includes this approach, as well as the Artistic approach, and design approaches that could be used to build ambient and social infoVis. By comparing these different approaches, more commonalities can be found.

NEUVis would also include another approach, outlined in a paper in IEEE transactions on visualization and computer graphics, 2010, called *Narrative* visualisation [178]. Current visualisation tools do not adequately support storytelling through visualisation, though narrative is a compelling way of communicating data [220, 120, 72, 79]. The chain of causality that connects events in a narrative can be used as a metaphor in visualisation, which is common across different genres of narrative visualisation [178]. These visualisations also tend to use interactive checkpoints through the visualisation, rather than being freely interactive, so that the narrative may progress. One excellent example of this technique *The Fallen of World War II* (2015), an interactive documentary about war and peace, directed, coded and narrated by Neil Halloran [93]. This 15-minute interactive video uses narrative techniques and data to create a story around the devastating number casualties in World War II, and compare it to modern international conflict. The narrative is interspersed with interactive elements, where the user can explore the data that has been shown to them. The authors of [178] suggest that if it was established that users skim a narrative visualisation the same way that readers skim headlines and graphics in a newspaper, then it would provide a useful guide for narrative visualisation [178]. Grouping together these approaches under NEUVis allows the similarities to be observed without the implications of whether the visualisations are strictly infoVis, sciVis or visual analytics. One way that these approaches, as well as traditional approaches in infoVis, sciVis and visual analytics, have also been researched is according to their aesthetic value.

2.2.4   Information Aesthetics

Advances in computer graphics have helped visualisation mature, as we can see in figure 2.3. The first image, figure 2.3a, shows a state of the art visualisation from 1996, notably it uses dotted lines to allow the user to differentiate between each of the lines. By 2002, computer graphics had advanced, as had visualisation, now including colour, as seen in figure 2.3b [196]. With the increasing flexibility provided by advancements in computer graphics, research started to focus on the quality of the visual construction in visualisation. A model for information aesthetics was proposed in 2007 by Andrea
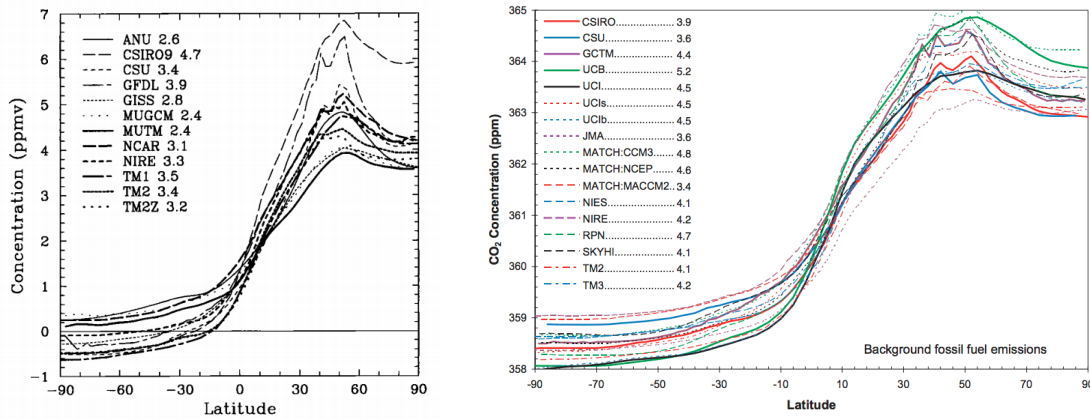
(a) A state of the art visualisation from 1996, [95].

(b) Computing advances lead to adding colour to help comprehension, [91].

Figure 2.3: Six years of evolution in visualisation

Lau and Andrew Vande Moere, from The University of Sydney [117]. This model merges aesthetics, interaction and data. It describes visualisation as something which is to be interpreted, rather than simply a means to facilitate tasks or represent a certain dataset [117]. In addition to advanced computing techniques, software availability, internet access and speed, interdisciplinary discourse and training, and open data have all contributed to the evolution, growth and importance of aesthetics to visualisation. The model shows a correlation between the data focus (intrinsic to extrinsic) and the mapping technique (direct to interpretive). Intrinsic data focus uses cognitive processes and perceptual psychology to produce an 'effective' visual mapping. This approach is closely associated with infoVis, sciVis and visual analytics. Extrinsic data focus aims to communicate meaning, or underlying data. This creates personal insights, and the user can appreciate the visualisation, rather than just use it, and is associated with creative visualisation and visualisation art [117]. Most visualisations fall on a continuum from data intrinsic/direct mapping (information visualisation) to data extrinsic/interpretive mapping(visualisation art). Outside this continuum is information aesthetic visualisation, including data art, ambient visualisation and social visualisation [117, p.90].

The design community knows that "beautiful is usable", and the visualisation research also shows this is true [30, 204]. Designed artefacts (including interfaces) that are beautiful and functional are a pleasure to use [149, 148]. Words such as emotion, pleasure, experience, expression and aesthetics are part of the vocabulary of HCI [1]. Aesthetics should become a part of all areas of NEUVis evaluation, especially as NEUVis often communicates to an audience outside work. Descriptions of what aesthetics is has varied broadly in visualisation research, with varying depth: (Emphasis added)

> Aesthetics is a concept that relates to the *beauty in both nature and art*, as something that enlivens or invigorates both body and mind, awakening the senses. [30]

This model is unique in its focus on *aesthetics as the artistic influence on the technical implementation and intended purpose* of a visualisation technique, rather than subjective aesthetic judgments of the visualisation outcome [117]

Conventional wisdom relates [aesthetics] to our *appreciation of, and attitudes towards computer systems.* [204]

In this context, we adopt a narrow definition of aesthetics in which aesthetics can be seen as a *synonym for visual beauty.* [204]

In general, aesthetics can be associated with the concept of beauty, and in one sense, aesthetics is *the measurement of beauty.* [170]

The term "aesthetics" is well known in everyday-speech and we use it to refer to *anything visually beautiful and pleasing our eyes.* Aesthetics has been termed as "the measurement of beauty"[10, p.8]

Aesthetics has been found as an important aspect. Several works of research propose that "enhancing the *artistic merit* of a visualisation can result in a more effective and more productive visual analysis." [10, 194]

It is unsurprising that some empirical visualisation research focusses solely on the visual sensation of an aesthetic experience. Even with controversies and debates surrounding what aesthetics is, it is not simply 'arting up' a visualisation that otherwise has no other artistic intent or merit, as if Photoshop can apply an aesthetics layer. Instead of describing visualisations as aesthetic, author Noah Iliinsky describes what makes visualisations beautiful: It must first be *novel*, then *informative*, *efficient*, and the final consideration is the *aesthetics*—which, for this case, should be substituted for *visual construction* [108]. This description also outlines the method for producing beautiful visualisations.

2.2.5   Visual Aesthetics

The aesthetic appeal of any interface is important, users are more willing to use a product if it provokes pleasurable feelings [157]: beautiful is usable [205, 204]. Computer scientist Gabriele Peters describes six dimensions of visual aesthetics for use in visualisation and user interface design, drawing insight from both visual arts and cognitive neuroscience [157]. Peters differentiates between images (implying photographs or drawings) and diagrams or charts. Images are used in interface design for four main purposes [192, p. 260]: to attract the user, also to amuse or persuade them; to communicate information, particularly spatial information; to support interaction; and to overcome the challenge of describing something in text, a picture is worth a thousand words. Peters states that this is the paradigm for most human-computer interaction applications [157]. After establishing the significance of image, Peters outlines basic dimensions of aesthetics: *colour*, *form*, *spatial organisation*, *motion*, *depth* and the *human body* [157].

Peters does not explicitly relate these dimensions of visual aesthetics back to visualisation; instead the paper outlines them and the underlying *aesthetic primitives* are compared to user interface design. However, one can consider these elements of visual design in comparison to an aesthetic visualisation.
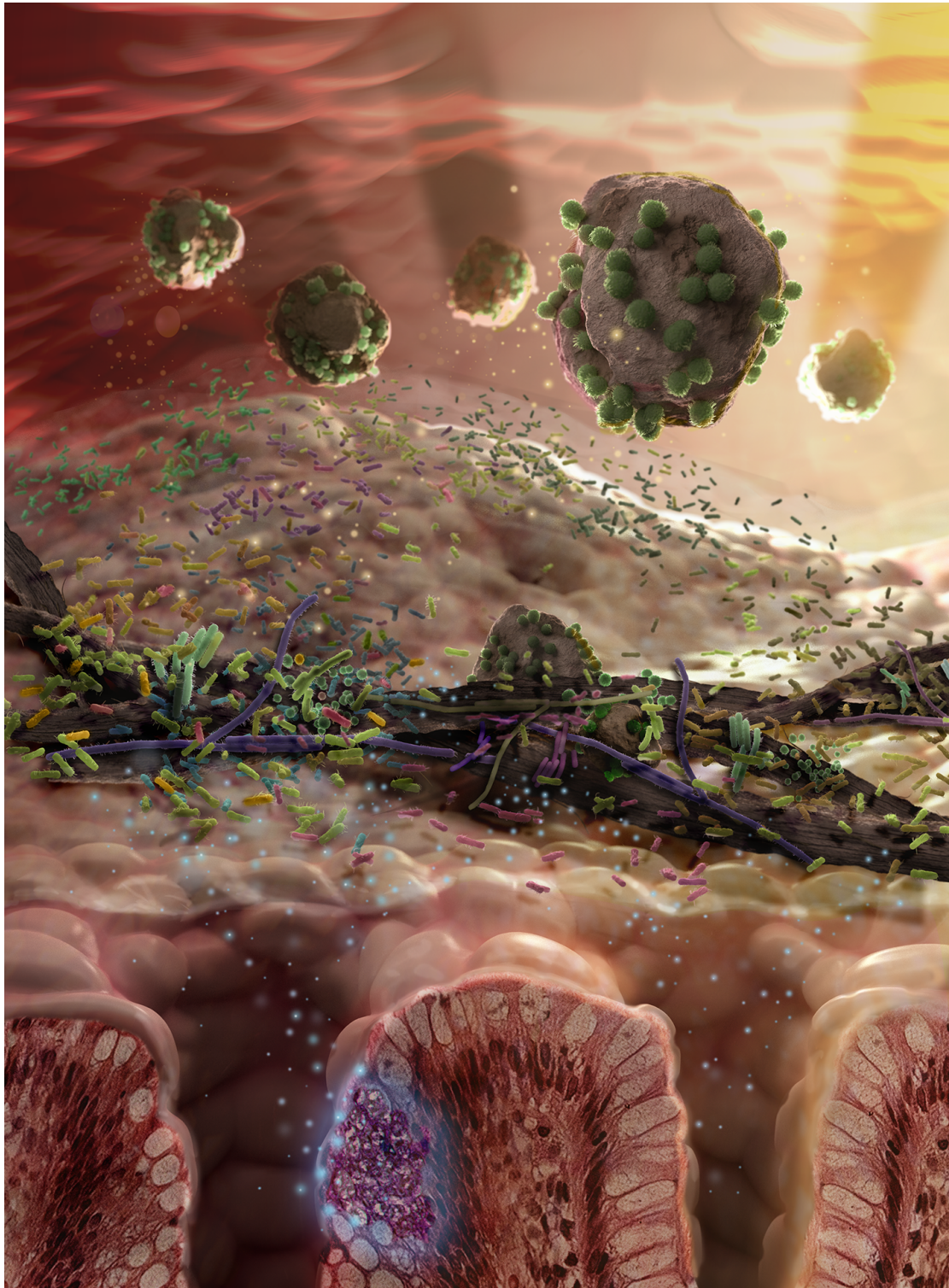
Figure 2.4: *The Hungry Microbiome — colour study* (2014) by Christopher Hammang and Christian Stolte. Image used with permission [191].

The Hungry Microbiome — colour study (2014) in figure 2.4 is a dramatic illustration of the function of the human microbiome in producing butyrate. This chemical is absorbed by the human body and has a substantial role to play in defending against colorectal cancer, which is explained in the video *The Hungry Microbiome*. This image was produced during the production of *The Hungry Microbiome* by members of the team producing the video by the same name (see figure 1.1). The video and the colour study shown in figure 2.4 are produced as part of the VisbiPlus project, which has the aim of improving communication of life science through exemplary, scientifically accurate animations. VisbiPlus commissions the production of animations to inspire and educate the general public about leading biomedical research. The style of animation produced by VisbiPlus is an expository documentary[5], similar to that of Drew Berry, an animator working at the Walter and Eliza Hall Institute in Melbourne, who has won an Emmy Award for a documentary series on DNA[201]. One visual element used in *The Hungry Microbiome*, and many other biomedical animations, that is used by Berry is the use of colour to label and clarify different elements within a scene [197]. This has become standard practice in the field of biomedical animation. Biomedical animations often describe processes or molecules to small to interact with visible light, and therefore have no colour. This allows elements to be labelled with colours for the sake of clarity and visual contrast, white maintaining scientific accuracy, as is visible as in figure 2.4. Some of Peters' principles of visual aesthetics can be examined in this image.

Colour: use only a few dominant colours, complementary contrast and exploit dynamic range.

This image demonstrates the use of only a few dominant colours. The pink colour used to represent the parts of the human body, and the greens used to represent the bacteria are the dominant colours, with an accent in the lower section of the image (the foreground) in blue showing the interaction between the body and the chemical butyrate. The pink colour of the surfaces of the intestines are complementary (on opposite sides of the colour wheel) to the green of the bacteria. This helps the user clearly distinguish between the different surfaces. The image also shows a wide dynamic range, from the bright and dramatic lighting from behind the starch (shown as the dull grey-brown blobs covered in green bacteria) to the dark areas below to create a visually interesting range of colours and intensity. The less dominant images uses in the darker areas do not overpower the main colours of pink and green.

Form: clarity of forms are created by lines and surfaces, a simple silhouette is also beautiful if it can capture the main characteristics of an object.

Form is created in the foreground through the use of colour gradients, projecting a three-dimensional surface in the two-dimensional rendering. Though the silhouettes of the out-of-focus starch at the top of the image are not an otherwise recognisable form, they are similar to the starch that is in focus. The lighting from behind these starch blobs highlights the outline, giving clarity to the form

---

[5]Expository documentaries are narrated, with the voice directly addressing the viewer, as described by Bill Nichols in [144]. This is sometimes referred to as the "Voice of God" and is a very common style of documentary.

of them and the bacteria fermenting the starch on their surface. Without this light on the outer edge of the bacteria their shape would be hard to distinguish, reducing the clarity and aesthetic value of the image.

Spatial Organisation: clarity and simplicity is most effective, texture and patterns give structure to surfaces.

The spatial relationship between elements of an image are as important as their colour and form. Without due consideration, spatial layout can detrimentally alter the aesthetics of an image. Often there is a variable that drives the position of graphical elements in a visualisation, but NEUVis can tell many stories with data, and they are often more complex than charts. Layout can be guided by rules that have been used for centuries. The *golden ratio*, denoted by $\varphi = a/b = b/(a + b)$, where the only positive solution is $\varphi = (\sqrt{5}-1)/2 \approx 0.618$ is one way of increasing the aesthetic value. The proportions used in sculpture and architecture, particularly of the classical era, use this ratio, and artists may use lines to divide an image using the golden ratio. In figure 2.4 the dark line across the lower portion of the image divides the image in two, roughly by the golden ratio. This gives a natural balance to the foreground, which (as a general rule) is in the lower portion of the image in proportion to the background. A second approach to spatial organisation is the *rule of thirds*, which is often used in photography and videography. This method aligns the dominant features of an image along lines that divide the image by thirds. Major points of focus will often be aligned to the intersection of these lines. In figure 2.4 it can be seen that the two largest pieces of starch are approximately aligned along the vertical lines that divide the image by thirds. These lines extend down to the cut-away at the lower portion of the image and roughly aligns with the vertical wall that creates the boundary between the cut-away section and the wall of the intestine in the centre of the foreground. The cut-away section appears flat because it is in contrast in texture to the surface that surrounds it. The surface is consistently textured, which aids the viewer in perceiving three-dimensional depth by varying the size and colour of the texture as it moves further from the viewer in the background of the image.

Depth: three-dimensional images are created by linear perspective, varying between sharpness and unsharpness, and contrasting light and shadow.

This image clearly shows the creation of depth by variance between sharpness and unsharpness and through contrasting light and dark. First, the effect of depth of field (a term also used in photography and videography) creates an illusion of nearness for the parts of the image that are sharp, and a sense of distance to the parts of the image that are unsharp. Second, though the dominant light is at the back of the image, the the contrast between light and shadow is used at the foreground in the lower part of the image, to show the form of the wall of the intestine, but also in the background. The contrast between light and darkness is reduced for parts of the image that are far away from the viewer. The reduced contrast in the pattern of the surfaces acts as an aesthetic cue that that section of the image is further away, appearing dull, with less dynamic range. Vanishing points and linear perspective are also useful attributes to include in an image to increase the perception of depth, but they are not strongly utilised in this image.

Motion and the human body: blur, phases of motion and the principle axes of the body.

The other basic elements of aesthetics that Peters presents are not utilised in figure 2.4. Motion is implied, but not captured using motion blur, which is unsharpness in one direction. It could be argued that the molecules of butyrate (indicated in the lower portion of the image as glowing blue dots) represent phases of motion, as the perception is that they are moving along the path that is implied by their arrangement. As the image shows a processes inside the human body, it does not utilise the human form.

There are many combinations of the core principles of aesthetics that can inform the broad applications of NEUVis. The forms that NEUVis can take vary as much as the scientific data that is being visualised. It is important to consider the data, and the story that it tells, in addition to the format of the visualisation, when determining how the visualisation is visually constructed. Without proper attention to principles of aesthetics, NEUVis will be limited, and can fail to engage a potential viewer. But, with a considered approach to the combination of aesthetics and data, science can be visualised for the everyday user in a way which is visually engaging and mentally stimulating.

In addition to visual elements of aesthetics, there has been research into the application of the aesthetic experience to interactive design by McCarthy & Wright [131] and Petersen et al. [158]. This research places the pragmatic approach to aesthetics of John Dewey [56] and Richard Shusterman [181] as a core approach to creating interactive experiences. The pragmatist approach sees the aesthetic experience in everyday situations, rather than isolated to fine art galleries. The aesthetic experience begins, develops and ends, the meaningfulness of an aesthetic experience is created by the viewer [56]. This experience is tightly related to the context and use of an interactive system, and the system is instrumental to the aesthetic experience [158]. Engaging with technology can be an aesthetic experience, as suggested by McCarthy and Wright [131]. They outline that four "Threads of Experience" can be considered in order to more clearly think about technology as experience. They first describe the sensual thread: the sensory engagement with technology. The second is the emotional thread, which is related to sense-making as well as emotional engagement. Third is the compositional thread, where the viewer connects the parts of an experience to a whole. Finally the spatiotemporal thread, where the experience is placed in relation to the past and future of the viewer [131, Chapter 4]. Understanding these threads will help create experiences with NEUVis, and there is space to connect these two topics through further research[158, 131].

2.3 Visualisation Practice

2.3.1 Historic Visualisation

Beautiful visualisations have been produced, even before the emergence of computer graphics—or computers at all. Historical backgrounds of mapping data to graphical elements have been presented many times (see [7, 12, 135, 68, 123]). Iliinsky uses two examples of Mendeleev's Periodic Table of Elements, and Harry Beck's map of the London Underground to illustrate what makes visualisations beautiful. Both of these visualisations predate the earliest definitions of information visualisation,

[78, 132, 213]. The creators of many early visualisations (see figure 2.5 and figure 2.6) were not specialists in visualisation, rather they were domain experts of other fields: Dimitri Mendeleev was a scientist with expertise in periodicity of elements (see figure 2.5a); Harry Beck was a technical draftsman who applied principles from drawing electrical circuits to a train network (see figure 2.5b); William Playfair, an engineer, was the first to publish graphs of economic data with respect to time in 1786 (see figure 2.6a); John Snow, a medical doctor and epidemiologist, used visualisation supported by a statistical model to bring about insight into what caused an outbreak of cholera in London (see figure 2.6b).

Classic visualisations, such as these, form the basis for most everyday data visualisations. Bar and pie charts, line graphs, scatterplots, and organisational flow charts seem so mundane that it is difficult to imagine that they were "invented."

2.3.2 Best Practices

The first two classic visualisation (see figure 2.5), Mendeleev's periodic table and Beck's map give significant insight into the nature of good visualisation. These are analysed by Iliinsky against his four aspects of beauty in visualisation: novelty, informativeness, efficiency and visual construction [108]. One element of their design stands out for each. First, Mendeleev's periodic table exploits the nature of the data; the periodic nature of the table reflects the periodicity of elements, and their electron shells. The relationship with the data and the visualisation let the expert find so much more information than what is available at a glance. Without this relationship, the periodic table is meaningless. Second, Beck's map of the London Underground reduces irrelevant and distracting data. To passenger on a train the bends in the track, even the distance between stations are irrelevant, especially since trains do not skip from one line to another. The passenger needs to know the relationship between the station where they get on and off, and where they can transfer to another line, if necessary. This is why most train maps (since most use the engineering style of Beck's: lines all at 45 or 90 degrees, with junctions indicated clearly from most stations, and each rail line being a separate colour) cannot be overlaid onto a road map of the same city. Classic visualisations are not infallible, and they are not the only best-practice examples of visualisation.

Video:

Research in the field of infoVis shows that video or animation is not as accurate or effective as other methods of visualisation. One chapter in *Beautiful Visualisation* examines video for visualisation [74]. In the chapter, the author states that moving image may offer a fresh perspective, and animations may help the viewer work through the logic behind an idea. The author points that out of the two tracks, infoVis and sciVis, of visualisation research at a prominent conference called IEEE VisWeek, almost none of the infoVis papers feature animation, while about half of the papers in sciVis do. SciVis papers have shown that animation is effective, possibly because sciVis uses phenomena about the actual world, where infoVis uses data that isn't. InfoVis research shows that animations were no more effective at transferring knowledge than any other form of teaching, though it was slower, and

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
H 1 1.00794																	He 2 4.002602
Li 3 6.941	Be 4 9.012182											B 5 10.811	C 6 12.0107	N 7 14.00674	O 8 15.9994	F 9 18.9984032	Ne 10 20.1797
Na 11 22.989770	Mg 12 24.3050											Al 13 26.581538	Si 14 28.0855	P 15 30.973761	S 16 32.066	Cl 17 35.4527	Ar 18 39.948
K 19 39.0983	Ca 20 40.078	Sc 21 44.955910	Ti 22 47.867	V 23 50.9415	Cr 24 51.9961	Mn 25 54.938049	Fe 26 55.845	Co 27 58.933200	Ni 28 58.6534	Cu 29 63.545	Zn 30 65.39	Ga 31 69.723	Ge 32 72.61	As 33 74.92160	Se 34 78.96	Br 35 79.504	Kr 36 83.80
Rb 37 85.4678	Sr 38 87.62	Y 39 88.90585	Zr 40 91.224	Nb 41 92.90638	Mo 42 95.94	Tc 43 (98)	Ru 44 101.07	Rh 45 102.90550	Pd 46 106.42	Ag 47 196.56655	Cd 48 112.411	In 49 114.818	Sn 50 118.710	Sb 51 121.760	Te 52 127.60	I 53 126.90447	Xe 54 131.29
Cs 55 132.90545	Ba 56 137.327	La 57 138.9055	Hf 72 178.49	Ta 73 180.9479	W 74 183.84	Re 75 186.207	Os 76 190.23	Ir 77 192.217	Pt 78 195.078	Au 79 196.56655	Hg 80 200.59	Tl 81 204.3833	Pb 82 207.2	Bi 83 208.58038	Po 84 (209)	At 85 (210)	Rn 86 (222)
Fr 87 (223)	Ra 88 (226)	Ac 89 (227)	Rf 104 (261)	Db 105 (262)	Sg 106 (263)	Bh 107 (262)	Hs 108 (265)	Mt 109 (266)	110 (269)	111 (272)	112 (277)	114 (289) (287)		116 (289)		118 (293)	

58	59	60	61	62	63	64	65	66	67	68	69	70	71
Ce 140.116	Pr 140.50765	Nd 144.24	Pm (145)	Sm 150.36	Eu 151.964	Gd 157.25	Tb 158.92534	Dy 162.50	Ho 164.93032	Er 167.26	Tm 168.93421	Yb 173.04	Lu 174.967

90	91	92	93	94	95	96	97	98	99	100	101	102	103
Th 232.0381	Pa 231.035888	U 238.0289	Np (237)	Pu (244)	Am (243)	Cm (247)	Bk (247)	Cf (251)	Es (252)	Fm (257)	Md (258)	No (259)	Lr (262)

(a)

(b)

Figure 2.5: Examples of early visualisations: a. A modern version of Mendeleev's Periodic Table of Elements; b. Harry Beck's map of the London Underground;
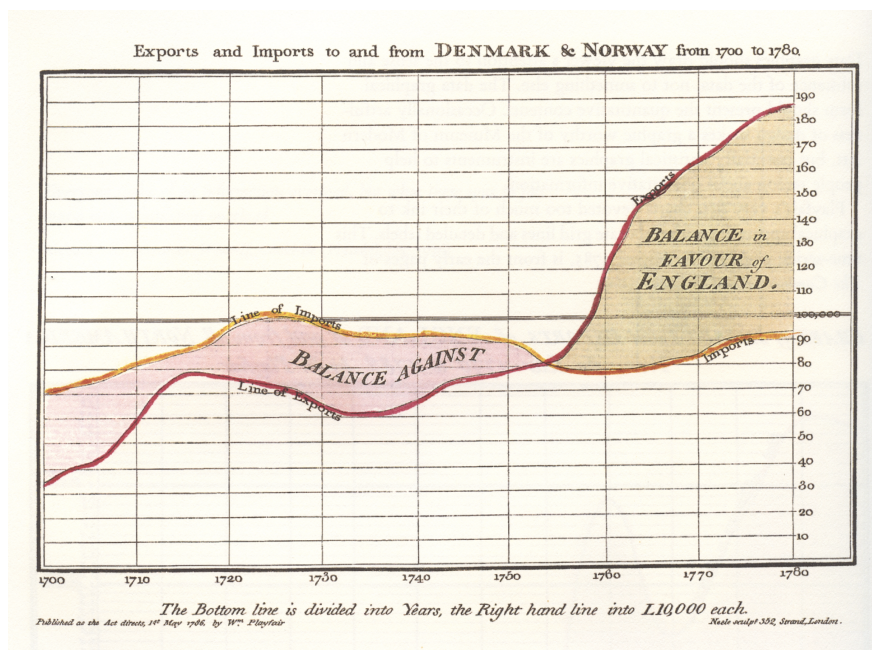
(a)
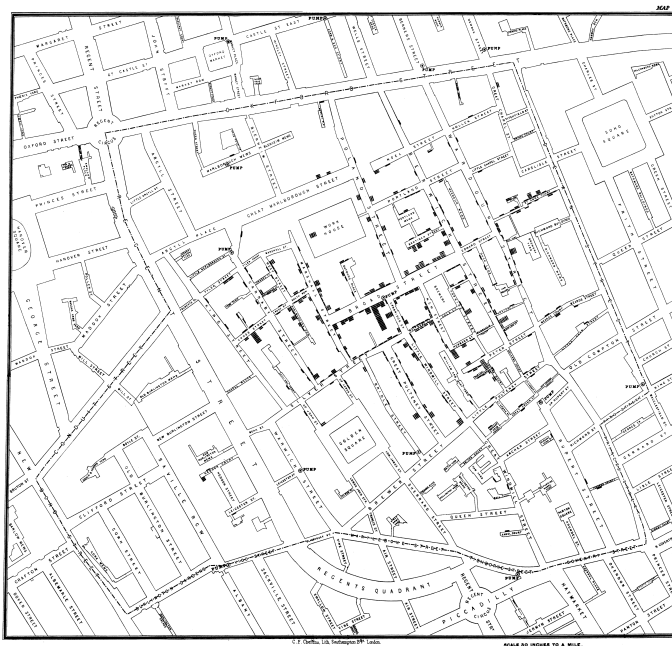
(b)

Figure 2.6: Examples of early visualisations: a. William Playfair's economic line chart; b. John Snow's map showing cases of cholera near the Broad Street water pump.

less precise [74]. The authors state that the experience of exploration is different from the experience of a presentation, which is important for infoVis [74, p.388].

Derek Muller, science communicator and host of the Popular YouTube channel, *Veritasium*[6], conducted his PhD research in the use of video as a tool to teach physics to high school students [139], a model he employs in his YouTube videos. He found that multimedia involving explicit discussion of alternative conceptions is more effective for learning than more concise expository summaries [139, p.15]. Processing the misconceptions involved more mental effort, and helped them learn more. His findings showed that students who watched a video that clearly explained a phenomena in physics didn't take in the new information, even though they said that the video was clear and easy to understand. On the other hand, other students watched a video recording of a (staged) discussion between a student and tutor, where the student explained their understanding of the scientific concept and was then corrected by the tutor. This second group of students found the video was confusing and difficult to understand, but they performed better when examined on the information in the video [138].

One research paper from 2015 analyses video visualisations from a cinematography viewpoint. The authors analysed 50 data videos and identified narrative structures. They define data videos as custom motion graphics that incorporate visualisations about facts. Notably, they found several types of narrative structures that existed with these videos [3]. The structures were based on four narrative elements: the *establisher* scene, providing referential information to the audience without engaging them in the actions or events of a narrative; *initial* scenes, which set the action or even in motion; the *peak* or climax, the most important event; the *release* which shows the aftermath of the peak. The authors speculate that videos without the peak or release will pose a question to the viewer, giving them something to think about and engage with [3, p.1462]. This may be the case, but it is conceivable that the question will turn into frustration—the last narrative element is called the *release* on purpose. Instead it may be better to deliberately choose questions that are answered, and those that are left for the user to engage with on their own.

Design:

Research shows that design of NEUVis has an effect on how the visualisation will be perceived. Stylistic choices influence the usability, depth of insight and the kind of insights that are obtained from a visualisation [215]. The designer or developer should apply the rule: *form follows data* [137]. One article published in the *CoDesign* journal discusses how a visualisation can make issues transparent and still be readable [173]. Communicating issues of interest and value to a broad public in a readable way is difficult; designers should focus on three characteristics discussed by the authors based on previous literature [173, p.181-182]: *engagement*, communicating meaning is as important as communicating facts, attract people by reducing complexity, grab attention while being unobtrusive. Reduce the perceived complexity, so that the backstory is more noticeable; *sense-making*, Designers must remember that visualisation is about insight, not pictures [180]. Visualisation should help identify and

---

[6]*Veritasium* has over 3.2 million subscribers and around 280 million views of Muller's videos at the time of writing. `https://www.youtube.com/user/1veritasium`

understand different perspectives; *reflection* and interpretation is facilitated by revealing lesser-known perspectives on an issue. These three elements make up the readability of a visualisation.

Another paper, published in *Information Visualisation* journal in 2011 [214], describes visualisation design as a balancing act between utility, soundness and attractiveness. In this paper Andrew Vande Moere and Helen Purchase, two leading researchers in infoVis, discuss why their field would benefit from expanding its definition to incorporate commercial and artistic visualisation. This notion seems to be at odds with infoVis being a science, and, as the authors note, would require a large paradigm shift within the field [214]. Moere and Purchase outline benefits to the field of infoVis that would come from a shift in practice and research to include design processes, instead of focussing solely on an empirical approach. The paper gives good insight into where effort would be required on the part of infoVis. This would include incorporating new fields of practice as infoVis, as well as bringing their experience into the body of infoVis knowledge, shifting infoVis practice to include design methodologies as a fundamental part of their exercise. Also, infoVis would have to revisit their best-practice examples in order to reframe them in terms of their design process, rather than the output [214, p.369]. This final point is fundamentally important for infoVis to include other design-based practices. Science requires that an outcome be repeatable; even if a new process is used, the result should be the same. For example, if two different classroom experiments are conducted to calculate acceleration due to gravity, they should produce with the same value. Design, on the other hand, may produce multiple solutions to the same problem, but what is important is the method used. The design process should be repeatable, and is not expected to produce identical results.

This paper fails to present the benefit to the design community if design practices fall under infoVis, rather than other design fields, which adjoin visualisation design. Fields such as Human-Computer Interaction (HCI), information design, user experience design (Ux), and user interface design have their own research practices, and visualisation design may fit within any of these spaces [214, p. 361]. The paper also includes "artistic exploration," though the authors may be using this term in the same way as they use "aesthetics"—reduced to "attractiveness"—rather than suggesting that artists should be included in infoVis. NEUVis can take many things from infoVis research, and contribute more. However, this paper does not present any benefit to visualisation design, particularly user-centred visualsiation for non-experat audiences, coming under the scientific field of infoVis, rather than being part of the design community.

2.3.3 Tufte and Holmes

Some design-led approaches to visualisation have come under strong criticism, particularly from statistical graphics, a sub-field within statistics. Author and statistician, Edward Tufte, has published several widely read books on information design. Tufte developed several visualisation concepts, which are commonly regarded as best practices. Tufte's *Sparklines* are intense, simple, high-resolution, word-sized graphics [207, p.47]. They are useful for showing data in context, and can be used for *writing data with graphics* [207, p.49] (see figure 2.7a). Another innovation by Tufte are *Small Multiples* (see figure 2.7b). He describes them as a series of graphics, showing the same combination of variables, indexed by changes in another variable [208, p. 170]. A series of images can show multidimensional

Using d3.js, we can fairly easily draw SVG-based sparklines. This is 2013 historical stock prices for

Google ~~~~~~ **$1084.75**. And this is for **Facebook** ~~~~~~ **$55.57**. And this is for

Apple ~~~~~~ **$550.77**. Each sparkline has 244 data points, but it's condensed very nicely.

(a) Sparklines displayed on a webpage, created with D3.js [147].
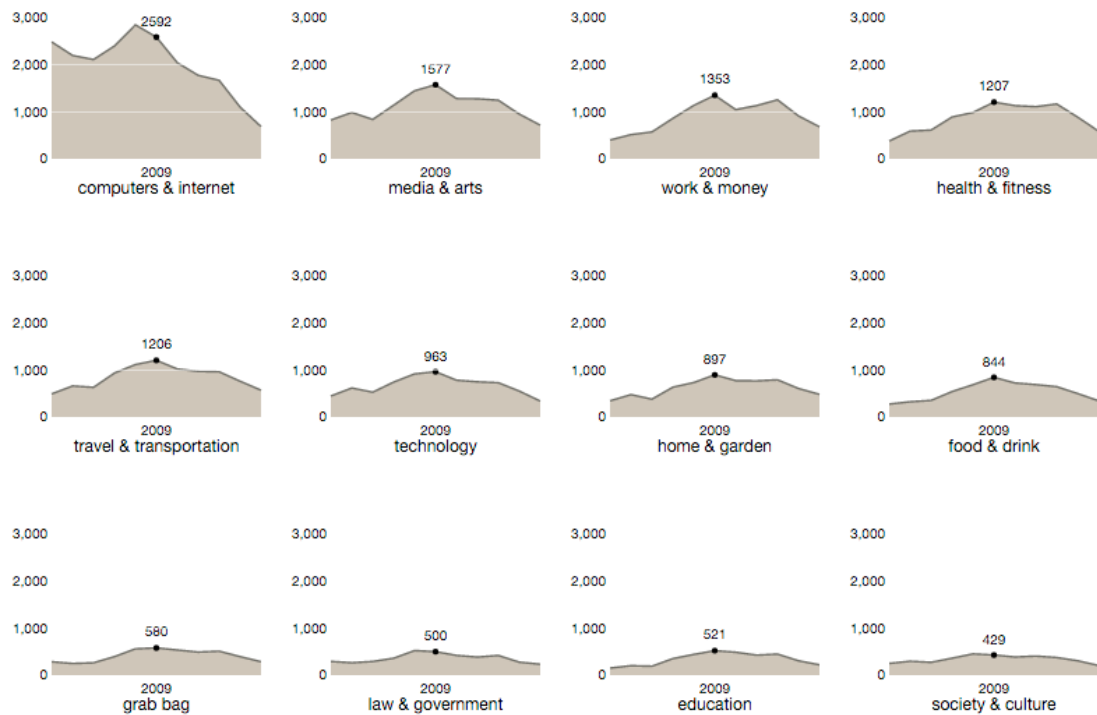
(b) Interactive small multiples displayed on a webpage [211].

Figure 2.7: Tufte's *Sparklines* and *Small Multiples*. These images show examples of interactive visualisations that are created using D3.js, and can be embedded into websites.

data and allow comparisons to be made. Tufte is also well known for the data:ink ratio and chartjunk, two terms that relate to the efficiency of information design. The first, the data:ink ratio is simply how dense the image is with data, originally described by a simple formula [208, p. 93]:

$$data : ink\ ratio = \frac{ink\ used\ to\ show\ data}{total\ ink\ used\ to\ print\ the\ image}$$

This is a test that does not really need to be applied, but what remains after the ink (or pixels, if the term were to be updated) that are needlessly added, and can be erased without any loss of information is almost always what Tufte named *chartjunk* [208, p. 107], excessive embellishments that adorn charts are unable to rescue data-thin designs. Tufte sees this as evidence of contempt for the audience, breaking the moral premise of information design: that the readers should be treated as alert and caring [209, p. 34]. However, Tufte offers no evidence that minimalist graphs are more trustworthy than embellished counterparts. Is Tufte suggesting that a minimalist graph is inherently more accurate, or factual than an embellished graph? Probably not, it would be just as easy to cherry-pick statistical graphics which are deliberately misleading, as Tufte has done in his books with embellished graphs. The designer of a minimalist graph is no more infallible than the designer of an embellished graph.

Designer Nigel Holmes' *Designers Guide to Creating Charts and Diagrams* includes many charts of the kind of that Tufte would criticise. His work has been examined harshly (and cherrypicked) by Tufte. Holmes approaches embellishment as a tool:

> As long as the artist understands that the primary function is to convey statistics and respects that duty, then you can have fun (or be serious) with the image; that is, the form in which these statistics appear. [104, p. 72]

Holmes uses embellishments to make an image stand out—users are not unintelligent, but busy, the chart needs to catch their eye. There is no reason that the designer can't have fun with an image, to create a coherent message that is consistent with the data. Graphics are aimed at a specific audience, and are always slanted in their favour, even cold, emotionless statistical graphics [96, p. 19] according to Holmes. All visualisation is mediated, and to some extent, subjective and interpretive [61, p. 2192]. There are no neutral visualisations [103].

Whether or not a chart should be embellished with additional information has been discussed in publications from authors in academia and industry [70, 69, 9, 109, 16, 182, 107, 122]. Research has discussed memorability, accuracy and preferences. The body of research shows that visualisations are intrinsically memorable, but including distinct features, such as colours, or a human image (such as a person or their face) in the image increased memorability [9, 16]. Familiar charts are preferable; extreme interpretations of a bar chart that remove all unnecessary ink are not preferable to a standard bar chart [109]. Designers also need to strike a balance between minimalism and embellishment [182]. Some of these research papers also cherry-pick designs, which is a difficult problem to avoid, and have been criticised for their methods by experts in industry [70, 69, 23]. Most of the research does not address, or even acknowledge *bad design*. If an embellishment fails to help the user understand the message of the data, if it hinders the user, obscures the data, or misleads it is bad design, or the

designer has made poor choices. Bad design can simply be the due to a lack of experience or talent, but also a symptom of poor taste, dishonesty, or laziness on the part of a designer, regardless of how much embellishment is included. Many of the charts that Tufte criticises are deserving of scepticism because they do not take into account all the necessary variables (such as those that do not include inflation when plotting money against time). These have nothing to do with visual additions, they are simply and plainly dishonest.

Tufte and Holmes represent two different audiences as much as two different approaches. Tufte, the statistician promotes charts that are useful for the domain-expert. They have a self-effacing presentation, and the user has a vested interest in reading the chart. Holmes' approach addresses a wider, non-expert audience, already flooded with information from other sources. By altering the visual construction, these charts augment the display with imagery that presents a single, clear message.

2.4   Science Communication

The field of science communication primarily involves scientists, journalists and traditional media [206], but artists, designers and technologists are also influencing this field [15]. The case for science communication has been clear since the 16th Century, when it is claimed that Francis Bacon said: "knowledge is powerful"[7]. Democratisation of science, and sharing knowledge empowers people [47], informs them on how to make better decisions about their lives [206], inspires critical thinking, stems the flow of bad information, and informs public policy [65]. Though some of the general public are simply not interested in science [118, 42], the pursuit of science communication is unquestionably important [206]. Scientific literacy among the general population can help people make better decisions and understand issues that are scientifically based, such as energy, food security, climate change, genetic modification, and nanotechnology [172]. On a national level, low scientific literacy may also effect public policy issues [42, p. 48]. However, the ultimate goal of science communication is not simply agreement, but fewer, better disagreements [73], though a system of communication involving a one-way flow of information, knowledge sharing and knowledge building [190].

Fighting myths and harmful misinformation is one area of concern for science communication. Fictional television and cinema can give plausibility to science-fiction, which is important for the viewer's engagement and their suspension of disbelief. An example of this is using the noises of real animals to create the sound and movements of the dinosaurs in *Jurassic Park* [8]. This leads people to question scientific possibility, by coupling familiarity with real world experiences and encouraging the unreal images to be seen as realistic, and scientific concepts presented to be sound [8, p. 188]. The popular television show, *Mythbusters* [58], was one way that traditional media communicates science and combats misinformation. The show, which ran for 13 years and 248 episodes, educates the viewer about science and engineering methods used [22] to debunk popular myths, and also showed

---

[7]This is discussed by British philosopher, Bertrand Russell in an essay called *Useless Knowledge* [168, p. 16]. Russell states Bacon refers to scientific knowledge, and how learning (during the renaissance) was part of the *joie de vivre*.

the culture of science and engineering [222]. This approach was popular and successful, but is not appropriate for all types of scientific research. *Mythbusters* used empirical scientific methods to address misconceptions about many issues, but it was still a television show; it did not tackle large issues that would take more time to explain than a single one-hour episode.

Scientists are also using interdisciplinary collaboration for science communication projects. One paper describes how natural scientists and social scientists communicate science, that is relevant to their intended audience, and then design and evaluate the result [219, p. 13662]. The authors report on their experience, facing 4 challenges in this type of project: agreeing on goals; balancing complexity and simplicity; relying on data, rather than intuition; and negotiating external pressures [219]. These challenges are similar to those faced by designers who develop NEUVis, and many of the difficulties faced by the scientific researchers would be familiar to designers. The process of communicating with a non-expert audience may not be a "science," as some science communicators suggest [73] but a design process. Science communication agrees that engaging the populace with science is a wicked problem [190].

Undertaking these tasks is not trivial for scientists, even in collaboration with designers or journalists. Scientists' traditional methods of communication, particularly scientific journals, are not likely to excite and engage the general public (as described in one tongue-in-cheek article, *How to write consistently boring scientific literature* [171]). Very little scientific research gets communicated through mass media, even though the rate of scientific publication is increasing [193]. Often the results of scientific studies are too specific to be useful to the general public and journalists often misinterpret results of scientific studies [82]. However, effective reporting on science is the only mechanism many people have for learning about recent scientific developments that may affect everyone [206, p. 311]. Research has shown that science communication is not done particularly well, for many reasons: the background of science communicators often includes no scientific training; editorial priorities may negatively influence science communication, causing great frustration to the communicator; some scientists don't care about sharing their work; some scientists are criticised for commenting outside of their own expertise; and the public has diverse views and interests [206]. Science communicators have developed process models for communication [73, 219], and best practices for different audiences [47, p. 110-114]. But, questions still exist regarding the processes of the general learning science, standards science journalism training, the effect of new sensationalism and hype on the reader, and the way readers determine which science news articles are reliable [206].

In addition to mainstream media, such as television shows like *Mythbusters*, and science journalism, scientists are also collaborating with artists within the science communication context. One example is a collaboration between scientists at CSIRO and Australian National Centre for the Public Awareness of Science, Australian National University. In 2014, artist and researcher Eleanor Gates-Stuart presented a paper that outlines the unforeseen consequences of science through art [77]. One model of research Gates-Stewart cites describes building knowledge as a means of creating new meaning or understanding from different knowledge systems, such as creative practices including art or design [190, p. 30]. Creative practice can build on scientific knowledge; its methods and ways of thinking about and addressing problems can used not only in science communication, but also within scientific processes. This can affect research methods of scientists as well as provide the public with an altern-

ative point of entry to science [77]. The art-science collaboration between Gates-Stewart and CSIRO scientist Chuong Nguyen, which is described in the paper, produced several research outcomes and artworks. One outcome used novel, high quality, optical scanning methods of small insects, a scientific outcome, to produce several artworks. These ranged from projection mapping images onto the Questacon building (a museum in Canberra Australia) to bugs 3D printed in titanium. Both of these, and other artistic outcomes, generated positive media attention beyond what could be achieved by either individual domain [77]. Collaboration created new ways of portraying and communicating scientific research, greater opportunities to publish work in different academic fields and provided the general population with more entry points to scientific research.

2.5   Artistic Visualisation

2.5.1   Definition

Both art and visualisation extend the functions of the brain. Visualisation is often used to aid reasoning, using the visual processing power of the brain to overcome its limitations, such as working memory, and providing insight into data. The function of the visual brain is described by neurobiologist Samir Zeki as *a search for consistencies with the aim of obtaining information about the world* [223, p. 76]. Zeki applies this definition "with equal vigour" to the function of art, describing the artist and the brain in the same terms:

> In order to represent the real world, the brain (or the artist) must discount ("sacrifice")
> a great deal of the information reaching it (or him), information that is not essential to
> its (or his) aim of representing the true character of objects.
>
> It is for this reason that I hold the somewhat unusual view that artists are neurologists...
> [223, p. 77]

This description could also be extended to visualisation: In order to represent the real world, the *visualisation* must *filter* a great deal of the information *supporting* it, information that is not essential to its aim of representing the true character of *data*.

If the role of visualisation is the same as the role of the artist (and the visual brain), then is all visualisation art? Viégas and Wattenberg, collaborating artists and leaders of Google's data visualisation research group, present a working definition that is useful for this section:

> Artistic visualisations are visualisations of data done by artists with the intent of making
> art. [216, p. 183]

This definition is useful for two reasons: it implies that these visualisations are actual mappings of data, rather than of just implications of science, or messages from scientific research; it also sidesteps the issue of 'beauty' in visualisation. This means that scientific visualisations that are beautiful, are not artistic, and not included with artistic visualisation, which doesn't need to be "beautiful". Consider the image in figure 2.8, showing a false-colour image from an electron micrograph. The image may

be beautiful, but it is a scientific visualisation; it was not intended to be artistic. This means that this image would not be considered artistic visualisation, nor would the beauty of nature, but their beauty is not diminished because they are not art. This definition gives useful, distinguishing characteristics to artistic visualisations.

2.5.2 Collaboration

Artistic visualisation has the ability to make scientific metaphors more tangible, according to research by Lesley Duxbury, from the Royal Melbourne Institute of Technology (RMIT University) [64]. Mass media channels often use language of catastrophe and imminent peril to communicate the scientific issues around climate change, which makes some climate scientists uncomfortable [64, p. 38]. People build an understanding of the world through analogy and metaphor, and if science can accept and embrace artistic metaphors, then a space where artists and scientists can collaborate will be formed. This can lead the general public to new ways of thinking about issues like climate change. It is the contrasts between art and science that make this possible, while bringing the two fields closer together through collaboration. Research and publication in artistic visualisation often focuses on, or outlines collaborative work between artists and scientists.

Forming a team for collaboration is an important step. One case study published from a psychological perspective on the production process in transdisciplinary collaboration presents five lessons [187]. First, team building should not be done solely based on individual expertise; geographical, cultural and individual differences are important. Collaboration is improved by personal familiarity, smaller team size, and proximity both in time and location. The second lesson is that collaboration should start with a meeting with all collaborators present. This helps standardise terminology and define key concepts of each individual area of expertise represented. In-person meetings are more important, especially to build trust, at the beginning of a collaboration. Third, mutual understanding of the outcome is developed through regular review of prototypes. Fourth, in order to minimise delays, it is important that individuals focus on their role as part of a larger whole, their subtasks are part of a single project. The final lesson presented is that it is a stressful experience: there is a lot of uncertainty at the start of a new transdisciplinary collaboration. Leaders need to trust the expertise of their team, motivate them, and try to reduce their stress [187, p. 320-321]. Collaboration between scientists and artists are a catalyst for creativity. Novel and useful solutions emerge from exploratory responses to ill-defined and complex problems; without these, there is no chance for creativity [187, p. 320].

The third lesson from this case study recommends regular reviews of prototypes. Collaborative projects can use this lesson to further leverage the expertise of artists through the artistic critique. Artists use an established vocabulary and art theory to criticise artwork [114]. InfoVis, sciVis and visual analytics would benefit from establishing similar paradigms for critically thinking about, highlighting and learning from mistakes [115].

A paper by Graeme Forbes, published at ACM SIGGRAPH 2015, articulates additional roles that the artist, media artists in particular, can play in transdisciplinary visualisation [76]. Within typical art-science projects media artists tend to see themselves as either the leader, communicator, visionary,
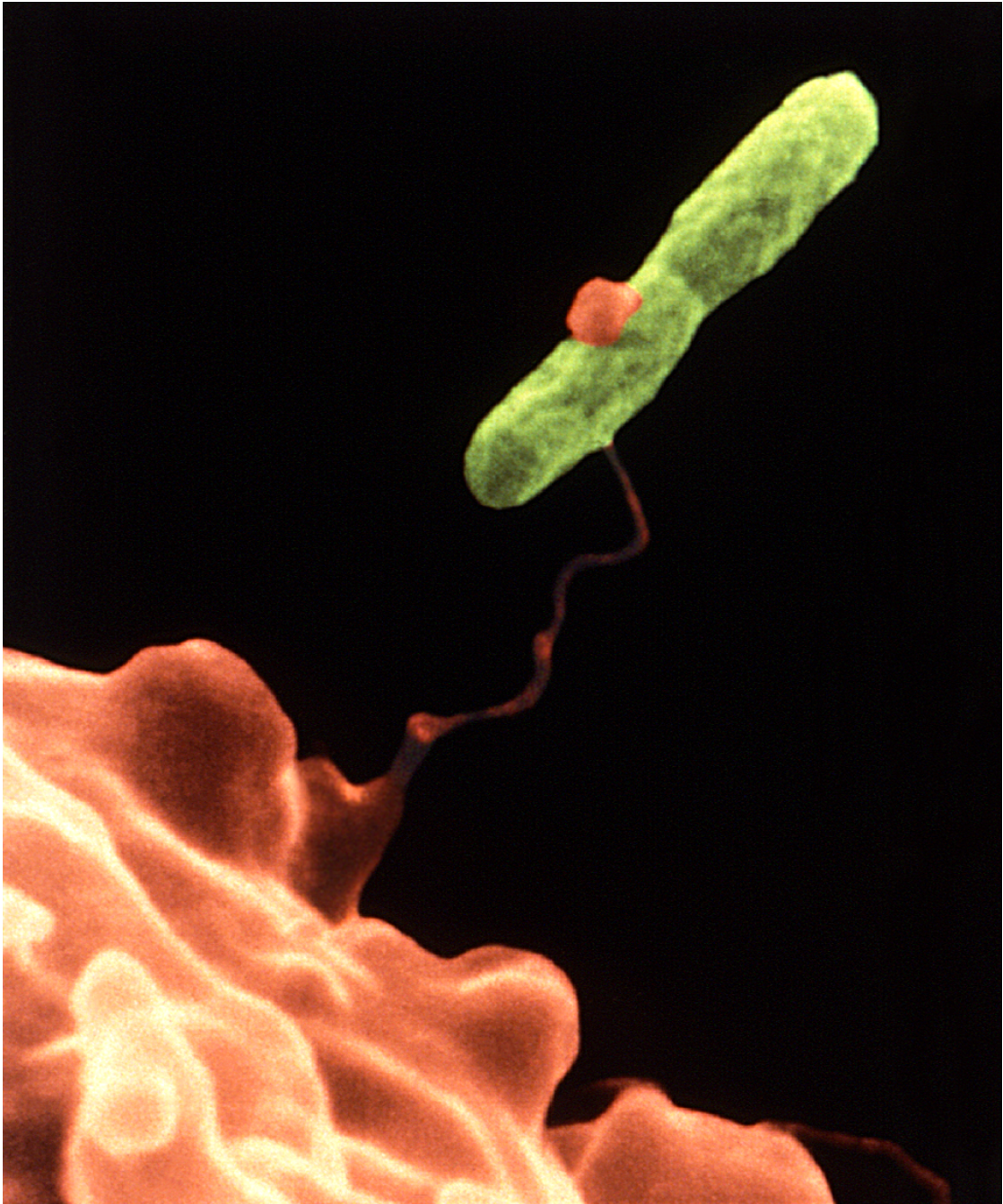
Figure 2.8: This electron micrograph depicts an amoeba, Hartmannella vermiformis (orange) as it entraps a Legionella pneumophila bacterium (green) with an extended pseudopod. Public Domain image downloaded from the CDC Public Health Image Library [71].

or challenger [76, p. 333]. Collaboration will benefit further from a new framework of activities that Forbes proposes. Media artists can function as *augmenters* of research, as *generators* of research agendas, as *provokers*, who challenge assumptions, and as *mediators* between perspectives and languages [76, p. 333-334]. The challenge to media artists is balancing these roles with producing artistic output, as that is an important objective for an art-in-residence. Forbes created these roles by examining several "ethnographies and postmortems" of "artist-in-lab experiences" [76, p. 333]. His research draws the conclusion that media artists play a more substantial role than beautification and public outreach, education or community building in an art+science collaboration [75].

There are many examples of collaboration in practice, but there are differing degrees of engagement with the primary researchers. Artists such as George Khut collect and visualise data themselves. Khut's *BrightHearts* project is a biofeedback work that was used in paediatric wards with patients that must undergo painful, recurrent procedures [112]. It uses immersive multimedia to help patients manage pain; engaging with the work on an iPad distracts the children from the medical procedures [113]. Khut collects the data in real time and visualises it through abstract, artistic representations. This work was created in collaboration with paediatrician Dr Angie Morrow, Staff Specialist, Kids Rehab, The Children's Hospital at Westmead. Another model of collaboration involves the artist-in-residence programs with scientists. Melbourne-based artist Chris Henschke created several works during a residency at the Australian Synchrotron [97]. During this time Chris was able to use data from the synchrotron to create works, but also used input from the scientists themselves, creating a "two-way creative process" [43]. Henschke compares media art to scientific research: visualisation has methods common to both disciplines. Henschke aesthetically analysed data from the synchrotron to produce art, fundamental to which was the science and technology which composed the data [97]. Artist-in-residence programs can inform future works [177]. *Grow* (2012) was developed by Erica Seccombe after a residency with the Department of Mathematics, at the Australian National University. Seccombe developed the skills required to collect data from an electron microscope, then visualise it with a specialised software, called *Drishti*, which means "insight" in Sanskrit [177, p. 38]. This was a foundation for Seccombe to create *Grow*. In an artist-in-residence colaboration Eleanor Gates-Stewart and Sherry Mayo produced *StellrScope* (see figure 2.9). The artwork which benefited both the artist (Gates-Stewart) and scientist (Mayo) by creating desirable outcomes for each party: exhibition for the artist, publications for the research scientist and public engagement for the research organisation, CSIRO. Two images from this artwork were included in *Science of the Unseen*, an online exhibition published by ACM SIGGRAPH Digital Arts Community.

2.6 Reflective Practice

The process of reflective practice is to take experience as data, and mentally engage with it in order to make sense of what has occurred. Reflecting on the act of producing a visualisation [18]. Internally processing the choices made in the design of a visualisation would be useful for the practitioner, but can also benefit others in the same field of practice. This can be done at several stages: before undertaking the design, in anticipation of the exercise; during a process, allowing the designer to

Figure 2.9: *StellrScope* by Eleanor Gates-Stewart and Sherry Mayo. Image used with permission.

notice, and adjust their design where appropriate; and after the event, particularly as a learning process [18]. Research into reflective practice was heavily influenced by the work of Donald Schön, who framed his research as an educational practice [217]. However, reflective practice is useful for the purpose of communicating to other practitioners about the decisions made in the process, as much of the knowledge of creative practice is esoteric, and done in the language of their practice [217]. The challenge for creative practitioners is to create a link between the visual and the textual; coherent arguments and clear links need to be made in a multimodal environment, which is not always trivial [60]. These reflections are often hard to find, perhaps as a result of the difficulty of reconciling the visual and textual modes of communication.

United States gun death data visualization (2013), published by Periscopic [154], data visualisation design consultancy, is a web-based visualisation the number of years of life that have been stolen by gun violence in USA in 2010 and 2013. In an article on their company website[8], designer Dino Citraro reflects briefly on the sobering project after it has been published [39]. The visualisation is striking, not because of novel design, but because of the scale of loss of potential life in a single year: over 400,000 years for 2010 and over 500,000 years of life in 2013. Citraro notes the confrontational nature of the information being visualised [39]. The short reflection describes their dataset, the method of modelling the data (the number of years a gun violence victim may have lived, given their demographics) and some of the interesting insights that they found when visualising the data. The reflection does not go into detail about the way in which a particular method of mapping data to visuals was chosen, but the visualisation itself is not complex, so this information is likely to be inferred by a reader. Citraro's reflection [39] is a good example of how the process of data processing that lead to a visualisation can be communicated. As the visualisation is available online, it is not difficult for the reflection to also be published online making it accessible to the viewer, though in

---

[8]http://www.periscopic.com/

this case the visualisation webpage only includes as descriptive note about the sources and methods used in the visualisation [154].

A keynote address at the Tapestry 2017 conference, by Neil Halloran, creator of *The Fallen of World War II* (2015) [93], which was discussed in 2.2.3 on page 37, describes his use of war statistics to make an emotional story[9] [94]. Halloran notes in the presentation that the creation of the work was tied to a personal reflection: his retort to advice that the emotion of the a story he tells through the data needs to be tied to the story of an individual, in order for it to be meaningful [94, time 29:16]. Halloran continues from this reflection in anticipation of creating the visualisation, to share his reflection on the technical challenges he experienced during the creation of the visualisation.

The reflection in anticipation, and during the design process, as in *The Fallen of World War II* (2015), [94] and the reflection after the design process in *United States gun death data visualization* (2013), [39] are examples of designers who have used different media (the conference presentation and an online article) to communicate to the wider community of visualisation designers. Reflective practice is useful for the practitioner, to learn from their process, but accessible reflections are a useful learning tool for other creative practitioners.

2.7 Research Opportunities

The literature on visualisation is a background, from which NEUVis can establish its own tools, techniques and methods. This body of knowledge can inform how to present information efficiently and effectively, what best practices should be used, and what made seminal visualisations effective. Gaps in literature exist where the visualisation is produced for a user who does not have domain knowledge, or has different values to the audience of sciVis, infoVis and visual analytics. The literature values the effectiveness of visualisation, but not the effect on the user and the way that they feel about the data. The literature (particularly the work of Tufte) does provide many best practice guidelines, but they only relate to an optimum construction of visualisations. They do not outline how the designer should take into account either the needs or context of the user, how these needs and context are best expressed, and what implications they will have on the design process. The next chapter investigates how these opportunities were investigated through two user experiments, explaining the methodology and execution of the studies.

---

[9]The presentation is available online in its entirety at https://youtu.be/TCqcpL8F99k

Chapter 3

Experiments

The method of science depends on our attempts to describe the world with simple theories: theories that are complex may become untestable, even if they happen to be true. Science may be described as the art of systematic over-simplification—the art of discerning what we may with advantage omit.

—Karl Popper in *The Open Universe*

3.1   Aim

The objective of the experiments is to facilitate reflection on the design process used to create NEUVis. Domain-novice users will also compare their own "affective and effective" responses to three different types of NEUVis: static, moving and interactive. The term "affective and effective" invites users not only to express their understanding of the science that is presented, but also the response they have in terms of their emotions and feelings. Users were given opportunity to compare their preferences as well as the way that they related to the data—how it is relevant to their own context. This is an important step for analysing visualisation practice, particularly for NEUVis, since most research focuses on the aspects of visualisation which can be empirically measured, such as speed, accuracy, and short or long term recall of information [36, 16]. These elements of visualisation design are important, and have done great work in helping the visualisation community to become more effective, especially for the domain-expert user group. However, the current corpus of research does little to understand the way that the non-expert audience experience visualisations, and how they perceive the information in their own context.

Questions about the nature of visualisation include:

- How does the user respond to different kinds of NEUVis?

- What models of collaboration between primary researchers and creative practitioners exist, and how do they differ?

- What design considerations are essential for developing NEUVis?

- How does the presentation's construction, medium and message relate to the end-user experience?

In order to study this, user testing focused on one question:

> *How does the non-expert user describe their affective and cognitive response to common modes of NEUVis?*

Other questions of collaboration, design considerations and the relation between visualisation and user experience are explored through the design and testing of a novel interactive installation, which visualises science, and is designed for the non-expert audience.

3.2   Qualitative Research Methods

This research employs qualitative methods to explore and triangulate user responses to visualisations, as opposed to empirical methods, such as preferential studies or measures of efficiency, which are commonly used in HCI testing. These evaluative methods are not likely to answer the questions defined above on the nature of visualisation, and are empirical in nature. As seen in the previous chapter, there are many examples of quantitative analysis of visualisations (see 2.2 on page 30), but they do not allow the non-expert user to describe their own experience with the visualisations, their own reality. Qualitative methods were employed in contrast with existing published research, so that the user's real experience with the work is recorded. These methods were developed based on John Zimmerman's [226] Research Through Design model for practice-based research in the field of Human-Computer Interaction (HCI) and Lincoln and Guba's highly influential book, *Naturalistic Inquiry* [124].

3.2.1   Research Through Design

Zimmerman's model of research through design [226], defines the process and evaluation used to develop the interactive artwork. Research through design requires a novel integration of theory, technology, user need and context. The design process is then evaluated against four criteria: process, invention, relevance, and extensibility. Research *through* design, can be contrasted to research *for* design (developing new methods of designing) or research *on* design (research into current practices and processes of designers). The interactive artwork created for this research was called *18S rDNA*. It is named after a gene that is present in all eukaryotes (most cell-based life forms) that scientists can use to distinguish between organisms present in soil samples.

Reflecting on the development of *18S rDNA* allows the processes to be developed and expressed in a way that is extensible and useful to visualisation designers. The processes used to develop the installation are then expressed, moving from tacit to explicit knowledge. Because of this, the methods can then be used to develop a final installation. This will allow the whole process discovered to be tested, communicated, and made extensible to the design community. The detailed discussion of the design of *18S rDNA* will take place in chapter 5.

3.2.2 Naturalistic Inquiry

Lincoln and Guba's model of naturalistic inquiry defines the characteristics of postpositivist qualitative research [124, pp. 39-43], though not all are useful for a research through design method. The following characteristics established by Lincoln and Guba informed this research:

Use humans as the primary data-gathering instrument. Rather than relying on instruments, the preferable method of collecting data is through human interaction. The inquirer and the subject are capable of grasping meaning of interactions in the text context, whereas instruments are not.

Use tacit knowledge The nuances of the realities of each subject in the observed context is exposed through tacit knowledge. Some of the interaction between the subject and observer only occurs at this level. In addition to knowledge expressible in language, tacit knowledge more fairly mirrors the values of the investigator.

Use qualitative methods, rather than quantitative Qualitative methods are more adaptable to different contexts and realities of the subject than quantitative methods.

Inductive data analysis, rather than deductive Inductive analysis of data is more likely to identify multiple realities experienced by different subjects. Generally inductive analysis infers general laws from specific circumstances; deductive analysis infers particular circumstances from a general law.

Emergent Research Design Since qualitative research is largely unpredictable, research design should emerge from the inquiry process. The inquiry should be a function of the interactions between the inquirer and the subjects, and their responses to the context.

Negotiate Outcomes The inquirer should allow the source of the data (in this case, test participants) to negotiate the outcomes. Any specific working hypotheses that might apply are best verified by the participants involved in the testing. Participants who nominated that they were willing to be contacted were sent an email with an outline of research that is presented in section §4.4 for review. No users chose to respond to the request for feedback on the research.

Interpret data ideographically, rather than nomothetical Data should be interpreted as specific facts in terms of the particulars of the case, rather than in terms of law-like generalisations.

Set boundaries to the inquiry on the basis of the emergent focus of the research As the research design emerges, the focus of research potentially shifting, the boundaries of the research should be similarly flexible. This allows multiple realities, the experience of the subjects and interaction with the inquirer, to guide and focus the research.

Establishing trustworthyness   Establishing trustworthiness is done by establishing *credibility*, *transferability*, *dependability* and *confirmability* [124, Chapter 11]. In this research, credibility is established using a variety of methods Lincoln and Guba propose. *Persistent observation* is used to render the inquirer open to multiple influences. As well as this, data was *triangulated* from different sources, using multiple methods to establish a reliable result. *Peer debriefing* was undertaken with a disinterested colleague, which helps the inquirer stay accountable and rational, can remind them of the "bigger picture", and provide the opportunity for catharsis. *Referential adequacy* was established through the use of multiple recording methods, and *negative case analysis* allowed results to influence the evolution of the research, reframing the experiment. Transferability, necessary since it is impossible to establish external validity in qualitative research, is established through thorough descriptions of the research methods. Dependability is established through credibility, in the same way that there is no scientific validity without reliability. Confirmability is established by the use of *triangulation* of data, and reflexive collections of raw data, data reduction and reconstructions and process notes.

3.3   Experiment

Three different styles of visualisation were compared in this experiment, *static*, *moving* and *interactive*. These represent the broad formats that are used for information visualisation [116, 125]. Infographics, still images that communicate information, were selected to represent *Static* visualisations. Infographics are a kind of data visualisation that is often shared through social media in the non-expert user context. Other examples of types still images used as visualisation are those created by news media organisations and government or global organisations. *Moving* visualisations, videos and animations are also a relevant medium for the non-expert audience. Videos are easily shared online through multiple media channels. They involve a large investment of effort to produce, so it was desirable to investigate the kind of responses that audiences have to this medium. *Interactive* NEUVis, such as interactive museum and art installations, or interactive websites also are useful ways of communicating with the non-expert audience. Museum and art installations represent a different context to the other two types of visualisations. These three approaches to visualisation do not represent all options available to creative practitioners, but they are not unfamiliar to the general public. Examples of other media types include physical works, sculptural and 3D printed artwork, or non-visual media, such as sonification or literary work. From the three selected modes of communication, specific visualisations were chosen for testing, which were published by, or in collaboration with CSIRO.

3.3.1   Experimental Method

For each experiment, 10 volunteers were recruited, each spending about one hour participating with the experiment. The participants were recruited from the Faculty of Architecture Design and Planning at The University of Sydney. An initial poster was created (see section §A.1), but additional students and faculty members were approached after the response to the poster was low. Participant eligibility was based on having no tertiary training in science. During the test, a user was shown three visualisation modes, and allowed to view them at their own pace; each was followed by a short

survey with a mix of likert scale responses and open-ended questions (see section §A.4). This gave
the user the opportunity to evaluate and express their reactions to the visualisation they were being
shown. Each visualisation showed different data sets, which was a point of concern during initial
development of this research project. It was decided that it was appropriate for different visualisa-
tion modes to present different data, so that the user would not find a different visualisation method
boring or repetitive after seeing the same data before, or have any assumptions about what was being
shown. If the same data set was visualised in each method viewed, it may have biased the response.
By conducting two experiments, this research project was able to respond to user feedback, review
the understanding of the user experience in light of collected data, and adjust the method of inquiry
accordingly, and update the design of the interactive installation. The surveys included three open
ended-questions, summarised as: in your own words, describe the information being communicated
through this visualisation; describe your emotional state while viewing this visualisation; describe
how you were feeling when viewing this information. The survey also asked users to select items
as many of the following list were engaged, or may be affected by the information in the visualisa-
tion: attention; memory; understanding of language; learning; reasoning; problem solving; decision
making; or none of the above. The last part of the survey was a likert scale, using a self-assessment
manikin [19], to help them assess the experience. The self-assessment manikin helps users involved
in HCI testing rate their experience in terms of pleasure, arousal and dominance. This feedback was
particularly significant for the interactive installation. The forms used by the participants to assess the
visualisations are found in A.4 on page 165.

   Triangulating data was especially significant for measuring emotional responses to the data. A
literature review published 2011 [127] discusses that there is little consensus of what emotions are,
let alone how they are represented or defined [127, p. 576]. The literature review is presented for
researchers to compare the existing methodologies in a way that enables them to be compared against
research agendas. In order to ensure more accurate collection of emotional responses, two methods
were used to gauge each participants emotional responses in this study. Participants were asked to fill
out a short questionnaire, self-reporting their emotional response [127, p. 581]. This is an an evalu-
ative emotional response to the visualisations. This questionnaire included an open ended-response
section to report on their feelings and their emotional state, and also a self-assessment manikin, which
helped users to rate their response to the visualisation by affective (emotional) responses of *pleasure,
arousal* and *dominance*, which the user may not typically consider. In addition to the self-reporting
method, two observation methods were employed for the recording of facial, vocal and gesture cues
to emotional stimuli[127, p. 578]. The first observer method employed was a speak-aloud exercise.
Participants were asked to vocalise their internal monologue, which is a common practice among in-
teraction design and HCI research communities [35]. The task did not contain a high cognitive load,
and users were not being quantitatively measured for speed or short term recall, but for their qualit-
ative, visceral responses to the visualisations. This meant that concurrent think-aloud methods were
an appropriate choice, rather than reflexive think aloud methods, as described in [89] and [212].
The second observer method used was observer notes, where the researcher noted somatic emotional
responses, such as body language, verbal exclamations and facial expressions. This process is non-
intrusive, and can be confirmed by other feedback methods. In order to make this confirmation,

a commercially available EEG, the Emotiv EPOC, was to be used to measure the neurophysiological response the user had, in addition to audio and video recordings. the Emotiv EPOC *Affectiv Suite* records the emotional state of the user through several metrics: engagement/boredom, instantaneous excitement, long-term excitement, frustration and meditation. It uses proprietary algorithms to produce values for these metrics, but research projects have shown that the readings given by the device relate closely to self-reported feedback [32, 31]. In order to collect data, a simple program built in Processing (an open-source platform for creative coding built on Java) was developed. This program simultaneously records the data from the EEG, as well as produce a .wav (audio) file of the default audio input of the computer the program runs on (a Zoom H4n was used in this experiment) and allows the user to make notes. The notes and data are both timestamped to allow them to be synchronised with the corresponding audio file.

Unfortunately, the first few participants found wearing EEG uncomfortable, and the process of correctly putting on the device was slow, frustrating and difficult. As a result of these experiences, the use of the device was abandoned, so that users were not starting the experiment feeling frustrated, potentially biasing their emotional response. The metrics measured by the EEG were not essential to the research question, so, while disappointing, this did not substantially hinder the collection of data, and self-reporting could still be confirmed by the other data collection methods. Triangulating emotional responses was important because it would either confirm or cast suspicion on findings if different methods of data collection conflicted. For example, it would be expected that if a user reported that they felt excited and happy while they were watching a video, this would also be reflected in the self-assessment manikin ratings of arousal and pleasure, and the body language would not indicate anything to the contrary.

3.3.2   Experiment 1

The visualisations shown in the first test were three infographics published by CSIRO (see B.1 on page 177), *The Hungry Microbiome* (see figure 1.1), a four-minute animation by Chris Hammang, published by CSIRO, and an early version of *18S rDNA*, an interactive artwork based on scientific data collected as part of CSIRO's research (see chapter 5 for a complete discussion of *18S rDNA*). The three methods of visualisation were well received, with generally positive feedback. The three infographics shown to users for the first test communicated information about climate change: the effect which consistent warming will have on the global climate system (see B.1 on page 178); potential methods of adapting to a changing climate using engineering and built environment solutions (see B.2 on page 179); and a timeline outlining of the history of climate data collection (see B.3 on page 180). Users felt that the infographics were direct and clear, but most users stated that they didn't engage with the content on an emotional level, even if they also indicated that it was a topic in which they were interested. However, the video received overwhelmingly positive reviews (see C.1.1 on page 183). The notes from this research can be found in C.1.2 on page 186.

Users found the videos a generally pleasurable experience, according to feedback from the self-assessment manikin, but did not give a significant feeling of arousal or stimulation, or a sense of dominance (feeling 'in control' of their situation). Descriptive statistics can be found in 3.1 on

page 69. This is reinforced by the observation of user's body language, as all participants in experiment 1 displayed the same behaviour: they each leant back in their chair and folded their arms. This would show that they are relaxed, rather than particularly excited by the experience of watching a video. The average user rating for arousal was in the middle of the scale. In addition to assuming this posture, it was noted that many users had an 'aha moment'—an exclamation of insight, such as "oh, really?", or something similar—at the climax of the video, indicating that they were actively engaging and processing the information, which allowed them to make new connections with the content from the video. From the questionnaire users were able to give accurate descriptions of the information presented in the video, and reported that it was very direct, rather than abstract, even though it was discussing digestion on a microscopic level. In open-ended responses about the emotional state and feelings of the users, some reported significant connections to the data on a personal level, relating the data to themselves and their own bodies, for example: (emphasis added)

> "[It] makes me *happy* to see a visualisation of something invisible to the naked eye. Like learning about *another universe*." (Experiment 1, user 2)

> "[I] grew *anxious* as my awareness of the reasons I should eat more healthy food became more clear… not excessively anxious." (Experiment 1, user 3)

> "It *freaks me out*, makes me feel like I've gotta eat some more healthy food." (Experiment 1, user 3)

> "I was feeling hungry whilst watching the video, but also visualizing what it would look like in my own stomach." (Experiment 1, user 7)

> "The part about the intestinal cell's DNA becoming corrupted and possibly leading to colon cancer was moving" (Experiment 1, user 9)

Users described themselves when watching the video using words, such as *interesting and vivid, compelling, engaged, excited, happy, focussed*. Most users did not say much while watching the video, probably because they were paying attention to the narration. User 4 (without any suggestion that they should do so) paused the video to explain their thoughts.

This user stated that they were impressed that the cell structures shown in the video were obviously supposed to look real, commenting that they appreciated that the video had "gone to the trouble" of showing the processes in a way that seemed realistic; the representation was scientifically accurate, instead of "just blobs." Though the user was not a scientist, they appreciated that the production of the video was not oversimplified. The user was not worried that the video used was more abstract information, as it seemed to him that the visual construction reflected what someone would see under a microscope, only coloured. The user compared the message from the video with "eat healthy, and you won't get cancer," which they had often heard, commenting that the video clarified the purpose of the statement:

> "I personally really enjoy knowing why I'm doing something—I feel kind of weird doing something unless I know what's happening, and what's the cause and effect." (Experiment 1, user 4)
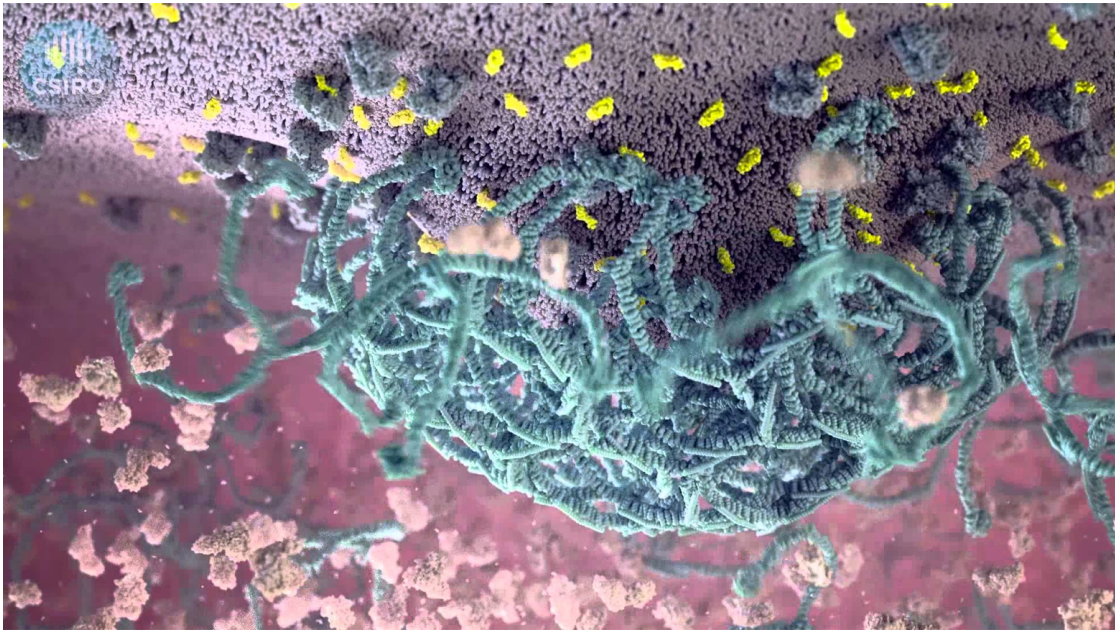
Figure 3.1: A still image from *Alzheimer's Enigma*. Animation and narration by Christopher Ham- mang. Published by CSIRO under Creative Commons Attribution Licence

This user noted that seeing the cancerous cell being destroyed by eating good food is important and engaging, and communicates a better lasting message.

From these observations about *The Hungry Microbiome* a question arose as part of the negative case analysis undertaken after the first experiment. The video was much more popular with the participants than the infographics or interactive installation, but *was it the message, or the medium?* The current research design did not account for this possibility, and the second experiment was adjusted to explore this unexpected response.

3.3.3   Experiment 2

In the second experiment *The Hungry Microbiome* was replaced with *Alzheimer's Enigma*. Both videos are high quality productions, of a similar style, animated by Chris Hammang, and published by CSIRO. The information narrative from *The Hungry Microbiome* was used to design an infographic image for the second experiment, using the same narrative, language, a similar colour palette and visual mapping (see B.2 on page 182). This meant that a comparison could be made between user responses to *The Hungry Microbiome* and *Alzheimer's Enigma* videos and also between the video and infographic versions of *The Hungry Microbiome*. The infographics in the first experiment did not have a narrative structure, so comparing an infographic and video, each with a narrative structure was also a more effective way to compare the responses to the different media.

Table 3.1: Self-reported values for likert scales in experiments.

Visualisation (experiment)	Clarity /5	Direct/Abstract /5	Understanding /5	Pleasure /9	Arousal /9	Dominance /9
Static (1 average)	3.3	2.3	3.4	5.8	5.2	5.3
Static (2 average)	4	1.9	3.7	6	4.9	5.7
Static (combined average)	**3.6**	**2.0**	**3.5**	**5.9**	**5.1**	**5.4**
Static (combined median)	**4**	**2.5**	**4**	**6**	**5**	**6**
Moving (1 average)	4.7	1.6	4.7	7.4	5.3	5.5
Moving (2 average)	4.5	2.6	4.7	7.4	6.1	4.1
Moving (combined average)	**4.6**	**2.1**	**4.7**	**7.5**	**6.5**	**4.5**
Moving (combined median)	**5**	**1.5**	**5**	**7.5**	**6.5**	**4.8**
Interactive (1 average)	2.7	3.8	3	7.1	6.9	6.7
Interactive (2 average)	3.1	3.3	3.1	6.1	7.2	4.7
Interactive (combined average)	**2.9**	**3.5**	**3.1**	**6.6**	**7.1**	**5.6**
Interactive (combined median)	**3**	**4**	**3**	**7**	**8**	**6**

The feedback from the two user groups shows some general trends for infographics and videos (see C.2.1 on page 219 for all responses). Average values for each metric reported on by users in both experiments, and combined average and median values are shown in table 3.1. Infographics were seen as generally clear and direct ways of communicating information. Users were able to express, in their own words, the information that was being communicated, showing that they had developed a general understanding of what they were shown. Most users also picked up on keywords from the infographic. Users reported in both experiments that they felt that their attention, memory and learning was being engaged by the infographic. In the second experiment, showing *The Hungry Microbiome* as an infographic, users reported that the infographic engaged or would affect their decision making. Users' reporting that they felt they learned something suggests that they may make a decision based on the information, and would be a long-term topic for future research. Users reporting that the infographics engaged their memory is in line with current research, such as Borkin's research paper titled *What makes a visualisation memorable?* [16].

Observation notes stated that in both tests many users' body language was like they were studying while reading infographics (see C.2.2 on page 221). Users leaned in and read closely, which lines up with open ended comments where users stated that they were focussed, or concentrating, more than just paying attention. Users appreciated the design of infographics: the way that text was broken up to match with images, use of colour, scale and form, and other general graphic design elements. However, users did not report that infographics were particularly pleasurable or engaging. The response through observation and self-reporting was positive, but not enthusiastic. In terms of their production cost, the infographics may be effective for sharing scientific research with the non-expert population, but they may not engage users on a level that would lead to any meaningful change in their behaviour. While the production cost of creating a video is much greater than a single image, the user response shows that there may be the potential to engage users with the scientific research.

Both experiments show a very positive reaction to the videos, more so than for the infographics. They were seen as the most direct, clear and users perception was that it helped them understand the videos, as the median score for each shows in 3.1 on the preceding page. The videos provoked curiosity and engagement, without the user feeling like they had to concentrate in order to follow the narrative. Users were able to internally process and communicate the information they were given. Users' body language was more relaxed, but still focussed on the video, most not saying as much for the think-aloud exercise until after the video had finished. The exclamation of insight was common for video, but not infographics. One user commented about *Alzheimer's Enigma*:

> "I think I would definitely struggle to understand [the visualisation] if it was just [text]... seeing it all in motion, and how it got carried out, is possibly one of the only ways I would be able to take that all in, certainly in that space of time." (Experiment 2, user 7)

This comment is in line with general objectives of visualisation, as Chen et al. outline [37]. Saving time is a useful measure for effectiveness of a visualisation, rather than 'insight', which is difficult to measure and define. It also may be difficult for a user, without any external help, to ever interpret the kind of information that was presented in the video and create their own, internal mental recon-

struction of the data. The insight that was provided by this mediated visualisation experience may be impossible to replace with a non-mediated experience.

3.4 Interactive Installation

The interactive installation developed using the research through design process was also tested with users. Two of the four iterations of the installation were tested with users, and usability feedback was incorporated into the design of the installation.

The responses users had to both iterations of the interactive installation that were shown during testing were similar. In total 17 our out 20 users gave the installation a high score using the self-assessment mannikin for pleasure and arousal. The high score for arousal is probably due to the fact that the user needed to physically interact with the installation, as well as mentally engage with the data it visualised. The first installation, however, was seen as confusing, even though users said that they had fun. The scores for dominance (how "in control" they felt) were higher with the second version, but this is expected after some improvements were made to the interaction. Their curiosity encouraged them to continue playing with the simulation, and uncover what it had to say. Fewer participants said they were confused by the second iteration, and many users also said that they were engaged, excited and having fun.

After reflection on the testing process, a final installation was produced, which is described in detail in chapter 5. This installation also represents an implementation of the tools and knowledge described in chapter 4. After testing was completed, notes on the audio recordings were made, as well as generalisations of the similarities between the responses. Notes for the first test are found in C.1.2 on page 186, and the second in C.2.2 on page 221. The next chapter discusses the findings as a result of user feedback, and presents ways that a designer can practically approach the challenge of designing visualisations of science for non-expert users.

Chapter 4

Reflections

Preamble

The discussion about boundary objects in section §4.2 was adapted from my contribution to a peer-reviewed book chapter titled "Climate Change Education through Art and Science Collaborations" published in *Promoting Climate Change Awareness through Environmental Education*, 2016 by IGI Global.

Gough, P., Dunn, K., & de Bérigny, C. (2016). Climate Change Education through Art and Science Collaborations. In L. Wilson & C. Stevenson (Eds.), *Promoting Climate Change Awareness through Environmental Education* (pp. 16–36). Hershey, PA: IGI Global. doi:10.4018/978-1-4666-8764-6.ch002

In section §4.3 I have included content which was first published in a paper at *VINCI'14* conference, which was also developed into an article for the *International Journal of Software and Informatics* and published in 2015. The paper was peer-reviewed at both stages of publication

Gough, P., Ho, X., Dunn, K., & Bednarz, T. (2014). Art and Chartjunk. In *Proceedings of the 7th International Symposium on Visual Information Communication and Interaction* - VINCI '14 (pp. 171–177). doi:10.1145/2636240.2636852

Gough, P., Dunn, K., Bednarz, T., & Ho, X. (2015). Art and Chartjunk: A Guide for NEUVis. *International Journal of Software and Informatics*, 9(1), 61–72. Retrieved from http://www.ijsi.org

A short paper based on section §4.3 and section §4.5 is currently under review for OzChi, 2016, to be held in Launceston, during November, 2016.

It was unthinkable not long ago that a biologist or palaeontologist would be at the same conference as an astrophysicist. Now we have accumulated so much data in each of these branches of science as it relates to origins that we have learned that no one discipline can answer questions of origins alone.

—Neil deGrasse Tyson in conversation with NOVA, PBS

4.1   Reflecting on the experiment

Through design research, the broader, fundamental issues around the design task are considered, in addition elements of design practice, such as aesthetics and usability [121]. The reflections on these issues are presented in this chapter. The first reflection observes the nature of collaboration between the primary researcher, and the creative practitioner. This emerges from the interactions as part of the research process, and observation of existing NEUVis created by artists and designers in collaboration with primary researchers. This is also compared to the way that NEVis transfers knowledge to the audience. The second reflection considers the process used to create the interactive installation, and generalises it to a process model. The specific process and evaluation of the installation as a designed artefact is discussed in 5 on page 89. The third reflection compares user feedback made for the infographics and videos used in the evaluations. The fourth reflection proposes an extensible design tool for NEUVis.

4.2   Reflection 1: Communication and the boundary object

> Visualisations of data may become memorable and meaningful experiences as a result of inter-disciplinary collaboration. Crucial in this process appears to be the evocative manner of presentation and a combination of intellectual together with embodied experience which also addresses multiple sensorial modalities, such as sound and touch. [103, p. 1042]

The ultimate goal of art-science collaborations is to create a site for exchange, fluid discourse, and reciprocity. With this, collaboration can be ongoing and create self-generative outcomes, forming what is known as boundary objects. Susan Star and James Griesemer [185] coined the term "boundary object". Boundary objects are devices that are used to help collaborators understand each other and communicate effectively, while allowing them to work independently. They were first observed in use among scientists communicating across different scientific fields and have been substantially developed since. Paul Carlile [27] has identified the syntactic, semantic, and pragmatic modes as three categories of boundary objects; each of these have different uses within transdisciplinary collaboration. Collaboration between scientists and creative practitioners is facilitated by the use of boundary objects, tools and methods that aid the collaborative process. NEUVis produced through collaboration can also be considered a boundary object, helping the audience understand the science informing the artwork (see figure 4.1).
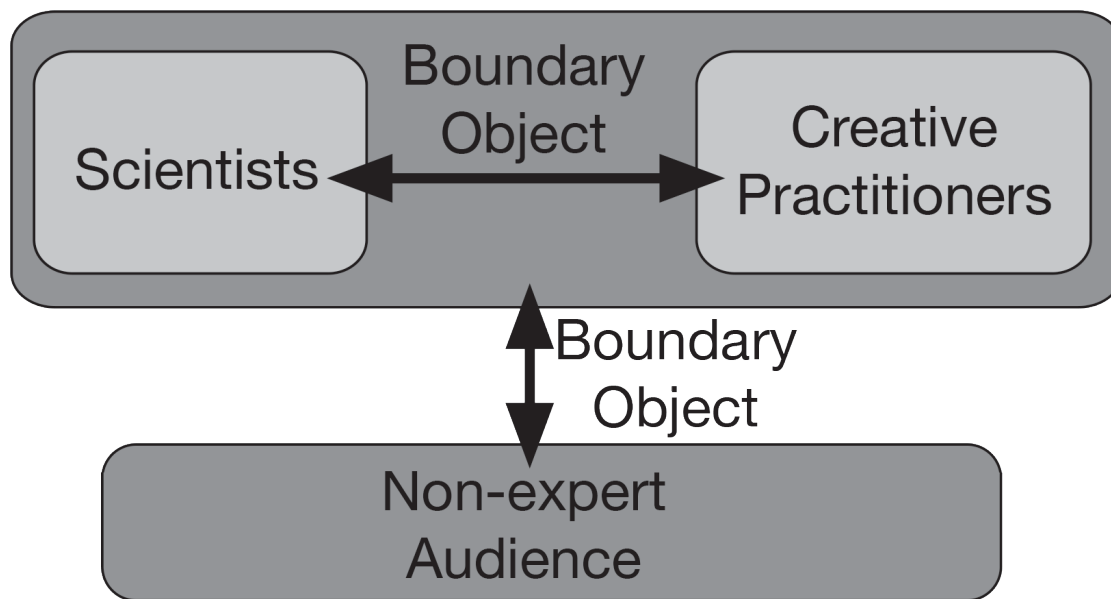
Figure 4.1: Boundary Objects in a NEUVis context

The major challenge in collaboration is communication between different fields [185]. It becomes critical to establish a means of crossing this boundary from one group to the other if they are to collaborate successfully. The boundary object establishes a clear set of methods that not only allows collaboration to take place, but also enables communication and encourages autonomous work by practitioners in their own fields [185]. The processes of developing a NEUVis are more aligned with those practices employed by creative practitioners, who are comfortable working within an ill-defined problem space. This kind of problem is often successfully addressed by creative practitioners, so it is sensible for scientists to leverage the expertise of such practitioners through collaborative partnerships. This collaboration can produce creative visualisations that transform the audiences' understanding of information and their emotional engagement with the science.

Creating a boundary object is difficult in any context, and often requires the collaborators to commit to adapting their mental model of the knowledge they have of their own field, so that they can overcome their semantic differences [27]. In the context of artistic NEUVis, there are two boundary objects to be negotiated. The dialogue among three social groups, the scientists, the creative practitioners, and the audience, crosses two boundaries. The first boundary is between the scientists and the creative practitioners for the creation of the NEUVis. This must be negotiated so that the creative practitioner can faithfully represent the outcome of the scientific research in a way that is able to engage the audience with the data on different levels. On one side of the second boundary object is the creative practitioner together with the scientist, and on the other side is the audience. In this way the work itself acts in translation on behalf of the scientist (see figure 4.1).

Carlile presents two different types of boundary objects, and introduced a third [27]. They are described as *syntactic*, *semantic*, and *pragmatic*. Syntactic boundary objects are repositories of knowledge that allow access to information without direct collaboration. The creative practitioner using this method can retrieve the scientific data for themselves; the largest concern is then how the data are processed. This may take the form of an indirect collaboration between the scientist and creative practitioner, as data can be retrieved from a repository, such as an online service. These repositories allow the group holding the knowledge to represent the data in their own terms, and puts the burden of processing that data on the group that wishes to make use of the knowledge.

Direct collaboration between creative practitioners and scientists allows both parties to learn about the differences between the two groups. This semantic boundary object illuminates the differences and allows the collaborators to gain an understanding of the source of the knowledge of the other group. A creative practitioner may collaborate directly with a scientist by sharing relevant scientific publications and presentations, but also research data and collection methods. This will help the creative practitioner develop an understanding of the data as well as its origins in scientific practice. To give the scientist an understanding of the creative processes that are used in developing an artwork, the creative practitioner may invite the scientist to be involved in prototyping, or user testing. These processes give each party an opportunity to learn about the source of their collaborator's knowledge.

The pragmatic boundary object goes further to promote the transformation of knowledge of each group, rather than just an understanding that there is a difference between them. This process will require the creative practitioner and scientist to engage in significant interaction and exchange. Carlile describes how boundary objects can be effective. Effective boundary objects should establish a shared language or syntax for representing knowledge. They provide a means for each group to specify what they know, and what is important to them, so that the differences in knowledge are made explicit. Effective boundary objects also allow collaborators to learn about differences between their fields, and facilitates the transformation of knowledge by incorporating the understandings of others [27].

The creative work, as a result of direct or indirect collaboration between creative practitioners and scientists, can also act as a boundary object, crossing a border between the knowledge of the collaborators and their audience. The artwork created needs to be adaptable to the audience as well as to audience contexts such as an exhibition or public installation in a museum or art gallery. While being adaptable it must also be a bridge to the knowledge of the informed user group, the scientists [185]. As the information crosses this bridge it needs to maintain its identity, that is, the data about science must not change its intent. This is not to say that concrete, direct representations are the only valid form of visualisation.

A NEUVis can faithfully represent data and still be abstract, culturally sensitive, interactive, physical, spatial, or beautiful. Exchange and collaboration between scientists and creative practitioners can result in work that honestly speaks on behalf of the research outcomes of the data it represents. NEUVis should be able to be described within Carlile's three descriptions of boundary objects. There is no "right" or "preferable" boundary object to use; designers can use different approaches that are available to them. As a syntactic boundary object NEUVis must establish a stable syntax that can be shared with the reader. In this case, many familiar methods of charting data to visual representations can easily act as this boundary object, as many users will already understand the existing syntax.

NEUVis can also communicate in a way that acknowledges different interpretations of common syntax. The use of artistic metaphor may be an example of how NEUVis can, in this way, act as a semantic boundary object. Recognising interpretive differences allows NEUVis to engage with sources of knowledge, and how they differ across the boundary of knowledge. As a semantic boundary object, NEUVis can be used tacit knowledge explicit. Finally, as a pragmatic boundary object, NEUVis can receive information from the audience. This can create a two-way flow of knowledge; though, this is is contrast to the goal of the field of science communication, as noted in 2.4 on page 52, which seeks to create a one-way system of communication. Using pragmatic boundary objects, NEUVis includes a process for transforming the knowledge from the audience, back across the boundary to the primary researcher/creative practitioner collaboration. This implies some form of interactive method used, but is not exclusive to digital representation.

4.3 Reflection 2: A process model for visualisation design

Design is a flexible and adaptive practice; a distinct field from the fine arts, or the natural or social sciences, it is a "liberal art of technological culture" [21]. There are many ideas and methods that can be called 'design' and a single definition cannot adequately cover them all. By starting with a common design process, and comparing it to the process of creating an interactive visualisation, this research reveals a design process for NEUVis.

Tim Brown, CEO of renowned design firm IDEO, states that the design process goes through three stages: *Inspiration*, the context that motivates the designer to search for solutions to a problem, or opportunity; *Ideation*, generating, testing and evaluating ideas that may lead to a solution; *Implementation*, transitioning to an artefact ready for market[167]. This three-step design process is the foundation for the reflection on a NEUVis design process.

The first stage in the process revolves around user needs, the actual desires or goals of a potential user that can be satisfied by the design. Human-centred investigation informs the technological design. There are many tools for discovering user needs, such as interviews and user observation in context. The second stage involves the designer using the uncovered needs as a platform for developing the artefact. One interpretation of this process is:

1. *Create*: a problem is defined, based on the user needs. The designer is solving a problem as they understand it, which satisfies the needs of the user. A tentative solution is proposed in response to this problem, which is developed into a testable prototype.

2. *Critique*: user testing with the potential audience or market for the design should be undertaken. As well as this, heuristic evaluation against specific criteria (Nielsen's usability heuristics [145], for example, see 2.2.1 on page 32) can provide important feedback. If the design satisfactorily solves the problem, and serves the user needs, it can be completed. If not the designer must reflect on how the user needs are not satisfied.

3. *Constraints*: this reflection allows the user to redefine the problem they are solving, in order to better satisfy the needs of the user. This technique of problem reframing [2] allows the designer

Design Thinking for NEUVis
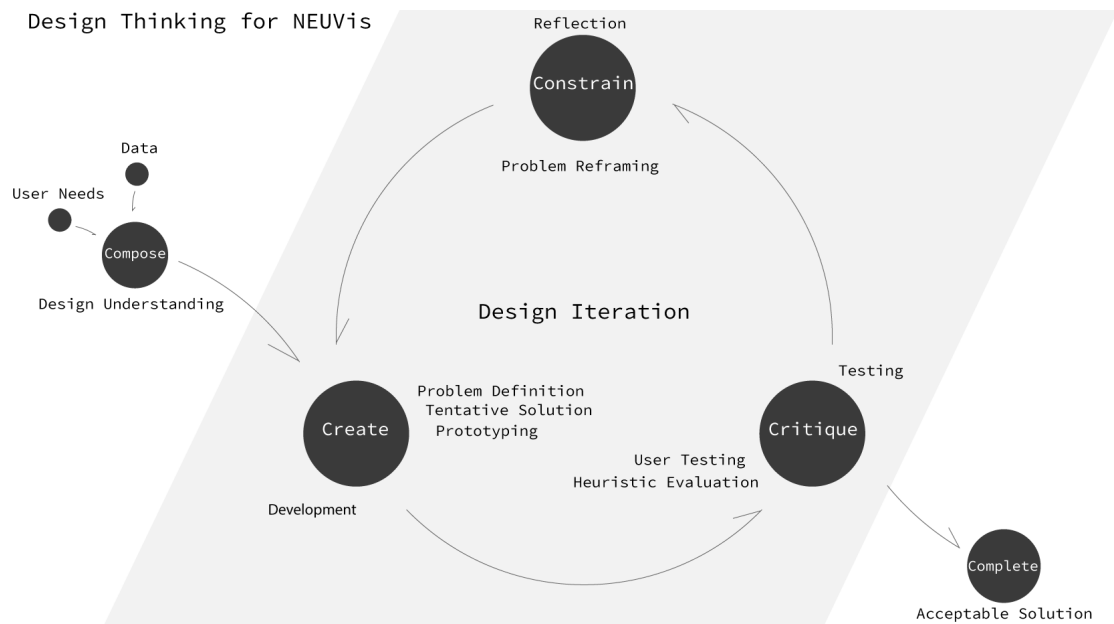
Figure 4.2: A Design Process Model for NEUVis.

> to begin a new iteration of the design, to leverage what has been learned from previous tentative solutions.

The final, implementation stage involves publishing or producing a satisfactory design. It also acts as a loop back into the beginning of the process, as the needs of the users change over time.

NEUVis fits into a similar framework; ideation still requires iteration over a cycle of creation, critique, and constraints. In response to the way that the message and implication of the data needs to be merged with the needs and context of the user Six Visualisation Questions that designers can use to merge the data and the user needs are proposed. This was formulated during an early investigation into the way that a designer can create an understanding of the data, and compose a unified message for their audience (see figure 4.2). The creation of this understanding is the defining difference between NEUVis and a standard design process. These questions help the designer clarify the relationship between the message and implications of datasets with the needs and context of the audience. It should be noted that these questions are not speculative: they should be supported by user research.

4.3.1   Six Visualisation Questions

1. How does this new knowledge benefit the user?   Addressing the needs and context of the user. This question prompts the designer to consider what practical outcome the new knowledge will give to the user. It is intended to help the designer empathise with their users.

2. What about this data is relevant or important? Addressing the message of the data and the context of the user. The designer should identify the elements and implications of data that are necessary for visualisation. It is also important to note that large portions of datasets may not be interesting at all, and may be irrelevant to the user, such as on the map of the London Underground, by Harry Beck (see figure 2.5b and the discussion in 2.3.2 on page 45). Superfluous data should not be visualised, and a pitfall for poor design is to cram in unnecessary information, as much as it is to embellish visual construction so that the data seems more interesting. As Tufte suggests, the right numbers are never boring.

3. What is otherwise inaccessible to the user? Addressing the message of the data and the context of the user. This is how designers can leverage novelty to engage users, stimulating curiosity. However, new information is not essential for visualisation, sometimes new representations are just as interesting. Either way, it is important that the designer understand how their data is positioned in the understanding of their audience.

4. What can the user access for themselves? Addressing the message of the data and the context of the user. Allow the users to continue to interact with data on their own terms. If most of the data is accessible to users, it is worth considering how users can engage on different levels, and the influence this will have on the construction of a visualisation. If most of the data is difficult to access for the general public (such as scientific literature behind a paywall), what implications can be presented that call the user to action, or engage with the content beyond the visualisation. This relates closely to one of the value-driven goals presented in [186]: encourage insight and insightful questions about the data. These questions can be prompted by the visualisation, and the user can be given the opportunity to engage further and find out the information for themselves.

5. What myths and misconceptions are relevant to the data? As discussed in section §2.4, traditional mass media shows such as *Mythbusters* and YouTube channels like *Veritasium* have built successful shows around addressing myths and misconceptions. But research has also suggested that this may have the opposite result, known as the *backfire effect*, and is discussed in [156]. The authors of this paper suggest that facts and myths presented together can become intertwined in the audience's memory, leading to incorrect reinforcement of myths that are being addressed, so the communication should deal in facts, rather than in myths. If myths are unavoidable, they suggest prompting the user to form their own attitudes of the information. Ask questions such as "What is your opinion?" or "Here are the facts, make up your own mind!" [156].

6. What is the potential for impact, and what are the risks of this visualisation? Express the potential for impact of a user empowered with data, as well as the converse risks. This will allow the designer to reinforce information that promotes the benefits of impacts. It can also highlight information that should be clarified in order to negate risks, in particular, the risks associated with the misunderstanding of data. This final question was influenced by the ongoing research described in 6.4.2 on page 131.

4.4   Reflection 3: The message or the medium?

The experimental design was altered for the second user test (as described in 3.3.3 on page 68). This reflection discusses the implications of comparing the message to the medium.

4.4.1   *The Hungry Microbiome*: Infographics compared to Video

The most significant difference in the video and infographic versions of *The Hungry Microbiome* was the exclamation of insight. Only one user was observed, and recorded, having an 'aha' moment while reading the infographic, at the climax of the narrative. This reaction was much more common in the video version. Users did self-report that they learned something new while reading the infographic, but there was no somatic reaction observed—the "aha" or "I see" comment, which was common when watching the video. In general, users reported that the video was more clear and helpful than the infographics, and also a more satisfying experience. When reading the infographic version, some users commented that as they didn't have a medical background, it was difficult to follow new terms being introduced, and they may need to re-read different parts to keep up with the terminology. This was not a comment users made after watching the video.

Participants also took different keywords from the two representations of the same content. The descriptions of the information in the infographic focus on the function of butyrate, a small molecule absorbed by the body, which is mentioned during *The Hungry Microbiome* narrative. The users who saw the video version described the function of resistant starch, (which is then broken down by the gut microbiome to make butyrate). Some reasons for this may be that the references to resistant starch are mostly in the introduction and conclusion, which may have been easily skimmed over by readers of the infographic. Another reason may be that 'butyrate' is not a common word and, when written, the word itself and the meaning behind it may be seen as the novel part of the infographic, rather than the function of resistant starch. Additionally, the call to action is not as explicit in the infographic as it is in the video. The call to action may have been completely missed by some users reading the infographic version. One user made the following comparison about *The Hungry Microbiome* infographic, when comparing it to *Alzheimer's Enigma* video:

> "Very different from the infographic - the infographic had a purpose, where this is something educational... [the infographic] was more about 'you should do this... because it will prevent you from getting cancer', whereas [*Alzheimer's Enigma* says] 'this is how your body works, and this could happen to you,' and because they know this already, they can put more research into it and they understand it better, which is a hopeful thing." (Experiment 2, user 3)

4.4.2   Video comparison: *Alzheimer's Enigma* and *The Hungry Microbiome*

This response to *Alzheimer's Enigma* shows an important contrast between the videos used in each experiment. Both videos were very well received by the users, more enthusiastically than any of the infographics, with 19 out of 20 users scoring moving visualisation 6 or higher out of 9 pleasurable.

Users were able to parse the information internally without feeling like they had to concentrate, their body language was much more relaxed than when they were reading the infographics. However, the depth and scope of personal reflection was much more limited after watching *Alzheimer's Enigma*, when compared to *The Hungry Microbiome*:

> "[It] always makes me happy to see a visualisation of something invisible to the naked eye. Like learning about another Universe, but one that I have more control over and can influence." (Experiment 1, user 2, after watching *The Hungry Microbiome*)

> "...visualising what it would look like in my own stomach." (Experiment 1, user 7 after watching *The Hungry Microbiome*)

The personal insights after watching *Alzheimer's Enigma* related to family and friends, but less vividly relating the information to themselves:

> "It is a subject I have a keen interest in as it affects my family as well as those of many friends." (Experiment 2, user 7)

> "The content definitely communicated its point effectively, so I felt general concern and feeling of hopelessness because of this comprehension." (Experiment 2, user 3)

Both videos have a similar, but not identical narrative structure. *The Hungry Microbiome* has four parts to its narrative, described here using terms from narrative visualisation, and data videos in [3]: (see 2.3.2 on page 45)

1. ***Establish* a scientific concept**: resistant starch nourishes the gut microbiome

2. ***Initial* scenes explain some of the science behind the concept**: processes of resistant starch being broken down to fuel for the human body

3. **The *climax*, which non-experts may find novel**: this fuel directly protects the human body from colorectal cancer

4. **The *release*/call for action**: by eating foods rich in resistant starch, you can protect yourself from cancer

The objective of this video was to communicate information that will inspire action (as mentioned in 1.1 on page 15, the video was funded by a grant from Inspiring Australia). *Alzheimer's Enigma* has a narrative structure which differs slightly:

1. ***Establish* a scientific concept**: An early sign of Alzheimer's disease is the build-up of plaques around the cells in the brain

2. ***Initial* scenes explain some of the science behind the concept**: protein recycling methods in the brain cells

3. **The *climax*, which non-experts may find novel**: some parts of the protein escape recycling and build up to form plaques inside the brain

4. **Instead of a call to action, the *release* introduces current research into the field**: a blood test can detect the build-up of these plaques decades before any loss in brain function

The objective of this video was to communicate information. By not giving a call to action, the users didn't have the opportunity to respond in the same way; even though both videos had excellent production quality, similar narrative structure, and were backed by scientific research. *Alzheimer's Enigma* is missing what user 4 in experiment 1 described as "a hook to engage you" that was in *The Hungry Microbiome*. The same user stated that it didn't matter that the video was not explicitly listing foods that contain the types of starch that the video talks about, as that information it is very easy to find. This would be especially true about users who are watching the video on CSIRO's YouTube channel. This user also pointed out that a viewer is "not going to look for the information if you are not really engaged at all."

Production of this kind of video may require a substantial investment, so it is important that these videos have a clear objective. In order to engage users, the responses users gave suggest two additional considerations for producing NEUVis:

1. **Introduce and explain information that the user would have difficulty discovering and deciphering for themselves**. The scientific information may be very difficult for the non-expert user to access, let alone process on their own. Of course this is possible, there are many open access journals and publications, but it is a substantial investment on the behalf of the user. In order to leverage novelty, the user must be shown something that is unlikely to be well known. For example, *The Hungry Microbiome* poses the question "Why should I eat resistant starch?" A non-expert user may not even know to ask this question, or what resistant starch actually is. The explanation provided by the video, which answers this question, involves a lot of research and collaboration between primary researchers (the scientists) and creative practitioners (the animation team.) The same level of understanding would be difficult for a non-expert user to attain by themselves, and the video can save that time for many users. This also centralised the effort necessary to understand this information, so that the benefit can be distributed among the general population.

2. **Leave the user with something they can to do**, within their context, that can promote further engagement with the content. *The Hungry Microbiome* does not explicitly answer the obvious follow on question that the video poses to the user "if resistant starch is good for me, where do I find it?" The audience is most likely watching the video online, so the user can simply search online for foods that contain resistant starch. This task is not as complex as finding out what resistant starch is, why it is good for you, or how it works, which is addressed by the video.

4.5   Reflection 4: NEUVis Data-Visualisation Schematic for visualisation designers

Design tools are often used by designers as part of their process. For example, they may be used to identify with and create empathy for users during the inspiration stage of the design process, or to help effectively iterate through concepts in the ideation stage. One tool that commonly is used in many design fields is the *user persona*. The Nielsen Norman Group, a significant voice in the field of User Experience design published an article describing benefits of user personas [11]. They define personas:

> A persona is a **fictional, yet realistic, description of a typical or target user** of the product. A persona is an archetype instead of an actual living human, but personas should be described as if they were real people. [11]

This tool is used to help designers identify with their users. In meetings the persona is identified by the name that is given to the person described. It acts as shorthand for all of the *"attributes, desires and behaviours"* [11] that require consideration during the design process. NEUVis design requires this kind of understanding about the user, but also about the data. In response to this, a tool was developed that is designed to act in a similar way, but for understanding datasets for visualisation, rather than understanding the intended audience of a product.

4.5.1   The NEUVis Data-Visualisation Schematic

The user persona tool was used as a model that can be used to construct a tool for NEUVis design. This tool is used to help the designer create an understanding of the data and visualisation goals in relation to the context of the users. The tool is shown in table 4.1. The name NEUVis Data-Visualisation Schematic was chosen because the tool is a symbolic and simplified version of the information to be included and design requirements of NEUVis.

4.5.2   Part 1: Data

Data Type

A description of the properties of the dataset being visualised.

Data Dimensionality

A description of the dimensionality of the data.

Data Establishment

This shows what background knowledge may be persistent in the general understanding. For example, is may be assumed that the general population understands more about "space" than "quantum

Table 4.1: NEUVis Data-Visualisation Schematic

Part 1:	Data	Consideration
Type	qualitative, quantitative, temporal, geospatial	Attributes
Dimensionality	2D, 3D, 3D temporal, high-dimensional, high velocity/realtime	Attributes
Establishment	Cutting edge research, new developments on old concepts, classical sciences	Relevance
Applicability	abstract, actionable, informational, warning, edification, insight	Relevance
Acquisition	Boundary object type: syntactic, semantic, pragmatic	Attributes

Part 2:	Visualisation	Consideration
Goals	The take-away message	Relevance
Interface	Playful, self-effacing, emotive, static, interactive, animated, category of interaction (active, reactive, interactive)	Interaction
Construction	Novel, artistic, ambient, narrative, exploratory, familiar	Interaction
Context	Museum, public space, art exhibition, social media project, website, news article	Relevance
Communication	Boundary object type: syntactic, semantic, pragmatic	Relevance
Responses	Emotions and feelings you wish to provoke	Interaction

mechanics." Therefore, if the data is acquired through astrophysics research, it has a different level of general understanding than data relating to quantum computing.

Data Applicability

Not all NEUVis is about "doing something", or achieving an objective. For example, artistic visualisation exists for the sake of making art and the aesthetic experience for the viewer. This section describes the application of the data to the user's context.

Data Acquisition

Describe the boundary object that is used to understand the data. Also how it was collected or generated, and where accountability for the data itself lies.

4.5.3   Part 2: Visualisation

Goals

Describe the take-away message of the visualisation, what insight is available to the users, or what objective the visualisation has.

Interface

Describe the kind of interface that lies between the user and the data. If the visualisation is interactive, the category[1] of interaction should be described. *Active* interaction systems allow users to select content to be displayed and act as syntactic boundary objects. *Reactive* systems respond to external stimuli, such as user behaviour or the surrounding environment. Reactive systems may act as syntactic or semantic boundary objects. *Interactive* systems allow the addition of new information into the system to influence its output. Interactive systems will act as pragmatic boundary objects.

Construction

Describe elements of visual design, artistic metaphor, or graphical mappings that are used in the visualisation. This consideration is similar to the way that infoVis uses the term aesthetic.

Context

Describe how the visualisation be available to the audience. How they will access the visualisation, and how does that relate to their context.

---

[1]This concept is originally (in German) from [80]. A brief summary in English is included in [202, p. 16].

Communication

Describe the kind of boundary object that is being used to communicate between the visualisation collaboration (primary researcher and creative practitioner) and the audience.

Reactions

Describe how the audience is supposed to feel. What their reactions will be; not just the goal (above), but emotions and feelings you want to provoke. This consideration is used in a similar way that user personas have quotes that describe the persona's attitude [11].

NEUVis considerations: Attributes, Relevance and Interactions   User experience design defines considerations as attributes, desires and behaviours of the users, similarly, there is a group of considerations that NEUVis needs to incorporate into their thinking. The data requires consideration of its *attributes*, or metadata, *relevance* to the user and *interactions* with the user. The interactions consideration does not suggest that all NEUVis require interactivity, instead, it refers to the design elements that act as a point of contact between the user and the data. To summarise: the NEUVis Data-Visualisation Schematic can be described as *a tool that acts as a shorthand for the attributes, relevance and interactions of NEUVis.*

4.6   Summary

This chapter has presented four reflections on the process of building and testing a NEUVis, and allowing users to compare their responses to different types of NEUVis. The first reflection described the nature of the collaboration between primary researchers and creative practitioners. The direct or indirect collaboration results in a designed artefact (the visualisation), which acts as a boundary object between the collaboration and the audience (see figure 4.1). The nature of these boundary objects define the way in which the user interacts with the knowledge present across the boundary.

The second reflection considered how NEUVis design can be differentiated from standard design practice, and what distinctive challenges it presents. The result is presented in a process model for NEUVis (see figure 4.2). The significant challenge of merging the *message* and *implications* of the data with the *needs* and *context* of the user can be addressed, in part, by considering the following questions:

- How does this new knowledge benefit the user?

- What about this data is relevant or important?

- What is otherwise inaccessible to the user?

- What can the user access for themselves?

- What myths and misconceptions are relevant to this data?

- What is the potential for impact, and what are the risks of this visualisation?
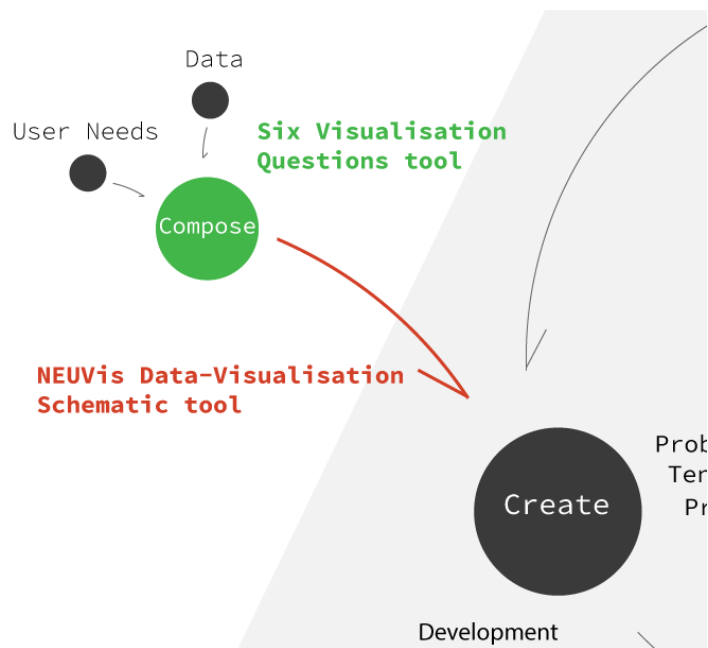
Figure 4.3: Design tools in the iterative process. The Six Visualisation Questions shown in green and the NEUVis Data-Visualisation Schematic shown in red. See figure 4.2 for the full process model.

The third reflection describes how users compared the video *The Hungry Microbiome* to an infographic presentation of the same information, and a second video, *Alzheimer's Enigma*. Comparison between the message and the medium suggests that NEUVis should *introduce and explain information that the audience would have difficulty discovering and deciphering for themselves*, and *leave the user with something they can do*. This may help engage the audience, but should be the subject of further, specific research.

The fourth reflection describes a design tool, NEUVis Data-Visualisation Schematic (see table 4.1) that was developed in response to these reflections, and tested wiht the final installation that was produced as part of this research. The tool, inspired by user personas, was used to *act as a shorthand for the attributes, relevance and interactions of NEUVis*. It describes the data in terms of dimensionality, establishment, applicability and acquisition. It also describes the visualisation in terms of the goals, interface, construction, context, communication and responses. The purpose of the tool is to help the creative practitioner merge the needs and context of their audience with the message and implications of their data. It can be created in negotiation with other stakeholders of NEUVis to clarify the design requirements, and help the creative practitioner create a prototype before testing, and transition from building the design understanding to the iterative step in the design process (see figure 4.3).

In addition to these reflections, this research has allowed a definition of NEUVis to emerge:

> *NEUVis is the user-centred design of visualisations by creative practitioners in collaboration with primary researchers, for the benefit of an audience without expertise in the domain of the data.*

The next chapter discusses how these findings effected the design process, particularly in the creation of the final interactive installation, *18S rDNA*, that was in development over the course of this research.

Chapter 5

The Designed Artefact

*All religions, arts and sciences are branches of the same tree. All these aspirations
are directed toward ennobling man's life, lifting it from the sphere of mere physical
existence and leading the individual towards freedom.*

—Albert Einstein in *Out of My Later Years*

5.1   Introduction

Museums can engage and enlighten a broad audience, and many use interactive installations to communicate science. Museum installations and artworks are used to engage the general population in unique contexts with interesting content and concepts. These contexts include public museums, and also small exhibitions, art festivals and online galleries. Museum installations may be communicative and direct, playful and engaging, and artistic. Museum content can include meaningful scientific research—more than points of data from empirical processes—including images, maps, models, ideas, and understanding. These can relate to and explain the knowledge acquired through scientific research practice. The designed artefact described in this chapter, *18S rDNA*, is interactive installation which visualises scientific research that I have developed. It combines empirical data with the implications of the research. This chapter also describes the application of the NEUVis design process described in 4.3 on page 77 and the NEUVis Data-Visualisation Schematic tool described in 4.5 on page 83. *18S rDNA* was developed in 3 stages: an initial, abstract concept; a more direct representation used in testing; and the final version incorporating the feedback from testing.

Museum installation artworks have the ability to communicate with large audiences, and are exceptionally effective vehicles for sharing scientific information. Interactive installations that use data visualisation can help the viewer to learn about science by facilitating audience engagement with the work. Science can be understood in museum installation environments in novel and engaging ways, that are informative and easily understood by a non-expert audience through sophisticated multi-sensory channels (sight, sound, touch). Virtual 3D immersion, video, visual imagery and sound can captivate and engage the audience. These channels can be used to address major societal

issues. Communicating science to non-scientists is becoming increasingly important, particularly in the age of anthropogenic climate change. Museums like New York's Climate Museum anticipate that science communication in the museum will help save the planet by promoting solutions to the human-caused warming of global climates through interactive displays, installations and 3D videos. The general public sees museums as an authoritative resource for climate change information [200].

5.2   Data
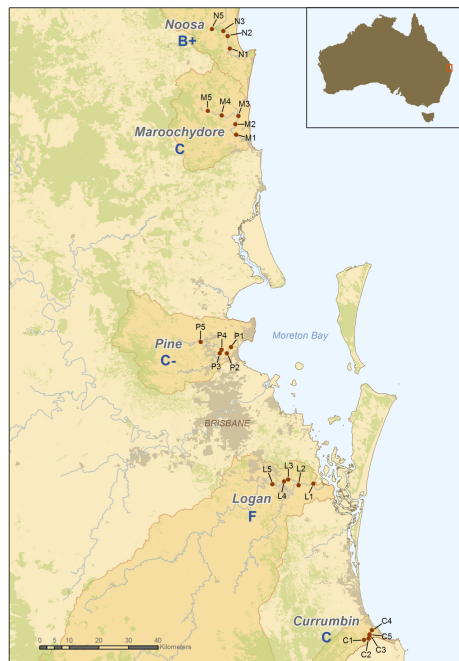
Figure 5.1: Locations and environmental ratings of estuaries studied in Chariton's research

18S rDNA visualises data from Anthony Chariton, from CSIRO Land and Water research division. The data are collected from several estuaries in South-East Queensland, Australia, and shows the natural and man-made changes to these ecosystems that affect the composition of organisms; some will thrive while others decline. The pH levels of estuaries differ naturally. Man-made changes are measured by the level of phosphorus, nitrogen oxides, and turbidity, though phosphorus is a good indicator of overall pollution levels. Phosphorus enters the water system through urban and agricultural activities, and can have serious detrimental effects on aquatic ecosystems [29].

Dr. Anthony Chariton, Research Team Leader for Molecular Ecology and Toxicology with CSIRO Oceans and Atmosphere, has supplied a data set that was visualised through interactive NEUVis. The stated aim of the scientific research conducted was to use metabarcoding of the 18S rDNA gene to examine the benthic composition along five estuaries of varying ecological integrity. In summary, this experiment used a high-throughput DNA sequencing technique to identify small organisms (a few millimetres in size) present in estuaries. These samples are taken of benthic communities: the top layer of sediment on the bottom of a marine body, such as a river or estuary [34]. Analysis of the 18S rDNA gene can be compared to a data repository in order to determine which organisms are present in the benthic community; alternatively, this would have been carried out by eye or microscopy. Analysing DNA from benthic soil samples is able to identify

a broader number of organisms, since all eukaryotes[1] contain the 18S rDNA gene [188]. The experiment used samples from five estuaries with different environmental qualities (see figure 5.1). These scores are calculated by the Health-e-Waterways project, a collaboration between The University of Queensland, Healthy Waterways and Microsoft Research to indicate overall ecological integrity [67].

5.2.1 Acquiring data

I obtained the data directly from meeting with Chariton, after a call for collaboration was sent through an internal "Monday Mail" newsletter at CSIRO on 16th September 2013. Several responses were received, and this dataset was chosen because it relates to a 'human impacts' issue; it is a topic that audiences may be able to relate to, or find insightful. Other responses to the call at CSIRO related to data that was either too specific, or too abstract to create something meaningful for the potential audience in comparison. This experience in collecting data and interacting directly with Anthony Chariton, and learning about the process of data collection, directly informed the first reflection on collaboration and boundary objects, discussed in 4.2 on page 74. The boundary objects used to facilitate the exchange of knowledge included research papers and PowerPoint presentations in addition to the data. These allowed transfer of knowledge of the data set as well as the methods of data collection. This helped me produce a "big picture" design understanding of the implications of Chariton's research.

5.3 Early Versions

Initial versions of the interactive installation were developed using the Processing [162] programming environment and the Leap Motion [119] human-computer interface. Processing was chosen because it allows interactive programs to be prototyped quickly (a Processing file is called a *sketch*, which reinforces this approach to creative coding). The device senses the hand of the user, providing comprehensive, high resolution positional data for the hand and fingers. The software also automatically detects several built-in hand gestures, and these are able to be used by Processing using a third-party library. The Leap Motion was chosen as is it a novel interface, that users may find interesting. During testing, only one user said that they had any previous experience using the Leap Motion.

Several of my previous works have used large-scale projections of two-dimensional scenes. Some have been algorithmically generated, while others have manipulated pre-drawn images. My interactive works have previously used sound from live bands as input, or the Microsoft Kinect. My interest in experimenting with the Leap Motion was a drive to use it in this project.
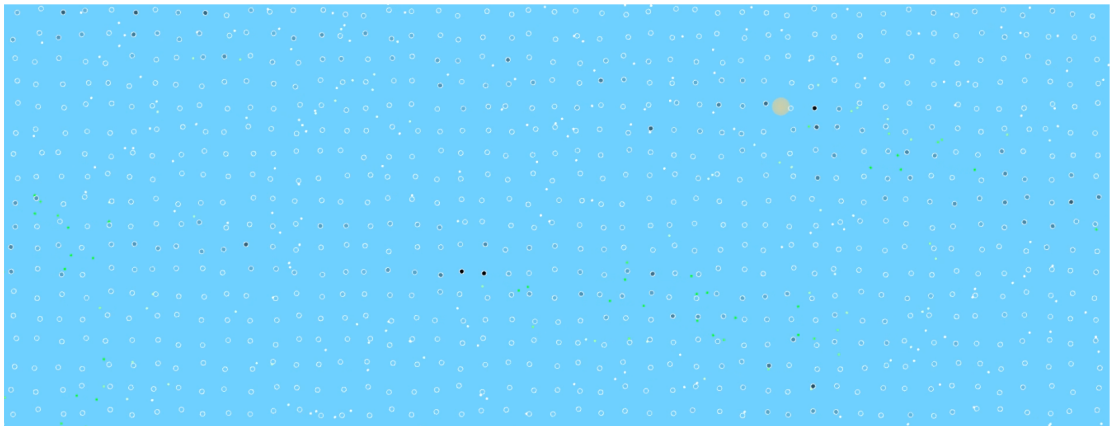
Figure 5.2: Screenshot of the first prototype of *18S rDNA*

5.3.1   Initial Concept

The first Processing sketch (see figure 5.2) used a very abstract visualisation that reflected a progression of my own visual style of algorithmically produced, 2D work. Primitive graphical elements and changes in colour were used to represent organisms of different types, changes in intensity of colour represented the response of organisms to pollution. This also gave a false sense of depth, even though the sketch was only rendered in two-dimensions. This concept was quickly built in Processing as an interactive projection. A user could interact with the projection by holding their hand in the area sensed by the Leap Motion, the user's (human) presence would introduce pollution into the water, which in turn affected the organisms displayed; the interaction with the system was meant to be playful. This early projection was critiqued by artists within the Faculty of Architecture Design and Planning at The University of Sydney from an early stage during supervisory meetings. The optical illusion providing the depth perception did not translate from a high-contrast computer monitor to a projection, and I was not satisfied with its use as a visual metaphor. The more fundamental issue, however, was that the visualisation was too abstract, and would not communicate the data effectively. This concept was of practical use, particularly for understanding the way that data from the Leap Motion can be used a Processing sketch.

5.3.2   Experiment 1

Using feedback from the critique, I developed a playful, but direct, visualisation for testing. This iteration used a new interaction system and visual construction. This concept (see figure 5.3) was tested with ten users in the first experiment. These early concepts helped clarify how it was best to address the user needs and data message simultaneously, and form a single message for the work. The

---

[1]Eukaryotes are cell-based life forms, including animals and plants. In contrast, the smaller, primitive, single-celled organisms, such as bacteria, are Prokaryotes, and would not be recorded by this method.
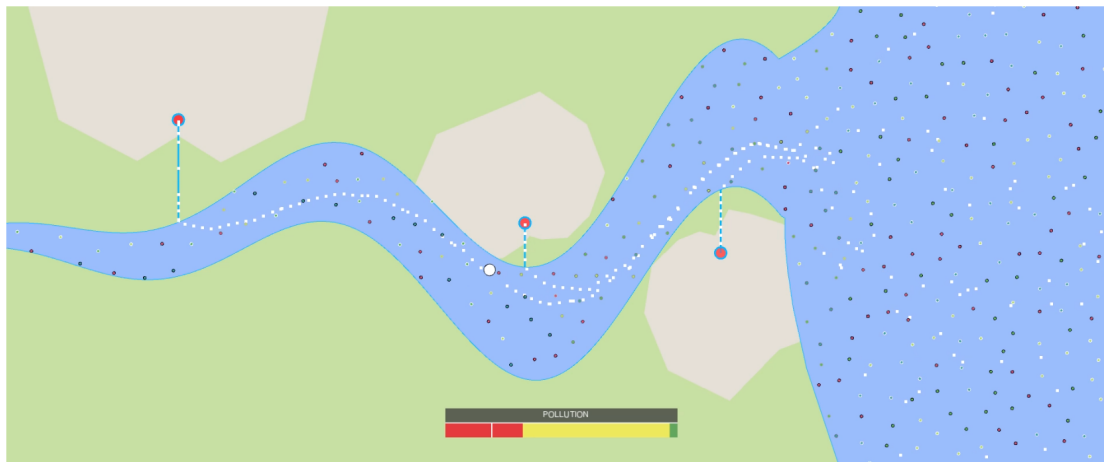
Figure 5.3: Screenshot of the second iteration of *18S rDNA*, used in experiment 1

experience with the first two iterations showed how a limited design understanding of data made it difficult to engage users; playful interaction with data was not sufficient.

The second (and subsequent) versions of *18S rDNA* allow users to explore the effect that pollution has on the estuary, while also uncovering the natural change described by Chariton's research, from fresh to salty water. Users were able to increase the human-impact on the estuary by adding sites of human activity, which pollute the river. As organisms thrive or die, they are able to see the impact of human activity. It was noted during observation that half of the users explored the overall effect by adding as many settlements as possible (see "Notes on Test 2" under the heading "Think aloud feedback and observer notes", in C.2.2 on page 231), often until the simulation started to slow down from the amount of pollution that was being simulated. After users observed effect of this on the whole ecosystem, they removed most of the settlements to observe the effect of pollution on individual organisms' health, comparing those which respond to pH and pollution.

Users expressed that the visualisation shown in the first test was generally enjoyable and engaging. Most users made an accurate connection between the data and the visualisation. However, some users did not notice the instructions that were presented, and did not make the same connection to the data. Users stated that the interaction system was playful and enjoyable, but observation showed that it was also prone to false positives. Users thought that a certain gesture related to a specific response from the system, when it was not the case. This gave the user the incorrect mental model of which gestures were programmed into the visualisation.

False positives are not unusual in novel, interactive art installations; they may not even be detrimental to the interactive experience unless they hinder the user, or make the system seem inconsistent and unreliable. An example of false positives occurring in other art installations is *Social Firefly*, an installation at Vivid 2011 in Sydney, Australia. At this large, public art festival users misunderstood how to interact with *Social Firefly*, which was programmed to respond to lights being shone onto small

robots installed into a large fig tree. For some reason, many users believed that the installation was designed to respond to sound, particularly to screams directed at the tree. This was documented on the personal site of Jason McDermott, one of the creators of *Social Firefly*:

> Now, we'd intended on the artwork itself being emergent, and possibly sparking emergent behaviour through direct interaction (you could influence the artwork if you had a bright enough torch or source of light), but what we got was something completely far beyond our wildest expectation. What we found, was that despite the festival being primarily a festival of light, many people seemed to take it on board that this artwork was an artwork of sound.
>
> ...Night after night, wave after wave of people descended on the large fig tree on Circular Quay, to shout, wave and scream really really loud noises at the fireflies. They made a real ruckus, dancing and shouting at what were, effectively, small deaf robots. [133]

This (amusing) misunderstanding was used as inspiration for an installation at Vivid the following year by the same designers. In Vivid 2012, the appropriately titled *Screaming Rapture*, reacted clearly to large groups of screaming people [195].

At this stage of the development of *18S rDNA*, the only built-in gesture from the Leap Motion that was used was a swipe motion with the hand. Swiping left or right opened or closed an information panel on the side of the screen. Swiping up or down showed or hid a small graph (visible in figure 5.3) that displayed the response the organism was having to either the pollution or pH of the simulated environment. Some users assumed that the system responded to their hand being open or closed (in a fist). This false positive did not profoundly impact their experience. False positives, and the instruction text were addressed in the next version of *18S rDNA*.

5.3.3   Experiment 2

After the second iteration, several changes were made to the graphical construction of the installation. At this point in development, the first five of the Six Questions (described in 4.2 on page 78) were formulated and used to help express how the understanding of data is integrated with needs of the user. The sixth question was added during the development of the final iteration, and also in conjunction with research described in 6.4.2 on page 131.

1. How does this new knowledge benefit the user?

This new knowledge can broaden the non-expert user's understanding of human impacts on marine ecosystems. It also has potential provide insight into biological science and the scientific process.

2. What about this data is relevant, or important?

The data is relevant because it relates to the impact of human activity, both from cities and farming, and its effect on the environment. Some organisms also thrive under these artificial conditions, and this is a significant distinction for the user to make.
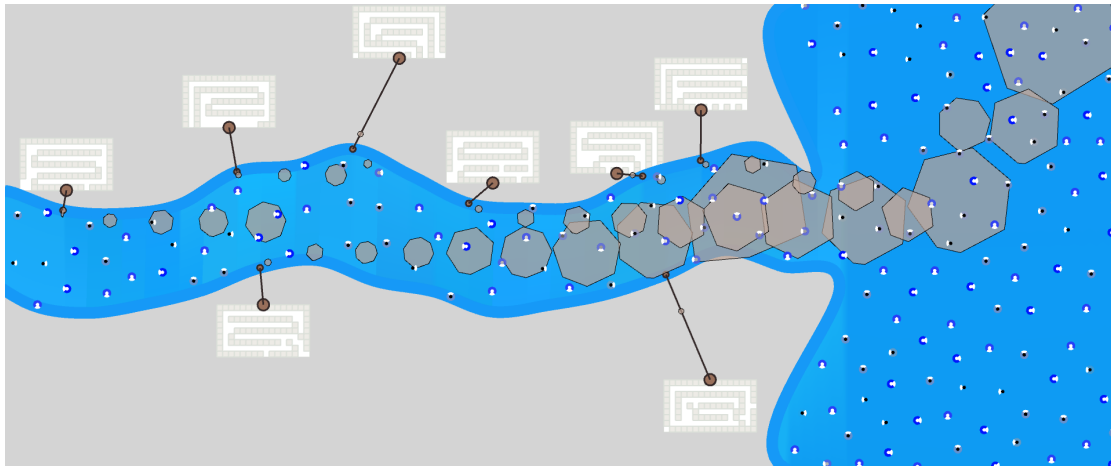
Figure 5.4: The third iteration of 18S rDNA used in experiment 2

3. What can the user access for themselves?

How to change habits, or minimise their impact on the environment.

4. What is otherwise inaccessible to the user?

What different kinds of organisms live in these environments, and how they react to different conditions. Also, how strong the reaction is, where the reaction to the environment occurs (at what pH level or concentration of phosphorus). The gradient between the fresh/salty water and the clean/polluted water.

5. What myths or misconceptions are relevant to the user?

The potential misconception the installation intended to address was that pollution simply kills all organisms. Instead it allows some organisms to thrive, while organisms which thrive in clean water are killed. This is not a prominent myth (as the myths "lightning never strikes the same place twice" or "a person only uses about 10% of their brain" may be—both of these are false), but it is relevant to the installation.

The design process model described in 4.2 on page 78 was also expressed at this time in an early form. The difficulties caused by the lack of understanding of how the data and user needs integrated informed the model and questions above. From these difficulties it became clear where in the design process the design understanding should be composed. In this model data can be treated similarly to user needs: fundamental to the design process, they should be understood before iterating over a solution to the formulated problem. It is the designer's understanding of the problem that is changed, rather than the user needs or data.
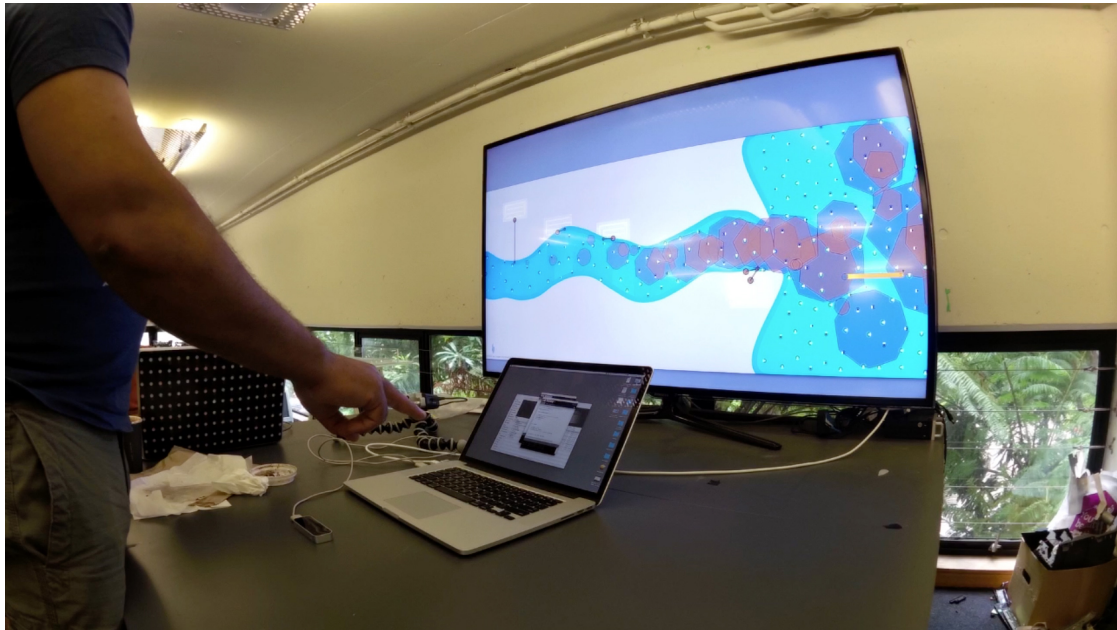
Figure 5.5: A screenshot of video taken during the second user test.

Using this approach, and a clearer expression of the design understanding, the third iteration of *18S rDNA* was produced (see screenshot of *18S rDNA* in 5.4, and the screenshot of video recorded during testing in 5.5). This also included an introduction the user could navigate through, before being presented with the visualisation. This described the four reactions that organisms have (positive or negative reactions to either Phosphorus or pH), and the sources of these environmental factors (artificial or natural). This helped users make the connection between what they saw with what was the underlying implication of the visualisation.

Each of the second group of ten users expressed that this version was also playful and enjoyable. At the same time their responses indicated a more accurate comprehension of the data. During the test some users asked if there was an objective, as if the simulation was a game. Without any objective, they explored the relationships between human activity, and the effect that the resulting pollution had on the organisms living in the estuary. Testing also revealed numerous software errors, which were addressed. Observation during testing also showed that some users had difficulty interacting with the system using the Leap Motion device, even though the use of gestures was removed, and the simulation gave clearer feedback on the interaction.

Feedback from testing showed that some elements of the design were successful, but the installation had several weaknesses:

The Leap Motion was restrictive, and prone to false positives.

The Leap Motion allows multiple users to interact with the system. There was no software limitation placed on the number of hands the system could track, but the limited space of the area tracked by the Leap Motion will limit the number of people who interact with the system. False positives found in the first experiment did not have a significant impact on enjoyment of the installation, but had the potential to impact the user experience if they were not addressed.

The installation was playful, but not collaborative.

The Leap Motion works well with a single-user, and users enjoyed the experience with the installation. Incorporating collaborative learning is one way that the user-experience can be improved. It was decided that collaborative play and a game-like challenge was desirable after several users asked if there was an "objective" to the simulations used in testing. Some users expressed that it was familiar with other games they had played (such as *Fruit Ninja*[2]). The versions of *18S rDNA* used in testing provided no incentive or reward, other than exploring the data. Collaboration, reward and incentive could be used in future versions to encourage users to interact.

The installation acted only as a syntactic boundary object.

Interactive installations have the potential to act as semantic, or potentially pragmatic boundary objects. Though a semantic or pragmatic boundary object is not inherently "better" than a syntactic boundary object, the potential to communicate information about how the data was collected was a desirable outcome for *18S rDNA*.

5.4 Final Version

After the experiments were completed, further consideration was given to the way that user needs can be integrated with the data. At this point, I developed the NEUVis Data-Visualisation Schematic, presented in 4.5 on page 83. This tool was used to develop a final version of the installation. In addition to the use of the NEUVis Data-Visualisation Schematic, this version uses the Microsoft Kinect[136] as the interface, and was developed using openFrameworks [152] in Xcode 7 [4], a development environment for Mac OSX. The Kinect (version 1) was chosen as an interface to the simulation, as it enables robust, multi-user interactivity. The decision to use openFrameworks was based on the availability of useful third-party libraries (particularly OpenNI [153], which captures and processes data from the Kinect) and overall improvements to performance of the installation. This presented a significant learning experience as openFrameworks was an unfamiliar development platform to me.

The series of images in 5.6 on page 99 and 5.7 on page 100 outlines the way in which the user can interact with the system. A video demonstration of the interaction is also available at `https://youtu.be/OyIGzpOlgZU`

---

[2]see http://fruitninja.com/

5.4.1 Creating the Design Understanding

Before starting the final iteration the initial steps of the design process (see 4.2 on page 78) were reiterated, so that the entire process can be more effectively evaluated. This involved observational activities at a science museum, to observe the mix of people who visited. User personas were created from the observations, as well as a NEUVis Data-Visualisation Schematic (see table 5.1). The responses to questions, as stated in 5.3.3 on page 94, had not changed, since the same data set was being used.

An observation exercise was undertaken on a weekend at the Queensland Museum, to examine the way that users engaged with museum installations in a natural context. Two digital installations, *4,000 Species* (see figure 5.8) and a digital projection as part of the *Lost Creatures* (see figure 5.9) exhibition were observed. *4,000 Species* is an interactive installation that allows users to explore the tree of life using one of three large touch-screen displays. It is situated in a main thoroughfare that experienced consistent traffic. The screens are integrated into the wall, and there were two tangible exhibits in front of the installation (they do not block access to *4000 Species*). The installation appeared to be thoughtfully designed, and interacting with the installation was simple and straightforward. Museum guests of a very broad range of ages passed through the area; parents with children in prams, teenage or young adult couples, families with children, senior citizens. A few adults noticed the installation, but chose not to interact with it. The installation was not as interesting to the visitors as the two tangible installations that were nearby. After several minutes, the first user observed interacting with *4,000 Species* was a child, who was part of a group of guests, which seemed to be two or three mothers who were taking all their children to the museum together. The child was able to explore the installation easily, without assistance, after loosing interest in the nearest tangible exhibit (a preserved giant squid in a glass case), with which the other children were still engaged. *4,000 Species* did not attract users on its own, it had little novelty to offer in comparison with the specimens in front of it, which most people stopped to look at. It was often noticed that users looking at the squid would turn to the wall to see what it was, and looked away without interacting or moving towards the screens. This is not to say that *4,000 Species* is a failure, but it did not offer the same novelty as a giant squid in formaldehyde—something tangible, which is less likely that guests have seen often, if ever. One design flaw of *4,000 Species* may be that it offers little more than a well-designed application for a smart phone or tablet, which is what the children who were fascinated by the tangible exhibits may have been doing on a bus trip to the museum.

In contrast to *4,000 Species*, a projection as part of the *Lost Creatures* exhibition appeared to be implicitly engaging, especially with children. *Lost Creatures* is described on the museum website:

> Lost Creatures introduces you to some of Queensland's long-lost inhabitants, including dinosaurs, giant marine reptiles and megafauna. Meet some of our state's inhabitants from millions of years ago and marvel at their diversity and immense size. [164]
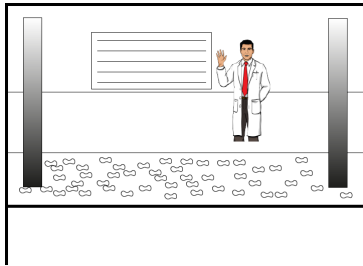
(a) The display in a waiting state, with Anthony, the NPC, prompting a user to wave their hand.
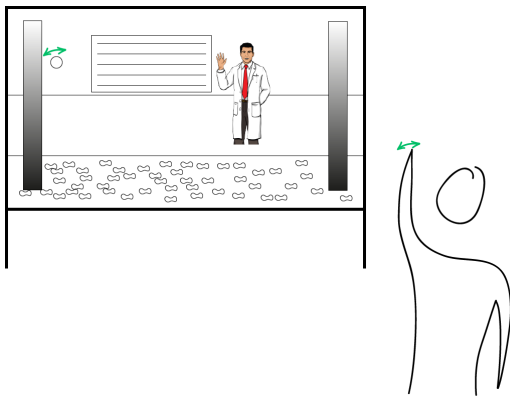
(b) A user has approached and waved their hand, the system has welcomed them, and changes state to the guided tour of the estuary that is being simulated. A marker on the screen shows the position of the hand in the model of the system.
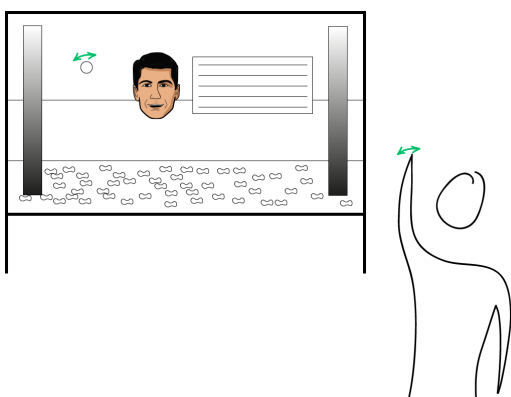
(c) Anthony is describing the effects of environmental conditions on the water. The user is prompted to interact with the bars on either side of the display to compare the effects of pollution and salinity on the estuary.

Figure 5.6: Model of interaction for 18S rDNA.
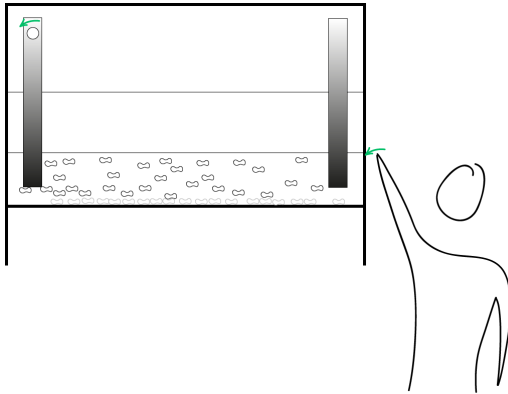
(a) User examining the effect of high pollution on the organisms of the estuary by moving the marker over the left hand side bar. Organisms that would not survive under these conditions turn grey and sink to the bottom of the benthic layer, indicating that they have died.
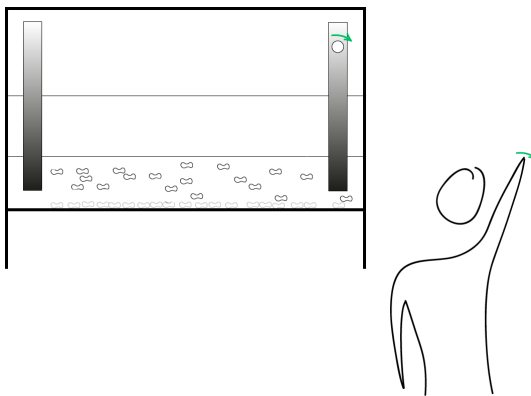
(b) With their other hand, the user is examining the effect of salinity on the estuary, with the marker on the right hand side bar.
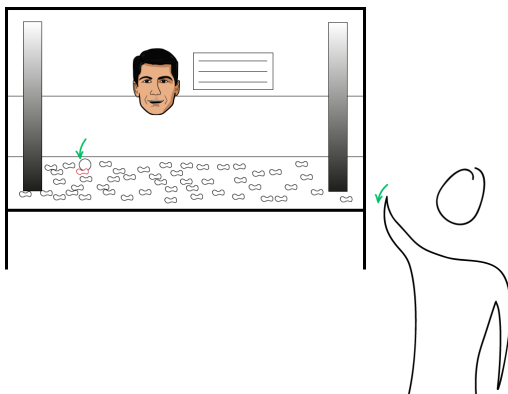
(c) After Anthony has finished giving the tour of the estuary the simulation changes state again. Now the user can examine individual organisms to find out their name and the environmental condition which causes them to thrive or die.

Figure 5.7: Model of interaction for 18S rDNA continued.

Figure 5.8: The interface for 4,000 *Species* the three lower displays are interactive touch screens. Photo taken with permission.
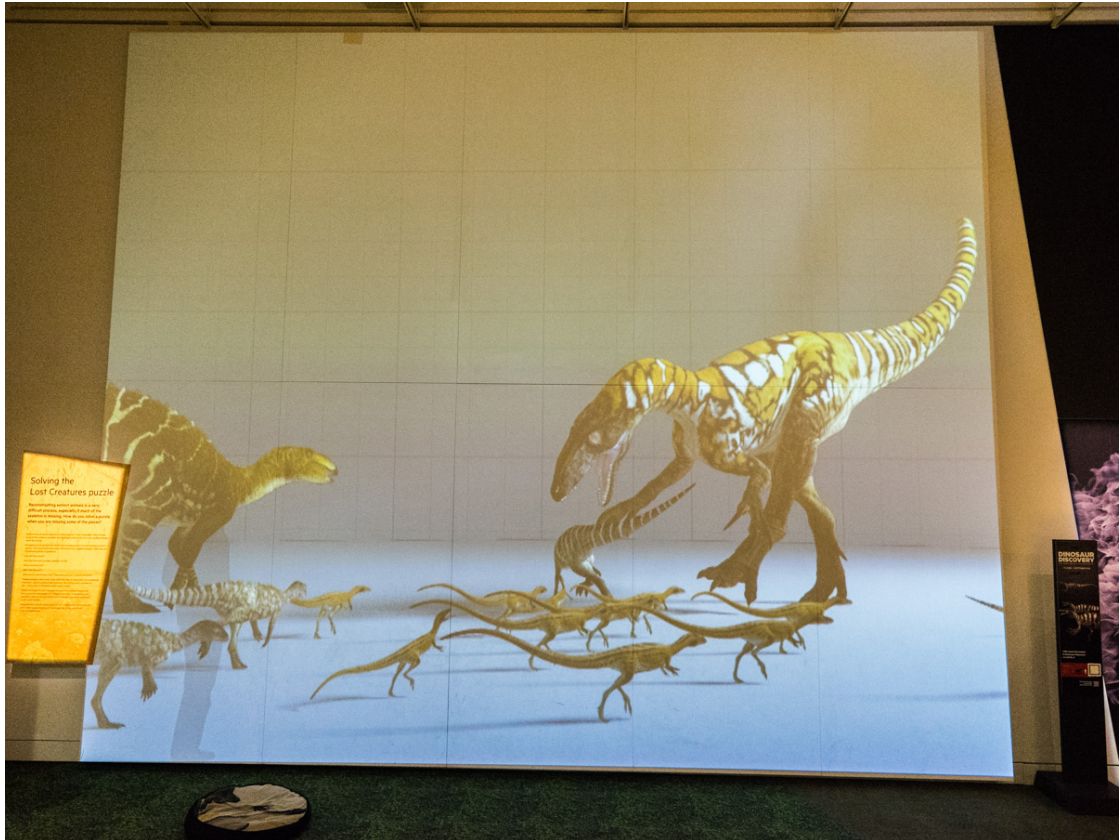
Figure 5.9: The projection in *Lost Creatures* comparing the silhouette of an adult (left side of projection) to several dinosaurs from the Southeast Queensland area. Photo taken with permission.

<center>(a) (b)</center>

Figure 5.10: Volunteers testing an iteration of the final concept for *18S rDNA*.

The large exhibition included interactive touch-screen displays that presented information relevant to fossils and other tangible specimens, which they were near. Users were observed to make use of these displays often, as they augmented the experience with the tangible displays. However, one attraction for young guests was a projection. This projection displayed dinosaurs and Australian megafauna on a wall that appeared to be about two or three stories tall. The projection used very simple animation, but was very popular with children. They played "with" the projection, though it was not interactive, many jumping up to see how high they could reach on the leg of a huge dinosaur that was projected at 1:1 scale. This installation was not interactive at all, but the audience enjoyed playing with realistic digital representations of life-size dinosaurs.

No concrete laws of interaction can be formulated from this single example, but it does show that interactive installations, such as *18S rDNA* need to leverage novelty, in order to engage users, whether they are children or adults. The interaction system needs to be designed in a way that is unique to the context where it is being shown. This reinforces the selection of the Kinect, a body-tracking system, as the interface for *18S rDNA*.

The next iteration of the installation also includes some elements from video game design, particularly non-playable characters. These characters help the user understand the objectives of the installation and the science informing it. With the understanding of the data and observation of the way that museum guests were comfortable interacting, the design persona was developed for *18S rDNA*, shown in table 5.1.

5.4.2 Final Iteration

The final version of *18S rDNA* was developed and tested informally with multiple users for software bugs, and to obtain informal feedback on interaction (see figure 5.10). This process was useful for development, particularly to observe how the system responded to multiple users. In this version, I introduced a non-playable character (NPC) to the installation: Anthony, a scientist who invites the

Table 5.1: NEUVis Data-Visualisation Schematic for *18S rDNA*

Part 1:	Data	Consideration
Type	.csv files of qualitative, *empirical* research.	Attributes
Dimensionality	Non-geospatial/temporal, not "big data" High-Dimensional - Organism description (EG OTU etc) - What the organism reacts to - Strength/rapidness of reaction - Concentrations of pH/Phosphorus that cause reaction	Attributes
Establishment	*Biological Sciences* Scientific Method used to collect data, rather than simulation Advanced, high-throughput DNA sequencing	Relevance
Applicability	Abstract, but actionable elements *Informational*	Relevance
Acquisition	Using *Semantic* boundary object	Attributes

Part 2:	Visualisation	Consideration
Goals	Compare the the *natural* and *artificial* gradient of reactions to pH and Pollution that different organisms have.	Relevance
Interface	*Playful*, Multi-level interaction, interacting with NPCs	Interaction
Construction	*Novel*, Exploratory	Interaction
Context	Museum installation - Museum guests including the general public, school groups etc. Conference exhibition - November 2016 conference: Global Ecologies - Local Impacts Conference - Research Visions 2016 at The University of Sydney.	Relevance
Communication	*Semantic* boundary object: - Users can access data, with guidance, through video game elements, particularly NPCs - The user is given information about the source of the scientific knowledge, and the source of the data. NPCs may be scientists. - Creating a language that the user can understand, but cannot give feedback on, so not a pragmatic boundary object	Relevance
Responses	Happiness, game-like challenge, *play and physical engagement*	Interaction
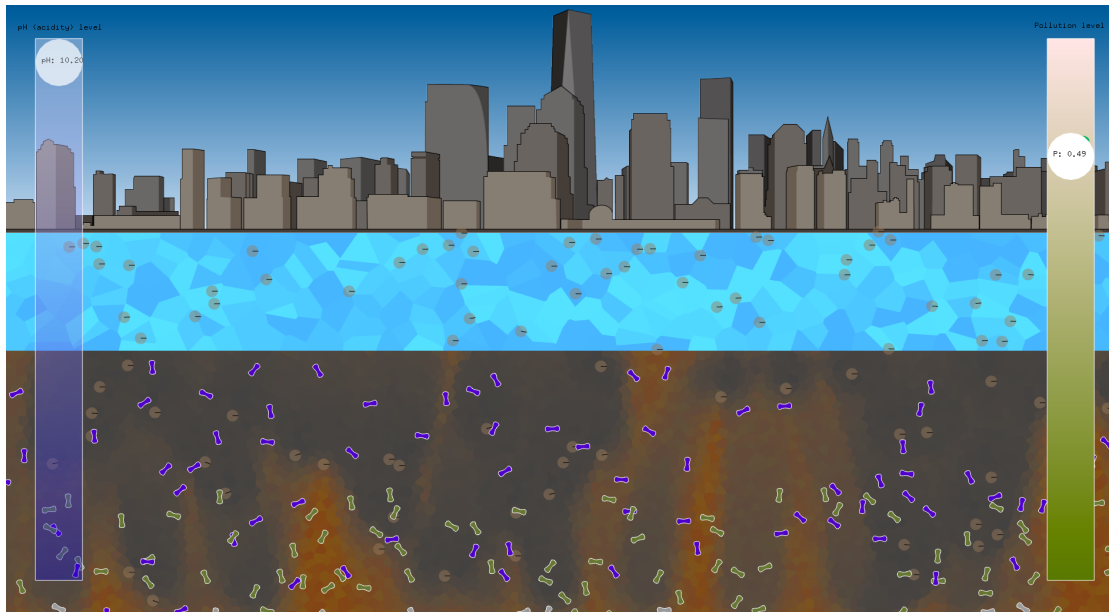
Figure 5.11: A Screenshot of the final iteration of *18S rDNA*.

user to to explore the results of his research. The NPC acts as guides to explore the data; he does not explicitly state objectives or tasks that the users must complete. Video game research suggests that interactive software affects the audience by energising behaviour [110], using game-like elements in a museum installation may have the same effect.

The visual construction of the installation was updated, displaying a side-view of the estuary, rather than a top-down view used in previous iterations. The NPC and background scenes were drawn using Adobe Illustrator for the visualisation (see figure 5.11). I chose a visual style that uses strong outlines around visual elements, to produce a visual separation between the graphical elements. Background elements were constructed based on composite images which combined to represent bushland, farmland and a city. I also used realistic, rather than cartoonish and exaggerated, proportions for the visual design of Anthony. This approach was influenced by the visual style of animations such as *Archer* (2009 animated TV series) or *Frisky Dingo* (2006 animated TV series). Visual effects were added to enhance the appearance of water in the river and the soil where the organisms live. The process used to design the final iteration allows the process and visualisation schematic tools to be evaluated.

5.5 Research Through Design Evaluation

Zimmerman's model of research through design [226] expresses how designs are evaluated according to their invention, relevance and extensibility. The approach used in this research is *grounded*, aiming

to address real-world problems faced by designers [225]. The issues addressed in this research stem from the experience of the design process: the gap of knowledge around how non-expert users respond to different visualisations; and what tools, processes or practices exist that help the designer make informed decisions. Expressing the understanding of how to navigate knowledge boundaries, the creation of the design process model, and the creation of the NEUVis Data-Visualisation Schematic addresses the complexity of the NEUVis design process. These three reflections in chapter 4 codify the knowledge gained during the experience into a specific set of tools and theories [225].

5.5.1   Invention

18S rDNA is a useful case study on how a NEUVis design process can be applied. The integration of the data and user needs into an interactive installation through this process was novel, but not the significant invention of this research. The significant invention of this research is a clarification of the nature of collaboration in NEUVis, the NEUVis design process, and the development of the NEUVis Data-Visualisation Schematic tool. Reviewing the literature showed that, though there are many creative practitioners producing visualisations for a non-expert audience, there was no existing framework or tools for this process. Design tools allow creative practitioners, particularly designers, to express and justify their creative process. The NEUVis Data-Visualisation Schematic, used in a similar way to other need-finding design tools, can also help other NEUVis stakeholders understand processes and decisions made by creative practitioners. Tools like this allow collaborative partners insight into the NEUVis design process by making tacit knowledge of the design process explicit.

Research through design requires that significant invention should include a novel integration of theory, technology, user need, and context, not just refinements of products that already exist. The process model for NEUVis design is an exploration of a typical design process to outline differences that are apparent when dealing with user-centred design for data visualisation. This does not represent a substantial or significant invention. The reflection on the nature of collaboration, as well as the NEUVis Data-Visualisation Schematic represents the new knowledge. These were integrated into the development of *18S rDNA*. The new theory on combining data and user needs is a novel integration with the technology and context of the installation.

5.5.2   Relevance

Relevance in research through design is similar to validity in scientific practice [226], and was described as applicability by Lincoln and Guba in *Naturalistic Inquiry* [124]. In design, there is no expectation that if different designers address the same problem, or even the same problem framing, that the product designed will be the same, or even similar [226]. In this context, Zimmerman describes evaluation of relevance as the need for design researchers to articulate a desired state, and support for why that state is desirable.

The ideal state of NEUVis is that creative practitioners can collaborate with primary researchers to communicate data with a non-expert audience. The current state of visualisation and design has many "best practice" examples of how a visualisation should *look*, and how data can be mapped visually, but very little information to help collaboration or ensure that user needs are treated with

the same importance as data. The way that these two considerations can or have been merged (if at all) is a mystery in the current body of literature, and left unreported by the existing examples of visualisations. To information visualisation, scientific visualisation, visual analytics, perceptual psychology, statistical graphics and other fields there are "correct" visualisation approaches. Few needs or goals are relevant to these fields beyond accurately reading a visualisation. Automation and predictability is important to these fields, but their knowledge leaves the creative practitioner without a platform from which to start a user-centred visualisation. The ideal state of NEUVis is one where the user needs extend beyond perceptual psychology to an understanding of the goals and desires of the user, and presents them as an integrated starting point. The underlying, external motivation to read a visualisation that is present in visual analytics, information visualisation and scientific visualisation does not exist for the non-expert. It may be the case that a keen, non-expert user may find it fascinating and need no motive other than edification, but they may be considered "power users" of visualisation, who would still benefit from NEUVis if it effectively engages an audience.

The approach to the ideal state, then, is for the creative practitioner to have a method or tool that helps combine the message and implications of the data with the user needs and context, in order to create a relevant, informative data visualisation. The culture of using tools within creative practice justifies the creation of a new tool to help promote this ideal state, just as standard methods of visualisation, such as small multiples and sparklines proposed by Tufte (see 2.3.3 on page 49), are justified in other visualisation communities. The design tool has potential to be particularly useful for inexperienced NEUVis designers, whose experience in other creative practices is being applied to NEUVis. Without experience, merging user needs and data into a design understanding may be a difficult challenge.

5.5.3 Extensibility

Extensibility in research through design is described as the way that other designers can build on the research presented. This can be done by applying the process to other design problems, or understanding and exploiting the knowledge implicit to the designed artefact [226, p. 500].

The tools constructed while developing *18S rDNA* can be applied to any user-centred design approach to NEUVis. Designing for the domain-expert audience is a different problem, and the subject of extensive research. Automated visualisation processes in fields such as visual analytics may benefit from inclusion of considerations of user needs and context. However, the problems faced by information visualisation, scientific visualisation and visual analytics are not the same wicked problems that designers face. *18S rDNA* is the first example of these design tools being used in a NEUVis context. The design tools are currently being employed in research at Queensland University of Technology in collaboration with the Cancer Council Queensland (see 6.4.2 on page 131).

5.6 Discussion

Consider the two museum installations presented in 5.4.1 on page 98, 4,000 *Species* and the projection in *Lost Creatures*, and how they address the questions formulated before experiment 2.

1. How does this new knowledge benefit the user?

- 4,000 *Species*

    ○ Provides insight into scientific research, particularly species nomenclature.
    ○ Acts as a semantic boundary object.

- *Lost Creatures:*

    ○ Introduces interesting dinosaurs or megafauna that lived in the region where the museum is located.
    ○ Gives the user a clear understanding of the scale of the animals shown.
    ○ Acts as a syntactic boundary object.

2. What about this data is relevant, or important?

- 4,000 *Species*

    ○ Species shown are relevant to the region where the museum is situated.
    ○ How species shown are related to each other.

- *Lost Creatures:*

    ○ Species shown are relevant to the region where the museum is situated.
    ○ A sense of scale and perhaps a sense of "aura" as described by Walter Benjamin [13].

3. What can the user access for themselves?

- 4,000 *Species*

    ○ Users can find out information, such as who named a species of animal, using internet searches. The information is often included in wikipedia pages of a species, which would be the reverse of the approach from 4,000 *Species,* where the topic of interest is how the animals are named.

- *Lost Creatures:*

    ○ Broad information relating to dinosaurs and Australian Megafauna. Images of these are easily found on the internet.

4. What is otherwise inaccessible to the user?

- 4,000 *Species*

    ○ The relationships between species are displayed in a novel way in this installation.

    ○ Information about the processes of nomenclature is not easily accessible.

- *Lost Creatures:*

    ○ Perception of the scale of the different animals shown, especially in relationship with the viewer.

    ○ Ability to get close to the large creatures, particularly as dinosaur skeletons shown in museum exhibitions are usually guarded, for the safety of the guests, as well as to protect the exhibits.

    ○ Which dinosaurs were found in the region where the museum is located.

5. What myths or misconceptions are relevant to the user?

- Neither installation has significant myths associated with the data.

6. What is the potential for impact, and what are the risks of this visualisation?

- 4,000 *Species*

    ○ The impact for this installation is limited, in terms of the way it may change someone's perception of the scientific method.

    ○ The risks are also minimal. It is not likely to be misunderstood, and undermine confidence in scientific processes.

- *Lost Creatures:*

    ○ The impact of this installation is also to do with changing the perspective of the user, but there is little chance for real impact in this instance.

    ○ The risks are also low. The creatures are presented at scale, but there is no timeline of when they each lived. This may cause confusion about whether they all lived during the same era. This may be an area for potential clarification within the installation.

These two installations prompt different responses, and provide different benefits to the user. The *Lost Creatures* projection used a syntactic boundary object effectively. The physical scale of the creatures displayed visually is easily understood physically by the audience. It communicates simple, engaging information that would be difficult for the user to perceive with the same clarity without experiencing the installation. The information is tightly integrated into its presentation format, context and

audience. On the other hand, 4,000 *Species* does not leverage novelty as efficiently. Identifying the scientist who named a specific species does not have the same immediate, personal relationship to the audience, and its presentation format and design are not uniquely coupled. The large touch-screens it uses are useful and familiar devices, and their increasing ubiquity in the built environment is becoming a strength for the platform. 4,000 *species* is usable, and well designed, but the data, technology and context is not as tightly integrated as the projection in *Lost Creatures*. 4,000 *Species* may work as effectively in another format, such as a tablet computer, where *Lost Creatures* would lose its effectiveness in another platform, even a smaller projection. However, not every museum installation, or every NEUVis, needs to be groundbreaking. It would be difficult to argue that the content of 4,000 *Species* is as intrinsically exciting as the content of *Lost Creatures*; dinosaurs are cooler than the scientists who named them.

Integrating the message and implications of data with the needs and context of the user is a difficult process. However, the process can be described so it is repeatable, and applicable to different combinations of users and datasets. The tacit understanding of user needs and context, and how to integrate these with even simple scientific data, such as the appearance and size of Australian dinosaurs and megafauna, is made explicit in this research. Examination of the knowledge implicit to the *Lost Creatures* projection has helped describe this process, and formulate requirement for NEUVis design.

This process has been applied to development of *18S rDNA*. It is the result of examining many influences on the visualisation process, expressing them, and constructing a process model from these expressions. Early iterations of *18S rDNA* had difficulty mapping data to the user in a meaningful way, even if the interface was enjoyable to use. Each iteration allowed the understanding of the way that data and user needs are integrated to be expressed with greater resolution. Refining the installation acted as a way of refining the process used to build the installation.

5.7   Research Visions

The final revision of the installation was installed in the Hearth at The University of Sydney Faculty of Architecture, Design and Planning for ten days during September 2016 (see figure 5.12). This exhibition was organised as part of Research Visions, the annual faculty research conference. The final version of the installation went through three versions of the concept. Each was designed to use at least one NPC to guide the user, each used the Microsoft Kinect to interact with the installation, which was built in openFrameworks. The exhibited version is available on GitHub under a permissive MIT software license from `https://github.com/philgough/18s_rDNA`. The installation at Research Visions proved to be a valuable experience, as some software bugs were found and rectified. In addition to exhibiting *18S rDNA* at Research Visions, a presentation was given that outlined the outcome of this thesis to the immediate research community in the Faculty of Architecture, Design and Planning. In the final chapter of this thesis, we will discuss artistic visualisation, visualisation design and some of the implications of this research to the practice of NEUVis.

Figure 5.12: Two users exploring *18S rDNA* during Research Visions at The University of Sydney Faculty of Architecture, Design and Planning.

Chapter 6

Discussion

Preamble

This chapter includes a work from of *Science of the Unseen: Digital Art Perspectives* in section §6.2, an online exhibition I co-curated with Lindsay Zackeroff that was published by the ACM SIGGRAPH Digital Arts Community. The curator's statement was substantially developed by Lindsay and myself. All images from *Science of the Unseen* are used with permission from the artists.

Gough, P. & Zackeroff, L. (curators) (2016). *Science of the Unseen: Digital Art Perspectives* [online exhibition]. ACM SIGGRAPH. Retrieved from `http://science-unseen.siggraph.org/`.

In section 6.4.2 is a section adapted from a peer-reveiwed, extended abstract submitted to *BDVA*'16. To be held in November, 2016 at CSIRO, North Ryde. This section describes my contribution to the ongoing work with NEUVis design tools that were developed for this research.

Roberts, J., & Gough, P. (2016, Accepted). Communicating Statistical Uncertainty to Non-Expert Audiences: Interactive Disease Mapping . In *BDVA'16*, Sydney, IEEE.

How often people speak of art and science as though they were two entirely different things, with no interconnection. An artist is emotional, they think, and uses only his intuition; he sees all at once and has no need of reason. A scientist is cold, they think, and uses only his reason; he argues carefully step by step, and needs no imagination.

That is all wrong. The true artist is quite rational as well as imaginative and knows what he is doing; if he does not, his art suffers. The true scientist is quite imaginative as well as rational, and sometimes leaps to solutions where reason can follow only slowly; if he does not, his science suffers.

If we go through the history of human advance, we find that there are many places where art and science intermingled and where an advance in one was impossible without an advance in the other.

—Isaac Asimov in *The Roving Mind*

6.1   Key Findings

Two significant questions about NEUVis were introduced in section §1.1:

- What is the nature of NEUVis, and can user-centred design address this problem?

- How do audiences compare the different approaches that designers, or other creative practitioners, may take when communicating science to non-scientists?

This chapter will discuss how these questions have been addressed by this research through reflection on the literature review, user testing and NEUVis design process.

6.1.1   What is the nature of NEUVis?

NEUVis is the broad practice of visualising data for a non-expert audience. It encompasses the creative practices as broad as graphic design, interaction design, media art, illustration, animation and video. NEUVis shows all of the attributes of wicked problems: they are ill-defined, difficult to state, and lend themselves to the processes used by designers. The designer's need for NEUVis stems from the need to improve the general understanding of scientific research, a high-level need which cannot be easily solved in the short term. Of course, it is not the sole responsibility of the designer to work to improve general scientific literacy. As discussed in 2.5.2, as creative practitioners collaborate with primary researchers, there are many roles that they may play[76]. The visualisations designers produce (or that primary researchers can produce using designerly or artistic methods) are a kind of band-aid fix for the symptoms of the larger, complex problem of scientific literacy. This problem hasn't been ignored; there are many media outlets, museums, art exhibitions, events, science advocates, and a plethora of online content, which communicates science to the general public. So, the obvious question is why does there need to be another voice to contribute to this conversation and is there any benefit to investigating the nature of NEUVis from a design perspective?

The first reason why it is necessary to explore the nature of NEUVis from a design perspective is that designers (and other creative practitioners) already engage in this practice. Experienced visualisation designers may have little need for additional tools that support their tacit knowledge. However, as NEUVis practice grows, and more designers are engaged with data, it is useful to have a framework, through which inexperienced designers can explore the possibilities of working with data. This framework must help creative practitioners apply their own practice to the visualisation context. As with any subfield in design, there are many examples of poor design choices in NEUVis: misuse of visualisation principles without any justification, such as the many results from typing 'periodic table of' into a Google image search. Poor design is not exclusive to trivial, inconsequential data visualisations. However, it would also be possible to cherry-pick visualisations that use some principles of visualisation construction, but do not take needs of the end user into account, and are ineffective as a result. A user-centred design thinking approach to problem solving has been integrated into fields outside of design, particularly in the business world [167, 63], but also in science and engineering. As noted in 2.2.2 on page 36, domain-expert visualisation practice can benefit from an understanding of fundamental art and design principles: the ways in which creative practitioners would use to visually construct, critically evaluate and iteratively improve a visualisation. As this shows, another answer to this question is that design thinking and design tools are applicable to many different contexts, not just designers.

As discussed in 1.3 on page 20, scientific visualisation, information visualisation and visual analytics, all types of domain-expert visualisation, are are inherently different from NEUVis (see 1.1 on page 25). The domain-expert visualisation focuses on data; the needs of the user (if considered) are secondary to the data. User needs are very rarely discussed in any form of academic literature on domain-expert visualisation, possibly because the focus of domain-expert visualisation is the work context. However, there are many more incentives that drive the non-expert to use a visualisation. Creative practitioners may be commissioned to build visualisations which are engaging, pleasurable, edifying, or that have any other goal that is in addition to the primary outcomes of insight and saving time. A user-centred design approach, which is specific to NEUVis is therefore necessary to properly communicate data to the audience. Data is not just a constraint on the designer, such as time, budget. It is not a requirement of the final designed product, such as falling within a price range for the market. Data being visualised is an inherent attribute of the visualisation, as much as the user viewing it.

Therefore this problem is an appropriate challenge for designers: it is one of combining the message and implications of the data with the needs and context of the audience. This is done through direct or indirect collaboration with primary researchers, those who collect the data. The designer (through the use of some kind of boundary object, as discussed in 4.2 on page 74) must internally parse the data, and merge it with the user needs, creating an understanding of the scope and context of the starting point of the visualisation (the problem zone, see 4.2 on page 78). This can be used to define a problem, which can be solved, tested and refined. When an acceptable solution is achieved, the visualisation is then published. The tools described in 4 on page 73 described how the steps of this problem are addressed by user-centred design. The unique challenge of merging data and user needs is the defining attribute of the nature of communicating science to non-scientists.

6.1.2   How do audiences compare different approaches to NEUVis?

The key findings in this area are complex, and are explored using feedback after the user experiments. Both experiments show that NEUVis can prompt users to make meaningful connections between themselves and scientific data, but on different levels. The depth of engagement seems to be some function of how the data is applicable to the user, as well as how the data is presented. As noted in 4.4.2 on page 80, the comparison between narrative structure in *The Hungry Microbiome* and *Alzheimer's Enigma*, the release after the climax differed between the two videos were different. *The Hungry Microbiome* called the user to action, and was written to inspire the viewer to make personal changes[1]. It presented scientific research and the way it can be applied to the viewer. The application itself is easily found by a user through a web-search. In *Alzheimer's Enigma* the release simply told about new research in the field. The video presented scientific research, but made little attempt to capitalise on the way that it can be applied to the viewer. The video doesn't propose an action for the user to engage with and act upon beyond the video itself. It is not possible to tell from this research whether this distracted users from finding out ways to engage with the information. However, this video still may be of use to the general population, particularly those who are affected by the disease, or have some domain knowledge about the information in the video.

In order to follow-up with what they have learned, the audience of *Alzheimer's Enigma* can easily find information about how they can make choices which will help prevent Alzheimer's Disease. Since there is no call to action (that was present in *The Hungry Microbiome*) there is no incentive for users to reengage with the content. That is not to say that *Alzheimer's Enigma* is unsuccessful, but the brief given to the animator did not provide an opportunity to leave the audience with some way of connecting their actions to the science. Whether NEUVis includes a call to action for the user is a consideration more relevant to the primary researcher (or agent funding the NEUVis) to consider, than for the creative practitioner. Some objectives for NEUVis include simply sharing information. The way users engage with visualisation through modern media is important to examine.

A model of engagement developed from exploratory research by O'Brien and Toms [151] proposes four stages of engagement for user experiences with technology, which can be applied to NEUVis: [151]

1. **Point of engagement:** A user may start engaging with technology because of resonance between themselves and the aesthetic experience or information available to them through the interface. Engagement was secondary to the system supporting users' goals or allowing the user to complete a task, satisfying social motivations, presenting information of interest to the user and through novel layout and interfaces [151]. In the case of the research described in this thesis, users were asked to engage with the visualisations, so it is not possible to draw any new information to add about the point of engagement. However, NEUVis design can benefit from understanding how users start engaging with a visualisation.

---

[1] *The Hungry Microbiome* project was produced as part of the VizbiPlus initiative, which is partially funded by an Inspiring Australia grant from the Australian Government [53].

(a) *Supporting user goals and task accomplishment*: One of the established purposes of visualisation is to provide straightforward insight to the user and possibly save time. This is the obvious application for a point of engagement. The challenge for NEUVis practice is to connect the visualisation that is being created with the member of the general public that will benefit from the information that is being presented.

(b) *Social motivations*: The example of social motivations included in O'Brien and Toms' research described one online shopping user who read book reviews from others who they knew had similar tastes. NEUVis has the potential to leverage social motivations in a similar way by exploiting social media. Often NEUVis is publishable online, infographics and videos can be hosted online and shared to a wide community, formats such as museum installations are not always able to be made available through a web browser. In these circumstances, a point of engagement through social motivation can be created by augmenting an offline NEUVis installation with an additional online platform, which can be shared though social networks.

(c) *Presenting information of interest*: This is an obvious target for the point of engagement with NEUVis. Using the methods described in 4.6, NEUVis should establish the information from a dataset that is relevant to their audience. Topics of interest to a user may become a points of engagement when discovered using social motivations, assuming that people are connected with those who share similar interests through social media.

(d) *Using novel layouts and interfaces*: This point of engagement is particularly useful to artistic visualisation. Many artistic NEUVis use aesthetics to draw the user in to engaging with its message. Using any of these methods to capture attention will draw a user into engaging with a visualisation. Some users will engage with a system to achieve a goal, but other users want to open themselves up to an engaging experience [151]. Emerging technology, particularly virtual reality (VR), are examples of novel interfaces. VR is capable of providing the user with a deep immersion into the content being presented; one example includes VR experiences published by Google's Spotlight Stories [83]. These short animations leverage the strongest features of novel technology to support storytelling to create unique and emotive aesthetic experiences. NEUVis (and visualisation in general) would benefit from a critical analysis of excellent examples of the integration of technology from storytelling and narrative perspectives, such as *Pearl*, one of Google's Spotlight Stories [83]. Novel technology is an engaging pathway to draw users to interact with technology, but the experience can be sublime when the technology effectively supports the message that is being presented to the user who chooses to make the first engagement. The pitfall for NEUVis using novel layouts and interfaces to engage users is to forget that they are, in fact, people. NEUVis should use technology to support the goals of the person using it, rather than as an excuse to exist in the first place.

2. **Period of sustained engagement:** in order to sustain engagement, users interest must be maintained. Users who were engaged stated that they were surprised at how much time had

passed, indicating that they may have achieved a state of flow during the experience [51]. The paper notes that users focussed their attention on the task and sought out novelty. Users also desired feedback on their actions (for interactive systems) and needed to feel in control of their situation, that they had the skills required to meet the task they wanted to achieve. When facing a challenge it was seen as either negative or positive, depending on the user context; for online shopping, there should be as few challenges to overcome as possible, but video games without a challenge were seen as pointless [151]. NEUVis design can benefit from this by implementing different methods from different research areas. One example is the use of narrative principles, such as those used in animations like *Alzheimer's Enigma* and *The Hungry Microbiome* to sustain the interest of the audience. Gamification is one other method of engaging the user; game design elements are included in non-game contexts in order to motivate user activity and retention [54]. Gamification may also provide an extrinsic motivation for the non-expert user to interact. In comparison domain expert visualisation methods have an intrinsic motivation for the user, as they are most often using a visualisation at work. VR also has great potential to produce totally immersive experiences with data for NEUVis, as well as domain-expert visualisation, as it is able to create a sense of presence, the feeling that an experience that seems so natural that the user feels that it is not mediated by technology [126].

3. **Disengagement:** Users may stop engaging with their activity because of internal or external factors [151]. Internally, users may decide that they wish to stop their engagement because the user places a low importance on the task, or because of internal distractions such as other tasks that may be more important to them. These may be tasks that are time-sensitive, particularly if interacting with the system is not time sensitive, or uses a lot of time [151]. Disengagement can also be to external factors, such as interruptions like a phone ringing, or difficulty using the system [151]. To transpose this knowledge to NEUVis applications, a user that is disinterested with the content will disengage on their own accord, but may also do so if they feel pressure on their time, or from other tasks that need to be completed. Distractions, interruptions and usability issues also lead users to disengage [151].

4. **Reengagement:** Over the long-term and short-term, users may reengage with technology, particularly if the user was cut off by external factors. Users may disengage and reengage with varying levels of intensity of engagement [151]. O'Brien and Toms found that positive past engagements were a good indication of reengagement. If users were not ready to disengage on their own terms, had personal needs to attend to, needed to compare information or were multitasking or task-switching, they were also likely to reengage with technology [151]. O'Brien and Toms offer some insight into how technology can prompt user reengagement that is relevant to NEUVis design. Factors that drive positive past experiences will draw a user back to NEUVis, if the user has fun, finds the NEUVis to be a convenient way to analyse data, or is given an incentive, such as a gamification element, such as a ranking on a leaderboard, or virtual trophies. The final past positive experience which may draw the user back to the visualisation is that they discovered something new, the visualisation was able to clarify information for the user.

The clarity of the visualisation can also be influenced by the presentation format [143]. Users were able to understand the message behind the three modes of visualisation, but videos in particular were received more enthusiastically than other modes. When the narrative from *The Hungry Microbiome* was converted to an infographic for comparison, the users took hold of different details and terms, but did not engage with the data to the same degree. Most notably, the exclamation of insight at the climax was much more frequent with the video than the infographic. This does show that though it may have a smaller investment, infographics can still be useful in communicating information for insight.

Most importantly, this experiment shows how important it is to have a useful and relevant message to communicate. NEUVis must use the right medium within the constraints of time, cost, effort, expertise and desired outcome. A design methodology should support multiple creative practices, rather than presenting a narrow guide for one particular approach. The NEUVis Data-Visualisation Schematic design tool was developed in this research to allow the creative practitioner, as well as the primary researcher, to assess and define the various possible goals that NEUVis can have. This includes the overall message that the visualisation should communicate, and the desirable responses the user will have.

6.2 *Science of the Unseen: Digital Art Perspectives*

During this research project, after the user-studies were completed, I wave given an opportunity to curate an exhibition with the ACM SIGGRAPH Digital Arts Community (DAC). DAC hosts permanent online exhibitions, and has an active presence at the ACM SIGGRAPH and ACM SIGGRAPH Asia conferences. In collaboration with the DAC committee, a broad concept of an art+science exhibition was refined, and a call for public submissions to *Science of the Unseen: Digital Art Perspectives* was published in December, 2015. The relevance to this research was that the exhibition created a cohesive group of artworks on a broad topic of art and science, which could be critically examined in the context of communicating science through NEUVis.

In response to the call for works, there were over 140 submissions which responded to the topic *Science of the Unseen*. From these submissions, an international panel of 10 artists, including the co-curators, Phil Gough and Lindsay Zackeroff, selected 34 works were included for exhibition. The selected works represent a wide range of backgrounds in the arts, including students, independent artists, artists-in-residence, and scientific visualisation labs. The call for submissions was also promoted by media outside ACM, including *Wired* Magazine [189]. In addition to the exhibition, a panel discussion with some artists was held at the SIGGRAPH 2016 Conference in Anaheim, and a catalogue is being produced for publication by ACM. After the exhibition was published in June, 2016, it was published by media organisations such as *SciArt Magazine* [175], and *The Creators Project*, an online publication from *Vice* Magazine [25].

6.2.1 Art, Science and Responses to the Topic

The curator's statement outlines the topic of *Science of the Unseen*:

What goes unseen, unfelt, unheard? The artworks in *Science of the Unseen: Digital Art Perspectives* integrate science and art to amplify what may go unperceived in visual, social, and political registers.

Science and art express the echoes of our existence in the universe. The works featured here provide perspectives and insight into the awareness of the vital systems around us. Our hope is not to present the human mind as the center of all perception, but to combine the dynamics of human society with nonhuman ecologies, highlighting the infinite feedback systems that flow through our world.

The media the artists use here — including gameplay simulation, software engineering, performance, and video art — immerse the viewer in a world and collapse the limits of inside and outside. Art works in this exhibition challenge conceptions of interactivity, participation, and collaboration via both the media they use and how they approach the topic of research. The scientists, artists, and researchers extend the scope of their work outside of lab, studio, or library out into broader communities. By doing so, they create opportunities for viewers to experience their artwork, and together, the artist and viewer critically explore how art and science impact society.

Artists were invited to respond to the topic of *Science of the Unseen* using either still images, video, or interactive web-based technology. This freedom of digital art practice, in addition to the broad topic, drew attention from a wide group of artists and scientists, their practices spanning many fields, including: complex mathematical algorithms; silversmithing techniques; geological survey data; microscopy; interactive JavaScript; computer animation; particle accelerators; citizen science; generative algorithms; EEG devices; high-performance computing; snails, worms and even one artist's own tears.

The success of the exhibition is evident in the quality of works that were submitted, and selected for the exhibition. It is often claimed that art and science are disparate fields, separated by "a gulf of mutual incomprehension" (according to C.P. Snow, [184]) but exhibitions such as *Science of the Unseen* suggest otherwise. The similarities between art and science are explored by artist Rich Gold, in his book *The Plenitude: Creativity, Innovation, and Making Stuff* [81]. A creative polymath, Gold presents in this book a reflection on his personal experience working as an artist, designer, engineer and (psuedo-)scientist. He draws contrast between the creative thinking methods he used these four fields, but also notes their similarities. In opposition to current thought on the topic, Gold suggests that within these four fields the greatest divide puts design and engineering together, and arts and sciences on the other side of a wall (see figure 6.1). Gold outlines the dissonance between art & design and science & engineering, but also highlights some similarities between science and art that provides insight into reasons why art and design collaboration may be successful.

Gold states that all professions have *others*—other groups or professions that share a deep relation to the field. The *others* for science/art are a fundamental difference between them and design/engineering. Patrons and peers for art and science act in similar ways, though their outcome is different. Patrons fund both artistic and scientific endeavours. Peers perform academic review for scientists, and critique for artists. The *others* for designers and engineers are the client and the user. The client presents the user or engineer for a problem to solve. The user is the person for whom an artefact is actually
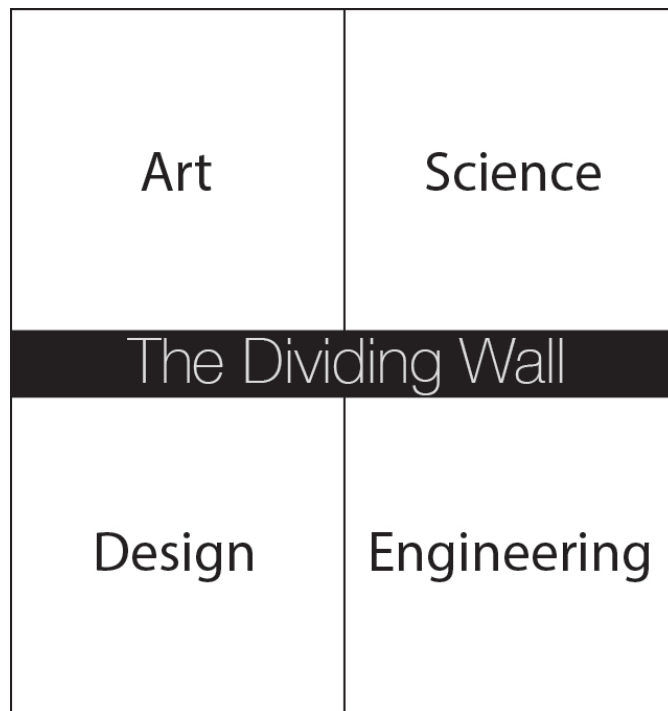
Figure 6.1: A diagram of the relationship between art, science, design and engineering according to Rich Gold.
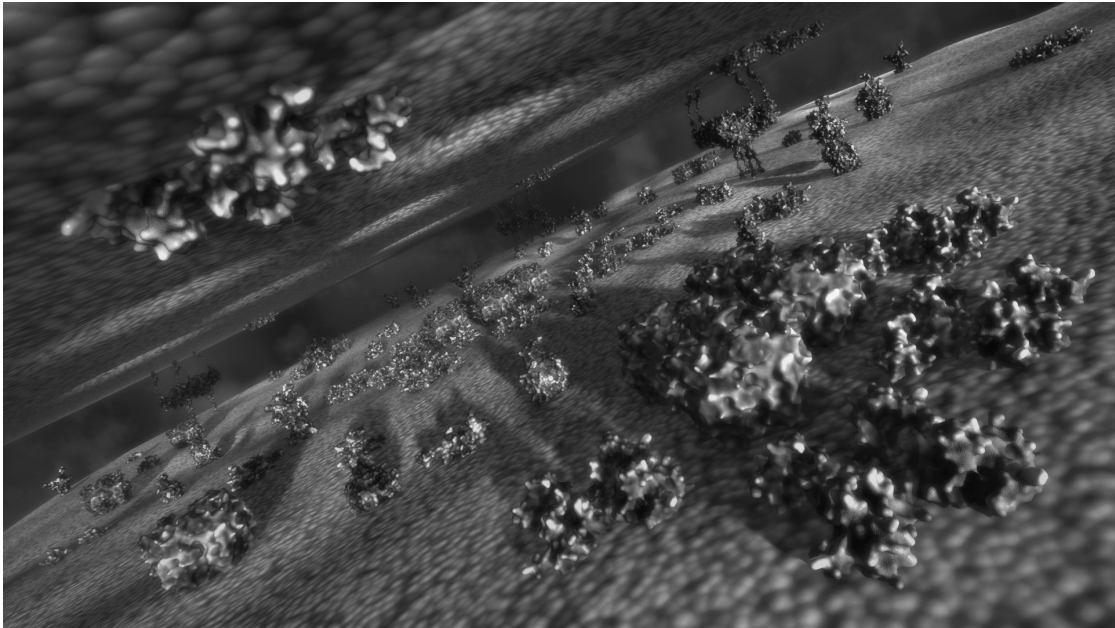
Figure 6.2: *The Dark Anim* by Zoppè, Loni, Cianchetta and Carlone. Image used with permission.

created [81, p. 28-29]. This contrast also outlines another similarity between art and science: the personal *vision*. Gold describes the importance of the *vision* to the artist and scientist. The artist uses their *vision* to inspire their own work; the *vision* comes from within, and artistic integrity is how well the final product the artist creates reflects this *vision*. The artwork is also judged as good or bad by their peers, other artists, as well as curators and critics [81, p. 13-14]. The scientist forms a theory from previous scientific work (by standing on the shoulders of giants, as Newton said) and a personal *vision*. The *vision* of the scientist is the hypothesis that is tested through experimentation, leading to its acceptance as a current truth by their peers or its falsification [81, p. 9-10]. Though their procedures are different, the suggestion that Gold makes that there is striking similarity between art and science is reflected in the responses to the topic of *Science of the Unseen*. This is reinforced by the submissions of works that were not primarily artworks, but rather developed as scientific visualisations.

One such submission to *The Science of the Unseen* was *The Dark Anim* (see figure 6.2) by Monica Zoppè, Tiziana Loni, Stefano Cianchetta and Ilaria Carlone, researchers from The SciVis Group in Italy [176]. The five-minute video describes the effect that serotonin (the "happiness hormone") within the human brain. The monochromatic video induces a feeling of buoyancy with a large pool, as if the viewer is suspended within a complex chemical soup. The artists state in their synopsis [87]:

> "The overall impression is reminiscent of Scanning Electron Microscopy images, but with a sort of 'underwater feel' that should elicit in the viewers the sense of living matter."

Figure 6.3: *Salt Mine* by Tarah Rhoda. Image used with permission.

The disorienting camera angles and dissonant music make the space within the video feel vast and cavernous, even though the scale of the scientific data is minuscule beyond the reach of optical microscopy. The work reflects the complexity of the processes in the brain, and the effect that a chemical process can have on the individual. The work concludes by contrasting the tiny scale of size with the enormous scale of complexity. Researchers have used artistic methods to communicate this complexity, and create an aesthetic piece to which the viewer can respond. This work is based on advanced scientific research, and represents one end of a spectrum of responses to the brief for *Science of the Unseen*. Another work that contrasts such a scientifically sophisticated approach is by artist, Tarah Rhoda.

Rhoda's work, *Salt Mine* (see figure 6.3), is a two-minute video that shows the artist's own reflection on the body [87]:

> "Investigating the body as an archeological site, literally 'mining' myself, I abstract the resulting observations and extractions into poetic reflections and devices, often utilizing laboratory equipment to set the stage."

In contrast to abstract view of an ambiguous brain *The Dark Anim*, Rhoda's *Salt Mine* is an intimate investigation of the body. The short film displays crystallisation of the salt in the artist's tears, showing emergence of different patterns that reflect the type of tears and the method of collection. Rhoda

Figure 6.4: *Meso* by Mark Stock. Image used with permission.

consulted with a lab technician to help control and compare variables such as how the tears are collected. This citizen-science method may not have the same rigour applied as peer-reviewed scientific publication, but instead the viewer is shown a perspective of using the techniques of science for a poetic investigation of the natural world.

Another poetic investigation of the natural world is by Mark Stock, in his work *Meso* (see figure 6.4). The three-minute video bridges both approaches seen in *The Dark Anim*, and *Salt Mine*. Stock's artwork uses accurate geological data, mapping elevations from the US Geologic Survey to a monochromatic image, to create a new, poetic rendition of nature on a large scale. This work transforms of perspectives that are familiar to the viewer. The familiar satellite views used in services such as Google Maps, are transformed through visual mapping into a new and unexpected attitude. The novel view draws the viewer into the previously unseen world created from topological data without the visual distraction of the colours of the land it represents.

Unusual and elegant mappings are used to bring data out of obscurity and into the tangible world by artist Luke Hammond in his work *In This Unfolding* (see figure 6.5). Hammond's two images exhibited in *Science of the Unseen* use and silversmithing procedures to create exquisite neurones that draw the user into closer consideration of the subject the artist has chosen to represent. As Hammond states [87]:

> "By carving and manipulating wax I transfer the dynamic processes observed in nature at
> the macro and micro scale into precious metal. Further experimentation in surface col-

Figure 6.5: *In This Unfolding* by Luke Hammond. Image used with permission.

ouration and stone setting techniques allows me to bring these objects to life. Through this approach, my works experiment with the phenomena of biophillia to generate immediate connection with the viewer whilst simultaneously encouraging reflection on what lies below the surface of our beings."

6.2.2   Special Session at SIGGRAPH 2016

A special session at SIGGRAPH 2016, included a panel of artists contributing to *Science of the Unseen*, lead by one of the curators, Phil Gough. This discussion covered many topics within an art and science context, particularly collaboration and the role of art in communicating science to a general audience. Eleanor Gates-Stewart, one of the artists on the panel described the aesthetic experience of art as a hook to draw people into the science that is being shown; the core of what the artist is saying may not be on the surface, they are starting a conversation with the audience. This bears a striking similarity to the comments made by User 4 in Experiment 1 of this research (see 4.4.2 on page 80). An artist in this context may have the role of conveying obtuse concepts about science and investigating different methods of communicating information. Exploration, as the artists noted in the discussion, is important to the artistic process and also to the relationship to the scientists with whom they are collaborating. Developing the dialogue between artists and scientists takes time. Some scientists need to develop their understanding of the contribution that the artists can make to research: artists are not engineers, but they can help the audience understand what the data *feels* like. Data journalist, David McCandless investigates this idea in *Information is Beautiful*:

> But can a book with the minimum of text, crammed with diagrams, maps and charts, still be exiting and readable? Can it still be fun? Can you make jokes in graphs? are you even allowed to? [129, p. 6]

His approach that the relationship between the facts, context and connections between data all work together to make data meaningful [129]. In his book *Knowledge is Beautiful* he describes the tacit understanding that he develops as a visualisation designer:

> When you understand something, you're able to perceive its structure its connections, its relationships, its significance relative to everything else. How it fits. You see-feel-intuit the fit. You know it. You know? [130, p.6]

McCandless states that fitting this knowledge with an understanding of context is essential to help the audience "get it" [130].

Another topic from this discussion was the ambiguity of scale. Many artworks from the installation use ambiguity of scale to shift and re-frame the perspective of the viewer. One work that uses this was *Solar Superstorms Visualization Excerpts: First Stars to the Solar Dynamo* by the Advanced Visualization Lab at National Center for Supercomputing Applications, University of Illinois (see figure 6.6). Ambiguity can be strategic tool that creates intrigue in the viewer. *Solar Superstorms* uses ambiguity of scale with respect to both time and three-dimensional space. It is based on supercomputer simulations
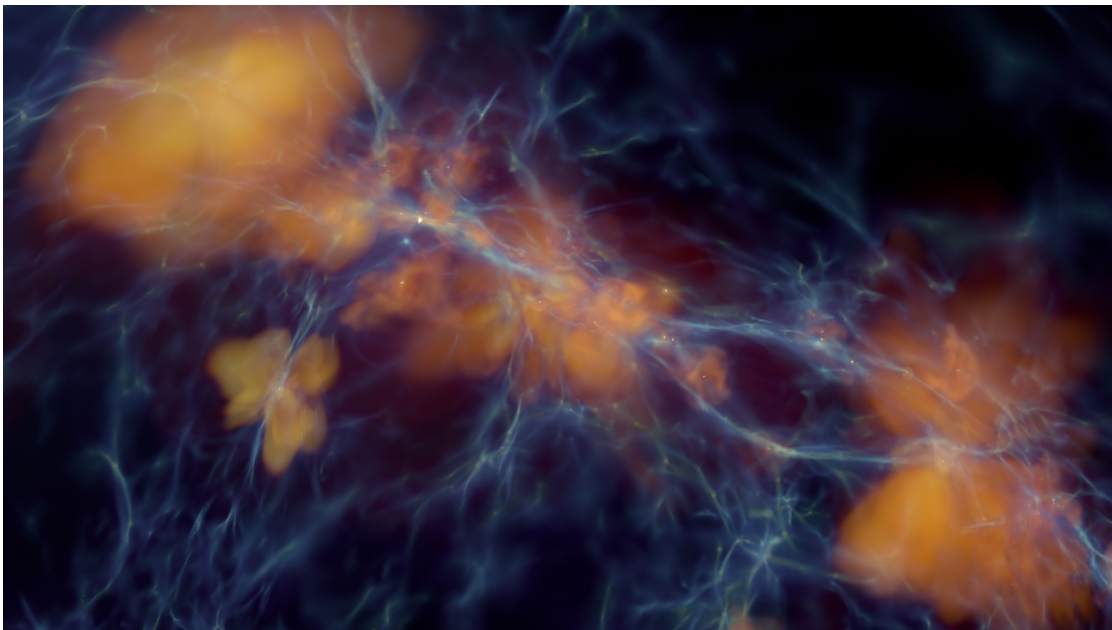
Figure 6.6: *Solar Superstorms Visualization Excerpts: First Stars to the Solar Dynamo* by the Advanced Visualization Lab, NCSA. Image used with permission.
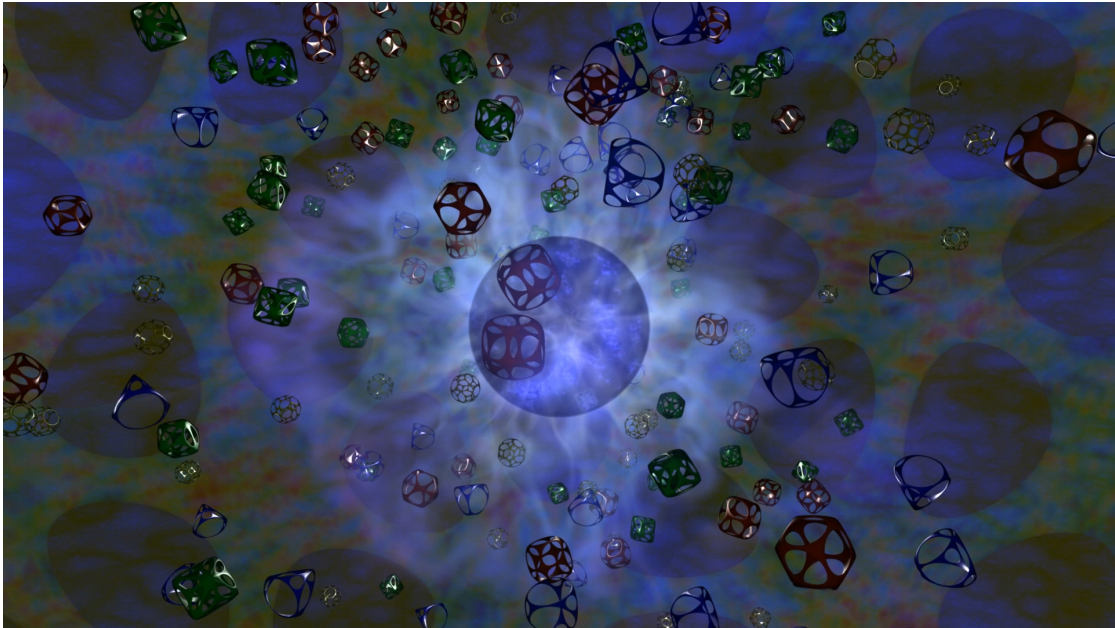
Figure 6.7: *Fractals, Particles, Photons, & Microwaves* by Alex Lee. Image used with permission.

that served several purposes. A computer scientist from the Advanced Visualisation Laboratory discussed in the panel how visualisations produced for scientific research showed insights that were not imperceptible without the visualisation. The same data that supported the scientific insight was also presented in a planetarium format for the general audience at SIGGRAPH 2015 [6], and then remixed for submission as an art work and exhibited in *Science of the Unseen*.

In contrast to this video, some artworks discussed at the panel session at SIGGRAPH 2016 were based on scientific ideas, rather than data. One example of this included *Fractals, Particles, Photons, & Microwaves*, a work that creatively expresses a quantum mechanical cascade of electrons emitting photons described by Steven Gusbner in the book *The little book of string theory* [90]. This process is visualised by Lee in the video, but it is not based on data. It is a visualisation of a scientific concept, rather than a data visualisation. This means it would not fit into the strict definition of artistic visualisation provided by Viégas and Wattenberg [216] (see 2.5 on page 54) but this type of knowledge visualisation is still meaningful and useful for the viewer.

The works exhibited in *Science of the Unseen* reveals great potential for the use of artistic representation of research data and scientific knowledge. The success of the show is a reflection of the burgeoning opportunities of collaboration between two fields that had typically been seen at opposition to each other. One area for development in the digital arts that was expressed in the panel session was the need for increased artistic critique within the digital arts [84], which is similar to research from computer scientist Robert Kosara [114, 115], who advocates a similar discourse within visualisation. Critical discourse would also increase the quality of all kinds of visualisation. The strength of NEUVis

may be that it has a broad foundation, spanning multiple fields: this thesis focuses primarily on art, design and animation. Upon this foundation lie many opportunities to learn from effective practices of separate fields, and apply them to NEUVis practice.

6.3 Implications of Findings

NEUVis builds on top of the theory of many visualisation approaches, applying a user-centred design process to visualisation. This new approach is applicable to a diverse set of visualisation practices, and is repeatable in many contexts.

The NEUVis Data-Visualisation Schematic design tool, as well as the questions that are presented in 4.6 on page 86 are a useful framework for constructing a design understanding of data when communicating science to non-scientists using visualisation. The framework can also be used for other data types, such as mathematical, economic or political data. There is potential that the framework will be useful for domain-expert users, applying a user-centred design approach to visualisation for work applications.

6.3.1 Theory of NEUVis

As shown in the literature review, there has not been substantial research that has contributed towards a theory of user-centred design for non-expert user visualisation. The majority of visualisation research has been conducted from perspectives that assume that the user is using visualisation for work [161]. This use pattern, or context of use, includes an intrinsic motivation for the user to read a visualisation. NEUVis are designed for other contexts, where there may be no external motivation for the user to engage with the visualisation, or the motivation to interact may be entirely due to the design of the NEUVis itself. Research from other fields can help inform NEUVis design in matching contexts. For example: museum installations can benefit from the "honey-pot effect" described by research on situated public displays [20, 199]; 3D animation and infographic NEUVis can benefit from research into narrative visualisation [178]; interactive NEUVis can benefit from research into the pragmatic approaches to interactive systems [158]. The challenge for the designer is to find and combine the relevant research for their project.

The common approach to all mediums of NEUVis is that the data must be visualised with an understanding of the user. Casual infoVis (see 2.2.3 on page 37) was introduced to encompass visualisations that are not typically covered by findings of traditional infoVis research, and are not considered ambient, social or artistic visualisations. The considerations of casual infoVis are similar to NEUVis: the user population is not necessarily expert in the data domain, and have different motivations for reading visualisation than analytic thinking; the usage pattern of this wide audience is not limited to work; the data used is often personally important, instead of motivated by work; and the kind of insights that casual infoVis may support are different than infoVis for analytical thinking [161]. However, research into casual infoVis does not present a new process of creating user-centred visualisations for their audience. The concepts presented in this thesis are applicable to casual in-

foVis, as well as ambient, social and artistic visualisation, and other approaches, such as narrative visualisation.

The theory of NEUVis also incorporates different models of collaboration. By understanding the way that creative practitioners and primary researchers exchange knowledge, it is easier to reflect on the way that the NEUVis exchanges knowledge with the audience. The way that NEUVis is used to navigate a knowledge boundary is a fundamental part to understanding what data should be visualised as well as the way in which data is visualised. Understanding how the NEUVis acts to cross the knowledge boundary to the audience may also be useful for agents that commission NEUVis from creative practitioners. An understanding of different ways that knowledge is transferred can be incorporated into a design brief, and appropriate outcomes for users can be specified in accordance with the desired goals for the audience. One example may be that a semantic boundary object, that allows users to learn about the sources of scientific knowledge, is desirable for a project, and can be stipulated in the brief. It is worth noting that though it is possible for NEUVis to act as a syntactic, semantic or pragmatic boundary object, reviewing examples of NEUVis showed no examples of an application of a pragmatic boundary object. This may be a desirable goal for future research in NEUVis.

The overarching goal of data visualisation for scientific visualisation, information visualisation and visual analytics is primarily to provide insight, and save time. The goals of NEUVis should also be to provide insight and save the reader time, but there are other relevant objectives that emerge from the literature review, particularly from the research on value-driven visualisations [186]. The additional, value-driven goals include: providing an overview, essence or take-away message of the data; prompt additional questions about the data, as well as provide insight; and generate knowledge, and confidence in the source of that knowledge. However it is relevant to describe a single goal, which encompasses the motive of NEUVis:

The guiding moral goal of NEUVis is the centralisation of effort required to build the understanding of scientific data, the democratisation of knowledge and distribution of the benefit of that knowledge to the non-expert audience.

6.4   Limitations and Future Research

6.4.1   Limitations

At the outset of this research the goal was to compare the different responses that non-expert users have to different kinds of visualisation, and to explore the responses to different visualisations through the production of an interactive installation. The major limitation was that the literature on visualisation does not express the visualisation design process, particularly for applications outside of work. Most of the literature discussing NEUVis (under more specific names, casual infoVis, artistic visualisation, narrative visualisation to name a few) define properties of different approaches, and present case studies that show where these properties are visible in practice. These are useful, but there were no tools that were available to this research that informed how visualisation should be approached in practice.

The culture of NEUVis practice does not typically value peer-reviewed publication. There are many examples of NEUVis practice, but, in comparison, there are few scholarly publications. Most scholarly publications are books that explain different approaches to visualisation, but often these don't address the way that user needs and data are merged. Many choices made by creative practitioners are often evident in the final product, but the complex sequence of decisions and iterations that inform the final display are difficult to decipher from a published work. The integration of the data and the audience is only expressed through the visualisation, and the process that the creative practitioner used is often a mystery. Reflective practice is common in art, but specifically in a NEUVis context, there are limited examples of actual frameworks for producing NEUVis that go beyond lists of different types of visualisation and what kinds of data they relate to. The choices made by designers regarding all of the aesthetic elements (as discussed in detail in 2.2.5 on page 40) are just as important as which kind of chart to use (or not). In response to this limitation, the research was adapted to include an expression of the process used to build the installation, *18S rDNA*. The application of the tools used to build the installation is one possible area of refinement and future research, but this research shows how it has been applied to the visualisation process.

6.4.2 Ongoing Research

The two design tools presented in this paper are being used in an ongoing research project that is a collaboration between the Cancer Council Queensland and the Australian Research Council (ARC) Centre of Excellence for Mathematical and Statistical Frontiers (ACEMS) at Queensland University of Technology (QUT). The Cancer Council Queensland developed a mathematical model for generating a cancer atlas: a series of maps of Queensland that present the relative risk of a population developing cancer and the relative rate of mortality within 5 years [45]. The map is divided into statistically local areas and coloured according to the relative risk. For example, the map in figure 6.8 outlines the health outcome inequalities for women diagnosed with breast cancer. This figure shows that women in the rural regions of Queensland are less likely to be diagnosed, and have a higher mortality rate within 5 years than women who live in the cities. These maps are published under public domain [24] and are potentially used by a wide variety of people, from public policy decision-makers, clinicians, carers and patients, media outlets, and the general public.

The research from this thesis is currently being used to develop an open-source guide for developing chronic disease maps that clearly and effectively communicate the statistical uncertainty around the risk estimates that are used to generate the maps. The disease maps currently colour the map regions using a point-estimate of the relative risk. This has the potential to be misleading, as the estimates may have a range of uncertainty: to simplify this problem, a relative risk of 45% to 55% is not the same as 30% to 70%, though the point estimate of each will be 50%. In addition to this, few potential users have a developed understanding of statistical uncertainty (that is, uncertainty about facts). The Cancer Council Queensland wishes to incorporate statistical uncertainty into these maps using an interactive, web-based technology, such as D3.js. The final design must be accessible and informative for the non-expert audience, so the tools described in this thesis are being employed in the design of the interactive maps.
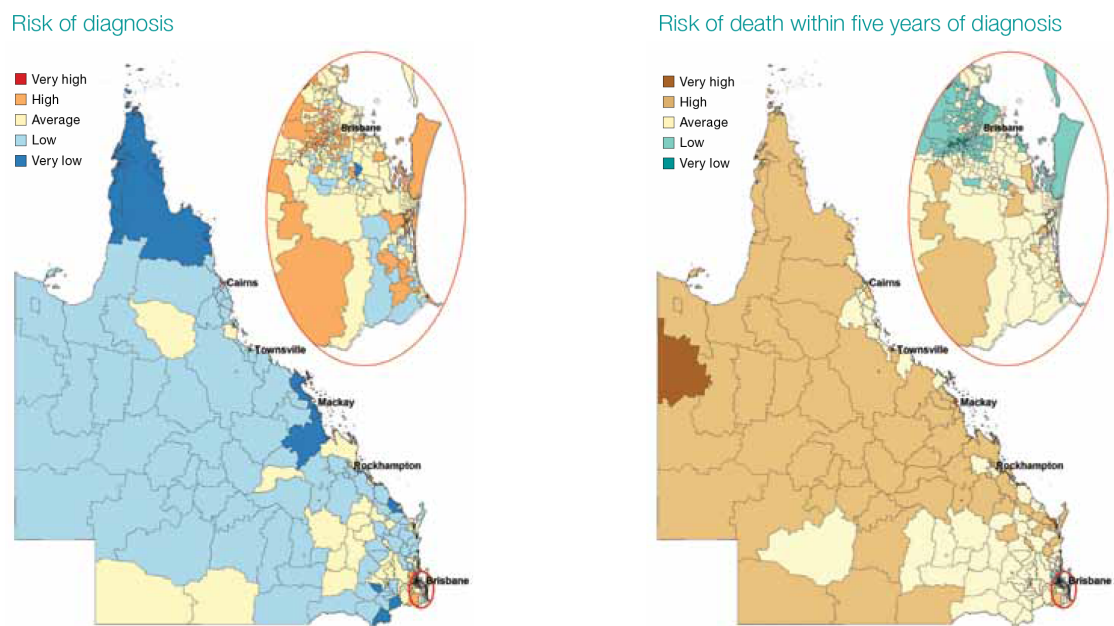
Figure 6.8: Risk of diagnosis and mortality within 5 years for breast cancer among women. Public domain image.

6.4.3 The Future of NEUVis

Many areas of this research can be investigated in further detail, to obtain specific answers to questions beyond the scope of this project. Some of these are discussed here:

Collaborative Learning in interactive NEUVis   It is not known how NEUVis that supports multiple-user interaction acts as a boundary object for collaborative learning. Collaborative learning is described in [57] as a situation in which two or more people learn, or attempt to learn something together. The way in which NEUVis facilitates this is unknown at this point, but would be of value to creative practitioners and those who commission them to work in NEUVis.

Designing NEUVis to act as a pragmatic boundary object   As noted above, there are no pertinent examples of how NEUVis can facilitate a two-way flow of knowledge between the non-expert audience and the primary researchers. A model of a NEUVis acting as a pragmatic boundary object is proposed by artist Kate Dunn, and is described in [86, p. 32]. This artwork will allow traditional knowledge of Australian land to be drawn, painted or carved into three-dimensional representations of climate change data. If successful, this would be an interesting case study for NEUVis as a pragmatic boundary object.

NEUVis and confidence in data presentations   During testing, there was only one user that commented on the source of the research. During the first test, user #7 audibly noted that the infographics were published by CSIRO. It is unknown whether other users valued the source of the information that was being shown, whether it is important to the average non-expert user, or whether it is simply assumed that the visualisation is accurate. In line with the value-based visualisation approach, it would be relevant to explore user's opinions on this matter.

Leave the user with something to do   A tentative suggestion presented in 4.4 on page 80 is that the user may engage further with information if they are not presented with all the answers to a question. This approach should consider the user's context and leave them room to engage on their own terms with the data. This is an area that would benefit from research.

Does this research support sciVis, infoVis or visual analytics?   The way in which outcomes from this research can be applied or incorporated into the practices of domain-expert visualisation is an area for further research. This would also improve the understanding of differences between domain-expert visualisation and NEUVis.

Further questions:

- What are additional goals for NEUVis?

- How is NEUVis distributed through social media, and what influences the user's decision to share a visualisation?

- What other tools are helpful for NEUVis?

- What levels of comprehension (that something is visualised, what is visualised, and how is it visualised) are influenced by various design elements in NEUVis? [105]

- How can NEUVis engage users in a state of flow? [169, 51]

- How can NEUVis be designed to create a sense of presence? [126]

- How can pragmatic approaches to the aesthetic experience inform NEUVis design? [158, 131]

As this thesis presents a new approach to visualisation, which is an established field, it is unsurprising that there are many additional areas of NEUVis that holds potential for further exploration. The immediate challenge will be to apply the design methods and tools presented in this thesis, and verify them in different contexts, using different datasets and visualisation formats. The opportunity to benefit the general population by improving the way that scientific data sets are visualised is an interesting area of research. Applying this process to economic, social, political or mathematical data can further distribute the benefit of concentrated efforts required of the creative practitioner creating NEUVis.

The need for transdisciplinary collaboration to produce effective communication of science for non-expert audiences grows as the frontier of science pushes forward. As the boundary of scientific discovery moves further from the domain of general knowledge, the general population will find it increasingly difficult to engage with these issues. Denial of scientific theory or assumption that a scientific "theory" is a matter for debate is already creating difficulties among government policy makers, particularly on the topic of man-made climate change. By accurately and aesthetically communicating complex science through collaborative engagement, NEUVis can act as one tool among many, which can help enlighten the general population. The processes investigated and outlined in this thesis are presented to clarify how, through collaborative visualisation for the non-expert audience the general population can explore, engage and enjoy science.

We are at the very beginning of time for the human race. It is not unreasonable that we grapple with problems. There are tens of thousands of years in the future. Our responsibility is to do what we can, learn what we can, improve the solutions and pass them on.

—Richard Feynman (1955) in The Value of Science, *Engineering and Science*, 19(3).

Index

Bibliography

[1] Ahmed, S. U., Al Mahmud, A., and Bergaust, K. (2009). Aesthetics in Human-Computer Interaction: Views and Reviews. In *Human-Computer Interaction. New Trends*, pages 559–568. Springer.

[2] Akin, Ö. (2008). Creativity in Design. *Performance Improvement Quarterly*, 7(3):9–21.

[3] Amini, F., Henry Riche, N., Lee, B., Hurter, C., and Irani, P. (2015). Understanding Data Videos. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI '15*, pages 1459–1468, New York, New York, USA. ACM Press.

[4] Apple Inc. (2016). Xcode 8 - What's New - Apple Developer. Available from: `https://developer.apple.com/xcode/` [accessed 2016-09-09].

[5] Australian Associated Press (institution) (2013). Climate Council raises $1m through its Obama-style fundraising drive. Available from: `http://www.theguardian.com/environment/2013/oct/05/climate-council-raises-1m-through-its-obama-style-fundraising-drive` [accessed 2016-01-25].

[6] AVL (2016). NCSA's Advanced Visualisation Laboratory. Available from: `http://avl.ncsa.illinois.edu/` [accessed 2016-09-08].

[7] Bailey, J. and Pregill, L. (2014). Speak to the Eyes: The History and Practice of Information Visualization. *Art Documentation: Journal of the Art Libraries Society of North America*, 33(2):168–191.

[8] Barnett, M., Wagner, H., Gatling, A., Anderson, J., Houle, M., and Kafka, A. (2006). The Impact of Science Fiction Film on Student Understanding of Science. *Journal of Science Education & Technology*, 15:179–191.

[9] Bateman, S., Mandryk, R. L., Gutwin, C., Genest, A., McDine, D., and Brooks, C. (2010). Useful junk? In *Proceedings of the 28th international conference on Human factors in computing systems - CHI '10*, page 2573, New York, New York, USA. ACM Press.

[10] Baur, D., Sedlmair, M., Wimmer, R., Chen, Y.-X., Streng, S., Boring, S., De Luca, A., and Butz, A. (2009). Trends in Information Visualization. Technical report, Hauptseminar Medieninformatik WS, Munich.

[11] Bedford, A. (2015). Personas Make Users Memorable for Product Team Members. Available from: `https://www.nngroup.com/articles/persona/` [accessed 2016-04-13].

[12] Beniger, J. R. and Robyn, D. L. (1978). Quantitative Graphics in Statistics: A Brief History. *The American Statistician*, 32(1):1–11.

[13] Benjamin, W. and Jennings, M. W. (2010). The Work of Art in the Age of Its Technological Reproducibility [First Version]. *Grey Room*, 39(1935):11–37.

[14] Bethel, E. W., Childs, H., and Hansen, C. (2012). *High Performance Visualization: Enabling Extreme-Scale Scientific Insight*. CRC Press.

[15] Bishop, A., Lee, E., Walker, K., Andrews, M., and Doherty, S. (2016). New narratives in Science Communication. Available from: `http://2016conf.asc.asn.au/new-narratives-in-science-communication/` [accessed 2016-03-13].

[16] Borkin, M. a., Vo, A. a., Bylinskii, Z., Isola, P., Sunkavalli, S., Oliva, A., and Pfister, H. (2013). What makes a visualization memorable? *IEEE transactions on visualization and computer graphics*, 19(12):2306–15.

[17] Bostock, M. (2015). D3.js - Data-Driven Documents. Available from: `https://d3js.org/` [accessed 2016-07-07].

[18] Boud, D. (2001). Using journal writing to enhance reflective practice. *New Directions for Adult and Continuing Education*, 2001(90):9.

[19] Bradley, M. M. and Lang, P. J. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry*, 25(1):49–59.

[20] Brignull, H. and Rogers, Y. (2003). Enticing people to interact with large public displays in public spaces. In *Proceedings of INTERACT*, volume 3, pages 17–24.

[21] Buchanan, R. (1992). Wicked Problems in Design Thinking. *Design Issues*, 8(2):5.

[22] Burkley, E. and Burkley, M. (2009). Mythbusters : A Tool for Teaching Research Methods in Psychology. *Teaching of Psychology*, 36(3):179–184.

[23] Cairo, A. (2012). *The Functional Art: An introduction to information graphics and visualization*. New Riders.

[24] Cancer Council Queensland (2016). Queensland Cancer Atlas - Cancer Qld. Available from: `https://cancerqld.org.au/research/queensland-cancer-statistics/queensland-cancer-atlas/` [accessed 2016-09-09].

[25] Capossela, F. (2016). Take a Peek at the Artistic Sides of Mosquitoes, Bacteria, and Scientific Processes. Available from: `http://thecreatorsproject.vice.com/en{_}au/blog/mosquitoes-bacteria-computers-watching-movies-online-exhibition` [accessed 2016-09-08].

[26] Card, S. K., Mackinlay, J. D., and Shneiderman, B. (1999). *Readings in information visualization: using vision to think*. Morgan Kaufmann.

[27] Carlile, P. R. (2002). A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development. *Organization Science*, 13(4):442–455.

[28] Carpendale, S. (2008). Evaluating Information Visualizations. In Kerren, A., Stasko, J., Fekete, J.-D., and North, C., editors, *Information Visualization*, volume 4950, chapter 2, pages 19–45. Springer Berlin Heidelberg.

[29] Carpenter, S. and Caraco, N. (1998). Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological Applications*, 8(3):559–568.

[30] Cawthon, N. and Vande Moere, A. (2007). The Effect of Aesthetic on the Usability of Data Visualization. In *2007 11th International Conference Information Visualization (IV '07)*, pages 637–648. IEEE.

[31] Cernea, D., Kerren, A., and Ebert, A. (2011a). Detecting insight and emotion in visualization applications with a commercial EEG headset. In *SIGRAD 2011 Conference on Evaluations of Graphics and Visualization-Efficiency, Usefulness, Accessibility, Usability*, pages 53–60.

[32] Cernea, D., Olech, P., Ebert, A., and Kerren, A. (2011b). EEG-based measurement of subjective parameters in evaluations. *HCI International 2011 Posters*, pages 279–283.

[33] Chang, R., Ziemkiewicz, C., Green, T. M., and Ribarsky, W. (2009). Defining Insight for Visual Analytics. *IEEE Computer Graphics and Applications*, 29(2):14–17.

[34] Chariton, A. a., Court, L. N., Hartley, D. M., Colloff, M. J., and Hardy, C. M. (2010). Ecological assessment of estuarine sediments by pyrosequencing eukaryotic ribosomal DNA. *Frontiers in Ecology and the Environment*, 8(5):233–238.

[35] Charters, E. (2003). The Use of Think-aloud Methods in Qualitative Research An Introduction to Think-aloud Methods. *Brock Education Journal*, 12(2):68–82.

[36] Chen, C. and Czerwinski, M. (2000). Empirical evaluation of information visualizations: An introduction. *International Journal of Human-Computer Studies*, 53:631–635.

[37] Chen, M., Floridi, L., and Borgo, R. (2014). What Is Visualization Really For? In *The Philosophy of Information Quality*, number February, pages 75–93. Springer International Publishing, Cham.

[38] Churchman, C. W. (1967). Guest Editorial: Wicked Problems. *Management Science*, 14(4):B141–B142.

[39] Citraro, D. (2013). Thoughts on Visualizing U.S. Gun Murders. Available from: `http://www.periscopic.com/news/2013/02/thoughts-on-visualizing-u-s-gun-murders` [accessed 19/03/2017].

[40] Climate Council (2016). About - Climate Council. Available from: `https://www.climatecouncil.org.au/about-us` [accessed 2016-09-11].

[41] Conklin, E. J. (2006). *Dialogue mapping: building shared understanding of wicked problems*. Wiley, Hoboken, NJ.

[42] Cook, S. B., Druger, M., and Ploutz-Snyder, L. L. (2011). Scientific literacy and attitudes towards American space exploration among college undergraduates. *Space Policy*, 27(1):48–52.

[43] Cooper, D. (2008). Synchrotron helps artist see the light. Available from: `http://www.abc.net.au/science/articles/2008/03/04/2178347.htm` [accessed 2016-03-20].

[44] Correia, P. R. M., Xavier do Valle, B., Dazzani, M., and Infante-Malachias, M. E. (2010). The importance of scientific literacy in fostering education for sustainability: Theoretical considerations and preliminary findings from a Brazilian experience. *Journal of Cleaner Production*, 18(7):678–685.

[45] Cramb, S. M., Mengersen, K. L., and Baade, P. D. (2011). Developing the atlas of cancer in Queensland: methodological issues. *International Journal of Health Geographics*, 10(1):9.

[46] Credico, G. and Dörk, M. (2014). The Pragmatic's Guide to Casual Information Visualization. pages 1–10.

[47] Cribb, J. and Hartomo, T. S. (2002). *Sharing Knowledge: a Guide to Effective Science Communication*. CSIRO Publishing.

[48] Cross, N. (1982). Designerly ways of knowing. *Design Studies*, 3(4):221–227.

[49] Cross, N. (2001a). Design / Science / Research : Developing a Discipline. In *Proceedings of the Fifth Asian Design Conference: International Symposium on Design Science*, Seoul, Korea. Seoul University.

[50] Cross, N. (2001b). Designerly ways of knowing: design discipline versus design science. *Design Issues*, 17(3):49–55.

[51] Csikszentmihalyi, M. (1975). A Theoretical Model for Enjoyment. In *Beyond Boredom and Anxiety: Experiencing Flow in Work and Play*, chapter 4, page 35. Jossey-Bass Publishiers, San Francisco.

[52] Csikszentmihalyi, M. (1990). *Flow - The Psychology of Optimal Experience*, volume 1. Harper & Row, New York.

[53] CSIRO (2014). The Hungry Microbiome. Available from: `http://www.csiro.au/hungrymicrobiome/` [accessed 2016-09-13].

[54] Deterding, S., Dixon, D., Khaled, R., and Nacke, L. (2011a). From game design elements to gamefulness. *Proceedings of the 15th International Academic MindTrek Conference on Envisioning Future Media Environments - MindTrek '11*, pages 9–11.

[55] Deterding, S., Sicart, M., Nacke, L., O'Hara, K., and Dixon, D. (2011b). Gamification. using game-design elements in non-gaming contexts. In *Proceedings of the 2011 annual conference extended abstracts on Human factors in computing systems - CHI EA '11*, page 2425, New York, New York, USA. ACM Press.

[56] Dewey, J. (1934). *Art as experience.* Perigee Books, New York, New York, USA.

[57] Dillenbourg, P. (1999). What do you mean by 'collaborative learning'? *Collaborative learning Cognitive and computational approaches,* 1(6):1–15.

[58] Discovery Channel (2016). MythBusters | Discovery. Available from: `http://www.discovery.com/tv-shows/mythbusters/` [accessed 2016-03-14].

[59] Dobrian, F., Sekar, V., Awan, A., Stoica, I., Joseph, D., Ganjam, A., Zhan, J., and Zhang, H. (2011). Understanding the impact of video quality on user engagement. In *Proceedings of the ACM SIGCOMM 2011 conference on SIGCOMM - SIGCOMM '11*, page 362, New York, New York, USA. ACM Press.

[60] Doloughan, F. J. (2002). The Language of Reflective Practice in Art and Design. *Design Issues,* 18(2):57–64.

[61] Dörk, M., Feng, P., Collins, C., and Carpendale, S. (2013). Critical InfoVis. In *CHI '13 Extended Abstracts on Human Factors in Computing Systems on - CHI EA '13*, page 2189, New York, New York, USA. ACM Press.

[62] Duke, D., Brodlie, K., Duce, D., and Herman, I. (2005). Do You See What I Mean? *IEEE Computer Graphics and Applications,* 25(3):6–9.

[63] Dunne, D. and Martin, R. (2006). Design thinking and how it will change management education:an interview and discussion. *Academy of Management Learning & Education,* 5(4):512–523.

[64] Duxbury, L. (2012). Breath-taking: Creating artistic visualisations of atmospheric conditions to evoke responses to climate change. *Local-Global: Identity, Security, Community,* 10:34–45.

[65] Eagleman, D. M. (2013). Why public dissemination of science matters: a manifesto. *The Journal of neuroscience : the official journal of the Society for Neuroscience,* 33(30):12147–9.

[66] Einstein, A. (2001). *Relativity.* Taylor & Francis Ltd, 2 edition.

[67] eResearch - The University of Queensland (2009). South East Queensland Health-e-Waterways. Available from: `http://www.health-e-waterways.org/` [accessed 2016-07-01].

[68] Few, S. (2009). *Now you see it: simple visualization techniques for quantitative analysis.* Analytics Press.

[69] Few, S. (2011a). Benefitting InfoVis with Visual Difficulties ? Provocation Without a Cause. *Visual Business Intelligence Newsletter,* (December):1–7.

[70] Few, S. (2011b). The Chartjunk Debate: A Close Examination of Recent Findings. *Visual Business Intelligence Newsletter*, pages 1 − 11.

[71] Fields, B. S. and Centres for Disease Control (2005). Public Health Image Library.

[72] Figueiras, A. (2014). How to Tell Stories Using Visualization. In *2014 18th International Conference on Information Visualisation*, pages 18–18. IEEE.

[73] Fischhoff, B. (2013). The sciences of science communication. *Proceedings of the National Academy of Sciences*, 110(Supplement_3):14033–14039.

[74] Fisher, D. (2010). Animation for visualization: opportunities and drawbacks. *Beautiful Visualisation*, 19:329–352.

[75] Forbes, A. (2013). Media Arts Roles in Art-Science Collaborations. In *Proceedings of the Re-new Digital Arts Festival*, pages 276–282. Re-new Digital Arts Forum.

[76] Forbes, A. G. (2015). Articulating Media Arts Activities in Art-Science Contexts. *Leonardo*, 48(4):330–337.

[77] Gates-Stuart, E. and Nguyen, C. (2015). Understanding Insects: Why Explore Through Science And Art. *Proceedings of the Australian Science Communicators National Conference. 2−5 Feb, 2014, Brisbane, QLD*, (October).

[78] Gershon, N. and Eick, S. (1995). Visualization's new tack: making sense of information. *IEEE Spectrum*, 32(11):38–40, 42, 44–7, 55–6.

[79] Gershon, N. and Page, W. (2001). What storytelling can do for information visualization. *Communications of the ACM*, 44(8):31–37.

[80] Giannetti, C. (2004). {Ä}sthetik des Digitalen: ein intermedi{ä}rer Beitrag zu *Wissenschaft, Medien-und Kunstsystemen*. Springer.

[81] Gold, R. (2007). *The Plenitude*. MIT Press.

[82] Goldacre, B. (2011). Battling bad science. Available from: `https://www.ted.com/talks/ben{_}goldacre{_}battling{_}bad{_}science` [accessed 2016-03-14].

[83] Google (2016). Google Spotlight Stories. Available from: `https://atap.google.com/spotlight-stories/` [accessed 2016-08-13].

[84] Gough, P. (2016). Science of the Unseen: Digital Art Perspectives.

[85] Gough, P., De Berigny Wall, C., and Bednarz, T. (2014). Affective and Effective Visualisation: Communicating Science to Non-expert Users. In *2014 IEEE Pacific Visualization Symposium*, pages 335–339, Yokohama. IEEE.

[86] Gough, P., Dunn, K., and de Bérigny, C. (2016a). Climate Change Education through Art and Science Collaborations. In Wilson, L. and Stevenson, C., editors, *Promoting Climate Change Awareness through Environmental Education*, chapter 2, pages 16–36. IGI Global, Hershey, PA.

[87] Gough, P., Zackeroff, L., and (curators) (2016b). Science of the Unseen. Available from: `http://science-unseen.siggraph.org/` [accessed 2016-09-08].

[88] Greenberg, D. S. (2001). *Science, money, and politics: Political triumph and ethical erosion*. University of Chicago Press.

[89] Guan, Z., Lee, S., Cuddihy, E., and Ramey, J. (2006). The validity of the stimulated retrospective think-aloud method as measured by eye tracking. *… of the SIGCHI conference on …*, page 1253.

[90] Gubser, S. S. (2010). *The little book of string theory*.

[91] Gurney, K., Law, R., Rayner, P., Denning, A. S., and Scientific, C. (2002). *TransCom 3 Final Report*. Department of Atmospheric Science, Colorado State University.

[92] Hall, A. (2013). Climate Commission relaunched as not for profit. Available from: `http://www.abc.net.au/news/2013-09-24/climate-commission-relaunched-as-not-for-profit/4978768` [accessed 2016-01-25].

[93] Halloran, N. (2015). The Fallen of World War II - Data-driven documentary about war & peace. Available from: `http://www.fallen.io/ww2/` [accessed 2016-09-16].

[94] Halloran, N. (2017). Emotional Statistics. Available from: `https://www.youtube.com/watch?v=TCqcpL8F99k` [accessed 19/03/2017].

[95] Heimann, M., Piper, S. C., Ramonet, M., Taguchi, S., and Taylor, J. A. (1996). Variations in modeled atmospheric transport of carbon dioxide and the consequences for CO2 inversions. *Global Biogeochemical Cycles*, 10(4):783–796.

[96] Heller, S. (2006). *Nigel Holmes: On Information Design*. Jorge Pinto Books Inc.

[97] Henschke, C. (2007). (FINALLY AN) ACCELERATED P_ART_ICLE. Available from: `http://henschke.anat.org.au/` [accessed 2016-03-20].

[98] Hernández, N., González, M., and Muñoz, P. (2014). Planning Collaborative Learning in Virtual Environments. *Comunicar*, 21(42):25–32.

[99] Hinchliffe, J. (2016). Dino Zoo at QUT's The Cube allows people to interact with life-sized digital dinosaurs. Available from: `http://www.abc.net.au/news/2016-01-05/walk-with-digital-dinosaurs-at-brisbanes-jurassic-park/7067876` [accessed 2016-01-21].

[100] Ho, K. T., Chariton, A. a., Portis, L. M., Proestou, D., Cantwell, M. G., Baguley, J. G., Burgess, R. M., Simpson, S., Pelletier, M. C., Perron, M. M., Gunsch, C. K., Bik, H. M., Katz, D., and Kamikawa, A. (2013). Use of a novel sediment exposure to determine the effects of triclosan on estuarine benthic communities. *Environmental toxicology and chemistry / SETAC*, 32(2):384–92.

[101] Ho, X., Tomitsch, M., and Bednarz, T. (2015). Conceptualising Inspiration Networks in Game Design. *Transactions of the Digital Games Research Association (ToDIGRA)*, 2(1):36–66.

[102] Hocknull, S. (2015). From dig to digital – breaking the 'rules' of museums | Scott Hocknull | TEDxQUT. Available from: `https://youtu.be/heENXNghbrk` [accessed 2016-01-22].

[103] Hohl, M. (2011). From abstract to actual: art and designer-like enquiries into data visualisation. *Kybernetes*, 40(7/8):1038–1044.

[104] Holmes, N. (1984). *Designer's guide to creating charts & diagrams*. Watson-Guptill Publications, New York.

[105] Holmquist, L. E. (2004). Evaluating the comprehension of ambient displays. In *Extended abstracts of the 2004 conference on Human factors and computing systems - CHI '04*, page 1545, New York, New York, USA. ACM Press.

[106] House, D., Interrante, V., Laidlaw, D., Taylor, R., and Ware, C. (2005). Design and evaluation in visualization research. In *VIS 05. IEEE Visualization, 2005.*, pages 705–708. IEEE.

[107] Hullman, J., Adar, E., and Shah, P. (2011). Benefitting InfoVis with visual difficulties. *IEEE transactions on visualization and computer graphics*, 17(12):2213–22.

[108] Iliinsky, N. (2010). On Beauty. In Steele, J. and Iliinsky, N., editors, *Beautiful Visualisation*, chapter 1, pages 1–14. O'Reilly Media Inc., Sebastpol.

[109] Inbar, O., Tractinsky, N., and Meyer, J. (2007). Minimalism in information visualization. In *Proceedings of the 14th European conference on Cognitive ergonomics invent! explore! - ECCE '07*, number August, page 185, New York, New York, USA. ACM Press.

[110] Kafai, Y. B. (2006). Playing and Making Games for Learning: Instructionist and Constructionist Perspectives for Game Studies. *Games and Culture*, 1(1):36–40.

[111] Keim, D., Andrienko, G., Fekete, J.-D., Görg, C., Kohlhammer, J., and Melançon, G. (2008). Visual Analytics: Definition, Process, and Challenges. In Kerren, A., Stasko, J., Fekete, J.-D., and North, C., editors, *Information Visualization*, volume 4950, chapter 7, pages 154–175. Springer Berlin Heidelberg.

[112] Khut, G. (2011). BrightHearts Research. Available from: `http://georgekhut.com/brighthearts/` [accessed 2016-03-20].

[113] Khut, G. P., Morrow, A., and Watanabe, M. (2011). The BrightHearts Project: A New Approach to the Management of Procedure-Related Paediatric Anxiety. In *OZCHI 2011 Workshops Programme*, Canberra.

[114] Kosara, R. (2007). Visualization Criticism - The Missing Link Between Information Visualization and Art. In *2007 11th International Conference Information Visualization (IV '07)*, pages 631–636. IEEE.

[115] Kosara, R., Drury, F., Holmquist, L. E., and Laidlaw, D. H. (2008). Visualization Criticism. *Computer Graphics and Applications, IEEE*, 28(3):13–15.

[116] Lankow, J., Ritchie, J., and Crooks, R. (2012). *Infographics: The power of visual storytelling*. John Wiley & Sons.

[117] Lau, A. and Vande Moere, A. (2007). Towards a Model of Information Aesthetics in Information Visualization. In *2007 11th International Conference Information Visualization (IV '07)*, pages 87–92. IEEE.

[118] Leach, J. and Medvecky, F. (2014). Why do some people not care about science? Available from: `http://theconversation.com/why-do-some-people-not-care-about-science-22473`.

[119] Leap Motion (2016). Leap Motion | Mac & PC Motion Controller for Games, Design, Virtual Reality & More. Available from: `https://www.leapmotion.com/` [accessed 2016-09-09].

[120] Lee, B., Kazi, R. H., and Smith, G. (2013). SketchStory: Telling more engaging stories with data through freeform sketching. *IEEE Transactions on Visualization and Computer Graphics*, 19(12):2416–2425.

[121] Leinonen, T. and Durall, E. (2014). Design Thinking and Collaborative Learning. *Comunicar*, 21(42):107–116.

[122] Li, H. and Moacdieh, N. (2014). Is "chart junk" useful? An extended examination of visual embellishment. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 58(1):1516–1520.

[123] Lima, M. (2011). *Visual complexity*. Princeton Architectural Press, New York.

[124] Lincoln, Y. S. and Guba, E. G. (1985). *Naturalistic inquiry*. Sage Publications, Beverly Hills, Calif.

[125] Locoro, A., Cabitza, F., Actis-Grosso, R., and Batini, C. (2017). Static and interactive infographics in daily tasks: A value-in-use and quality of interaction user study. *Computers in Human Behavior*.

[126] Lombard, M. and Ditton, T. (1997). At the Heart of It All: The Concept of Presence. *Journal of Computer-Mediated Communication*, 3(2):0–0.

[127] Lopatovska, I. and Arapakis, I. (2011). Theories, methods and current research on emotions in library and information science, information retrieval and human-computer interaction. *Information Processing & Management*, 47(4):575.

[128] Manovich, L. (2011). What is Visualisation. *Visual Studies*, 26(1):36–49.

[129] McCandless, D. (2009). *Information is beautiful*. Collins London.

[130] McCandless, D. (2014). *Knowledge is beautiful*. William Collins.

[131] McCarthy, J. and Wright, P. (2004). *Technology as Experience*. MIT Press, Cambridge, Massachusetts.

[132] McCormick, B. H., DeFanti, T. A., and Brown, M. D. (1987). Visualization in Scientific Computing. Technical report, ACM SIGGRAPH, New York.

[133] McDermott, J. (2012). Screaming Rapture Takes Off. Available from: `http://jasonmcdermott.net/tag/screaming-rapture/` [accessed 2016-05-25].

[134] McGowan, A. H. (1985). Science and the media: The vital connection. *Technology in Society*, 7(4):353–360.

[135] Meirelles, I. (2013). *Design for information: an introduction to the histories, theories, and best practices behind effective information visualizations*. Rockport publishers.

[136] Microsoft (2016). Kinect - Windows app development. Available from: `https://developer.microsoft.com/en-us/windows/kinect` [accessed 2016-09-09].

[137] Moere, A. V. (2005). Form follows Data: the Symbiosis between Design and Information Visualization. In *Proceedings of International Conference on Computer-Aided Architectural Design (CAADfutures'05)*, pages 31–40, Vienna, Austria. OKK Verlag.

[138] Muller, D. (2012). The key to effective educational science videos. Available from: `https://youtu.be/RQaW2bFieo8` [accessed 2016-03-03].

[139] Muller, D. A. (2008). *Designing Effective Multimedia for Physics Education*. PhD thesis, The University of Sydney.

[140] Munroe, R. (2012). Ten Thousand. Available from: `https://xkcd.com/1053/` [accessed 2016-09-12].

[141] Munzner, T. (2008). Process and Pitfalls in Writing Information Visualization Research Papers. In Kerren, A., Stasko, J., Fekete, J.-D., and North, C., editors, *Information Visualization*, volume 4950, chapter 6, pages 134–153. Springer Berlin Heidelberg.

[142] Munzner, T. (2009). A nested model for visualization design and validation. *IEEE transactions on visualization and computer graphics*, 15(6):921–8.

[143] Newell, R., Dale, A., Winters, C., and Alvares, C. (2016). A picture is worth a thousand data points: Exploring visualizations as tools for connecting the public to climate change research. *Cogent Social Sciences*, 2(1):1201885.

[144] Nichols, B. (2010). How Can We Differentiate among Documentaries? Categories, Models, and the Expository and Poetic Modes of Documentary Film. In *Introduction to Documentary*, chapter 6. Indiana University Press, Bloomington, 2nd edition.

[145] Nielsen, J. (1994). Usability inspection methods. In *Conference companion on Human factors in computing systems - CHI '94*, volume 25, pages 413–414, New York, New York, USA. ACM Press.

[146] Nielsen, J. (1995). 10 Usability Heuristics for User Interface Design. Available from: `https://www.nngroup.com/articles/ten-usability-heuristics/` [accessed 2016-02-25].

[147] Noda, T. (2013). SVG-based Sparkline with d3.js. Available from: `http://www.tnoda.com/blog/2013-12-19` [accessed 2016-07-12].

[148] Norman, D. (2002). Emotion & design: attractive things work better. *interactions*, 9(4):36–42.

[149] Norman, D. (2003). 3 ways good design makes you happy. Available from: `https://www.ted.com/talks/don{_}norman{_}on{_}design{_}and{_}emotion` [accessed 2016-02-29].

[150] North, C. (2006). Toward measuring visualization insight. *IEEE Computer Graphics and Applications*, 26(3):6–9.

[151] O'Brien, H. L. and Toms, E. G. (2008). What is user engagement? A conceptual framework for defining user engagement with technology. *Journal of the American Society for Information Science and Technology*, 59(6):938–955.

[152] OpenFrameworks (2016). openFrameworks. Available from: `http://openframeworks.cc/` [accessed 2016-09-09].

[153] OpenNI (2016). Open-source SDK for 3D sensors - OpenNI. Available from: `http://openni.ru/` [accessed 2016-09-09].

[154] Periscopic (2013). United States gun death data visualization by Periscopic. Available from: `http://guns.periscopic.com` [accessed 19/03-2017].

[155] Perry, N. and Benny-Morrison, A. (2013). Support for climate council takes off. Available from: `http://www.theaustralian.com.au/news/latest-news/climate-commission-experts-to-push-on/story-fn3dxiwe-1226725629960` [accessed 2016-01-25].

[156] Peter, C. and Koch, T. (2016). When Debunking Scientific Myths Fails (and When It Does Not): The Backfire Effect in the Context of Journalistic Coverage and Immediate Judgments as Prevention Strategy. *Science Communication*, 38(1):3–25.

[157] Peters, G. (2007). Aesthetic Primitives of Images for Visualization. In *2007 11th International Conference Information Visualization (IV '07)*, pages 316–325. IEEE.

[158] Petersen, M. G., Iversen, O. S., Krogh, P. G., and Ludvigsen, M. (2004). Aesthetic interaction. *Proceedings of the 2004 conference on Designing interactive systems processes practices methods and techniques DIS 04*, (January):269.

[159] Piggott, M. J., Vallotton, P., Bednarz, T. P., and Taylor, J. A. (2013). Accelerated implementation of level set based segmentation. 54:C327–C344.

[160] Plaisant, C. (2004). The challenge of information visualization evaluation. *Proceedings of the working conference on Advanced visual interfaces - AVI '04*, pages 109–116.

[161] Pousman, Z., Stasko, J., and Mateas, M. (2007). Casual information visualization: depictions of data in everyday life. *IEEE transactions on visualization and computer graphics*, 13(6):1145–52.

[162] Processing Foundation (2016). Processing.org. Available from: `https://processing.org/` [accessed 2016-09-09].

[163] Purchase, H., Andrienko, N., Jankun-Kelly, T. J., and Ward, M. (2008). Theoretical Foundations of Information Visualization. In Kerren, A., Stasko, J., Fekete, J.-D., and North, C., editors, *Information Visualization*, volume 4950, chapter 3, pages 46–64. Springer Berlin Heidelberg.

[164] Queensland Museum (2016). Lost Creatures. Available from: `http://www.qm.qld.gov.au/lostcreatures` [accessed 2016-05-21].

[165] QUT (2016). Jurassic genius: digital zoo shows the real world of dinosaurs. Available from: `https://www.qut.edu.au/about/news/news?news-id=101237` [accessed 2016-01-22].

[166] Rittel, H. W. J. and Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, 4(2):155–169.

[167] Rowe, P. G. and Brown, T. (2008). Design thinking. *Harvard Business Review*, 86(6):252.

[168] Russell, B. (2004). *In Praise of Idleness*. Routledge, Abingdon & New York.

[169] Saket, B., Scheidegger, C., and Kobourov, S. (2015). Towards Understanding Enjoyment and Flow in Information Visualization. In Puppo, E., Bertini, E., and Kennedy, J., editors, *Eurographics Conference on Visualization (EuroVis) - Short Papers*. The Eurographics Association.

[170] Salem, B. and Rauterberg, M. (2005). Aesthetics as a Key Dimension for Designing Ubiquitous Entertainment Systems. *The 2nd International Workshop on Ubiquitous Home — Ubiquitous Society and Entertainment*, (c):85–94.

[171] Sand-Jensen, K. (2007). How to write consistently boring scientific literature.

[172] Santow, S. (2010). Scientific Literacy at Risk of Extinction. Available from: `http://www.abc.net.au/news/2010-07-30/science-literacy-at-risk-of-extinction/925484` [accessed 2013-06-03].

[173] Schoffelen, J., Claes, S., Huybrechts, L., Martens, S., Chua, A., and Moere, A. V. (2015). Visualising things. Perspectives on how to make things public through visualisation. *CoDesign*, 11(3-4):179–192.

[174] Schwarz, N. (2000). Emotion, cognition, and decision making. *Cognition & Emotion*, 14(4):433–440.

[175] SciArt Magazine (2016). ON VIEW: "Science Of The Unseen". Available from: `http://www.sciartmagazine.com/blog/on-view-science-of-the-unseen` [accessed 2016-09-08].

[176] SciVis Group (2016). Scivis-Scientific Visualization Unit. Available from: `http://www.scivis.it` [accessed 2016-09-08].

[177] Seccombe, E. (2012). GROW: an investigation of 4D Micro-CT. In Rosengren, M. and Kennedy, C., editors, *Spectra: Images and data in art/science: Proceedings from the symposium SPECTRA 2012*, pages 37–46, Adelaide. Australian Network for Art and Technology (ANAT).

[178] Segel, E. and Heer, J. (2010). Narrative visualization: telling stories with data. *IEEE transactions on visualization and computer graphics*, 16(6):1139–48.

[179] Shneiderman, B. (1996). The eyes have it: a task by data type taxonomy for information visualizations. In *Proceedings 1996 IEEE Symposium on Visual Languages*, pages 336–343. IEEE Comput. Soc. Press.

[180] Shneiderman, B. (2008). Research Agenda: Visual Overviews for Exploratory Search. *Information Seeking Support Systems*, 11:4.

[181] Shusterman, R. (2008). *Body Consciousness: A Philosophy of Mindfulness and Somaesthetics*. Cambridge University Press, Cambridge, UK.

[182] Skau, D., Harrison, L., and Kosara, R. (2015). An Evaluation of the Impact of Visual Embellishments in Bar Charts. *Eurographics Conference on Visualization (EuroVis)*, 34(3).

[183] Skog, T., Ljungblad, S., and Holmquist, L. (2003). Between aesthetics and utility: designing ambient information visualizations. In *IEEE Symposium on Information Visualization 2003 (IEEE Cat. No.03TH8714)*, volume 2003, pages 233–240. IEEE.

[184] Snow, C. P. (1998). *The Two Cultures*. Cambridge University Press, Cambridge, UK.

[185] Star, S. L. and Griesemer, J. R. (1989). Institutional Ecology, 'Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. *Social Studies of Science*, 19(3):387–420.

[186] Stasko, J. (2014). Value-driven evaluation of visualizations. In *Proceedings of the Fifth Workshop on Beyond Time and Errors Novel Evaluation Methods for Visualization - BELIV '14*, pages 46–53, New York, New York, USA. ACM Press.

[187] Steinheider, B. and Legrady, G. (2004). Interdisciplinary Collaboration in Digital Media Arts: A Psychological Perspective on the Production Process. *Leonardo*, 37(4):315–321.

[188] Stephenson, S., Sutcliffe, B., and Chariton, A. (2013). A DNA-based approach for assessing and monitoring benthic communities. In *Coasts and Ports 2013: 21st Australasian Coastal and Ocean Engineering Conference and the 14th Australasian Port and Harbour Conference*, pages 193–197, Sydney. Engineers Australia.

[189] Sterling, B. (2015). ACM SIGGRAPH Art Community, call for submissions: Science of the Unseen: Digital Art Perspectives. Available from: `http://www.wired.com/beyond-the-beyond/2015/12/acm-siggraph-art-community-call-for-submissions-science-of-the-unseen-digital-art-perspectives/` [accessed 2016-09-08].

[190] Stocklmayer, S. (2013). Engagement with Science. In Gilbert, J. K. and Stocklmayer, S., editors, *Communication and engagement with science and technology: issues and dilemmas: a reader in science*, pages 19–38. Routledge Taylor & Francis Group, New York and Abingdon.

[191] Stolte, C. and Hammang, C. (2014). The Hungry Microbiome — colour study. Available from: `https://vizbi.org/Posters/2014/Y21` [accessed 2016-07-17].

[192] Stone, D., Jarrett, C., Woodroffe, M., and Minocha, S. (2005). User Interface Design and Evaluation. *German Research*, 21(3):705.

[193] Suleski, J. and Ibaraki, M. (2009). Scientists are talking, but mostly to each other: a quantitative analysis of research represented in mass media. *Public Understanding of Science*, 19(1):115–125.

[194] Tateosian, L. G., Healey, C. G., and Enns, J. T. (2007). Engaging Viewers Through Non-photorealistic Visualizations. *Proceedings of the Fifth International Symposium on Non-Photorealistic Animation and Rendering (NPAR 2007, San Diego, California, August 4–5, 2007)*, 1(212):93–102.

[195] Taylor, A. (2012). Bright idea speaks volumes. Available from: `http://www.smh.com.au/entertainment/art-and-design/bright-idea-speaks-volumes-20120512-1yixl.html`.

[196] Taylor, J. (2016). *The Art of Visualisation at CSIRO*. Queensland University of Technology, Presentation, Brisbane.

[197] TED (2012). Drew Berry: Animations of unseeable biology. Available from: `https://www.ted.com/talks/drew{_}berry{_}animations{_}of{_}unseeable{_}biology/transcript?language=en` [accessed 2017-02-25].

[198] Telea, A. C. (2014). *Data visualization: principles and practice*. CRC Press.

[199] Ten Koppel, M., Bailly, G., Müller, J., and Walter, R. (2012). Chained displays: configurations of public displays can be used to influence actor-, audience-, and passer-by behavior. In *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems - CHI '12*, number 1, pages 317–326, New York, New York, USA. ACM Press.

[200] The Climate Museum (2015). References. Available from: `http://www.climatemuseum.org/references/` [accessed 2016-05-25].

[201] The Walter and Eliza Hall Institute of Medical Research (2016). Drew Berry-Achievements. Available from: `http://www.wehi.edu.au/people/drew-berry/728/drew-berry-achievements` [accessed 2016-02-25].

[202] Tomitsch, M. (2008). *Interactive Ceiling: ambient information display for architectural environments*. na.

[203] Tory, M. and Moller, T. (2005). Evaluating Visualizations: Do Expert Reviews Work? *IEEE Computer Graphics and Applications*, 25(5):8–11.

[204] Tractinsky, N. (1997). Aesthetics and apparent usability. In *Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '97*, pages 115–122, New York, New York, USA. ACM Press.

[205] Tractinsky, N., Katz, A. S., and Ikar, D. (2000). What is beautiful is usable. *Interacting with Computers*, 13(2):127–145.

[206] Treise, D. and Weigold, M. F. (2002). Advancing Science Communication: A Survey of Science Communicators. *Science Communication*, 23(3):310–322.

[207] Tufte, E. (2006). *Beautiful Evidence*. Graphics Press LLC, Cheshire, Conneticut, USA.

[208] Tufte, E. R. (2001). *The visual display of quantitative information*. Cheshire, CT, 2nd edition.

[209] Tufte Edward, R. (1990). Envisioning Information. *Cheshire (Conn.)*.

[210] Turiman, P., Omar, J., Daud, A. M., and Osman, K. (2012). Fostering the 21st Century Skills through Scientific Literacy and Science Process Skills. *Procedia - Social and Behavioral Sciences*, 59(0):110–116.

[211] Vallandingham, J. (2014). Ask Metafilter Small Multiples. Available from: `http://projects.flowingdata.com/tut/linked{_}small{_}multiples{_}demo/` [accessed 2016-07-12].

[212] van den Haak, M., De Jong, M., and Jan Schellens, P. (2003). Retrospective vs. concurrent think-aloud protocols: Testing the usability of an online library catalogue. *Behaviour & Information Technology*, 22(5):339–351.

[213] van Wijk, J. (2005). The Value of Visualization. In *IEEE Visualization*, pages 79–86. IEEE.

[214] Vande Moere, A. and Purchase, H. (2011). On the role of design in information visualization. *Information Visualization*, 10(4):356–371.

[215] Vande Moere, A., Tomitsch, M., Wimmer, C., Christoph, B., and Grechenig, T. (2012). Evaluating the Effect of Style in Information Visualization. *IEEE Transactions on Visualization and Computer Graphics*, 18(12):2739–2748.

[216] Viégas, F. B. and Wattenberg, M. (2007). Artistic Data Visualization: Beyond Visual Analytics. In *Online Communities and Social Computing*, volume 4564, pages 182–191. Springer Berlin Heidelberg, Berlin, Heidelberg.

[217] Waks, L. J. (2001). Donald Schon's Philosophy of Design and Design Education. *International Journal of Technology and Design Education*, 11(1):37–51.

[218] Ware, C. (2012). *Information Visualization: Perception for Design*. Morgan Kaufmann, San Diego, 3rd edition.

[219] Wong-Parodi, G. and Strauss, B. H. (2014). Team science for science communication. *Proceedings of the National Academy of Sciences of the United States of America*, 111:13658–63.

[220] Yau, N. (2012). *Visualize this!* John Wiley & Sons.

[221] Yi, J. S., Kang, Y.-a., Stasko, J. T., and Jacko, J. A. (2008). Understanding and characterizing insights. In *Proceedings of the 2008 conference on BEyond time and errors novel evaLuation methods for Information Visualization - BELIV '08*, page 1, New York, New York, USA. ACM Press.

[222] Zavrel, E. A. (2011). How the Discovery Channel Television Show Mythbusters Accurately Depicts Science and Engineering Culture. *Journal of Science Education and Technology*, 20(2):201–207.

[223] Zeki, S. (1998). Art and the Brain. *Daedalus*, 127(2):71–103.

[224] Ziemkiewicz, C., Ottley, A., Crouser, R. J., Chauncey, K., Su, S. L., and Chang, R. (2012). Understanding Visualization by Understanding Individual Users. *IEEE Computer Graphics and Applications*, 32(6):88–94.

[225] Zimmerman, J. and Forlizzi, J. (2008). The role of design artifacts in design theory construction. *Artifact*, 2(1):41–45.

[226] Zimmerman, J., Forlizzi, J., and Evenson, S. (2007). Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 493–502. ACM.

Appendix A

Forms used in user studies

A.1   Participant Recruitment Poster

Research Participants Required!

Are you interested in SCIENCE?

This research is the labour of:
Phil Gough - PhD Candidate, The University of Sydney
Dr. Caitilin de Bérigny - Lecturer, The University of Sydney
Dr. Tomasz Bednarz - Research Scientist, CSIRO

What do you mean?

My research is into visualisations of SCIENCE, and I need keen volunteers for user testing.

NO, sir!
I am not interested in science

Very well then.
Perhaps you'd like to visit www.perceiving.info to see what happens when we mix art and science!

Why, YES!
I am interested in science

Are you STUDYING science?

Why do you ASK?

STUDYING science?
Been there, done that
I **AM** a scientist!

That's great, but we are looking for users with a little less expertise than you, but you can check out the project at www.perceiving.info

The visualisations we will test are designed to help non-scientists understand SCIENCE.

Actually, I am a SCIENTIST-TO BE!

SCIENCE? no,
I'm not studying science

That's fine, thanks for reading. If you'd still like to know more, you can visit www.perceiving.info

Great, well YOU'RE just the user I'm looking for!

No thanks,
I'm not THAT interested in science

Where do I SIGN?

But what will I have to DO?

Just send an EMAIL to the address on the tags below, we'll get back to you with the information you need!

We want to know your cognitive (understanding) and affective (emotional) response to different visualisations of SCIENCE. You need to wear a commercial EEG device, and answer some surveys after you view the visualisations.
We're not testing you, we're testing our visualisations.

Sign me up for SCIENCE
contact@perceiving.info

Sign me up for SCIENCE
contact@perceiving.info

Sign me up for SCIENCE
contact@perceiving.info

Sign me up for SCIENCE
contact@perceiving.info

Sign me up for SCIENCE
contact@perceiving.info

Sign me up for SCIENCE
contact@perceiving.info

Sign me up for SCIENCE
contact@perceiving.info

Sign me up for SCIENCE
contact@perceiving.info

Sign me up for SCIENCE
contact@perceiving.info

Sign me up for SCIENCE
contact@perceiving.info

Sign me up for SCIENCE
contact@perceiving.info

A.2 Participant Consent Form

THE UNIVERSITY OF SYDNEY

**Faculty of Architecture,
Design and Planning
Design Lab**

ABN 15 211 513 464

CHIEF INVESTIGATOR

Dr Caitilin de Berigny Wall (onacloV)

Lecturer

Room 279
Wilkinson Building G04
The University of Sydney
NSW 2006 AUSTRALIA
Telephone: +61 2 9351 5933
Facsimile: +61 2 9351 3051
Email: dr.onaclov@sydney.edu.au
Web: http://www.sydney.edu.au/

PARTICIPANT CONSENT FORM

I, ...[PRINT NAME], give consent to my participation in the research project

TITLE: Effective and Affective Visualisation: Communicating Science to Non-Expert Users

In giving my consent I acknowledge that:

1.   The procedures required for the project and the time involved have been explained to me, and any questions I have about the project have been answered to my satisfaction.

2.   I have read the Participant Information Statement and have been given the opportunity to discuss the information and my involvement in the project with the researcher/s.

3.   I understand that being in this study is completely voluntary – I am not under any obligation to consent.

4.   I understand that my involvement is strictly confidential. I understand that any research data gathered from the results of the study may be published however no information about me will be used in any way that is identifiable.

5.   I understand that I can withdraw from the study at any time, without affecting my relationship with the researcher(s) or the University of Sydney now or in the future.

6.   I understand that I can stop the interview at any time if I do not wish to continue, the video recording will be erased and the information provided will not be included in the study.

7.   I consent to:

- Audio-recording   YES ☐   NO ☐
- Video-recording   YES ☐   NO ☐
- Receiving Feedback   YES ☐   NO ☐

If you answered YES to the "Receiving Feedback" question, please provide your details i.e. mailing address, email address.

Feedback Option

Address: _____

_____

Email: _____

....
Signature

....
Please PRINT name

....
Date

A.3   Participant Information Statement

THE UNIVERSITY OF SYDNEY

Faculty of Architecture, Design and Planning
Design Lab

ABN 15 211 513 464

CHIEF INVESTIGATOR
Dr Caitilin de Berigny Wall (onacloV)
Lecturer

Room 279
Wilkinson Building G04
The University of Sydney
NSW 2006 AUSTRALIA
Telephone: +61 2 9351 5933
Facsimile: +61 2 9351 3051
Email: dr.onaclov@sydney.edu.au
Web: http://www.sydney.edu.au/

Effective and Affective Visualisation: Communicating Science to Non-Expert Users

PARTICIPANT INFORMATION STATEMENT

(1)   What is the study about?

You are invited to participate in a study of visualisations designed for non-expert users. This study will compare how different types of visualisations effect the emotion and understanding of information. This research will help us understand the different ways that different types of visualisations have an effect on the general public.

(2)   Who is carrying out the study?

The study is being conducted by Phillip Gough, PhD Candidate and will form the basis for the degree of PhD at The University of Sydney under the supervision of Dr onacloV.

(3)   What does the study involve?

For this study, you will evaluate three different types of visualisations:
1. Static visualisations (infographic)
2. Moving visualisations (3D animation)
3. Interactive visualisations (digital artwork)

For each visualisation, you will be asked to write a few words describing what information you learned, and also describe your emotional reaction to the information. This information will be recorded using a survey.

To help you concentrate on the information, we will video record you watching the moving visualisations and the interactive visualisations. After you have finished, we will watch the videos, and (audio) record you describing how you felt while you were watching or interacting.

In addition to this, during the experiment you will wear commercially produced headset, the Emotiv EPOC. This will measure your subconscious emotional state, including frustration, meditation, engagement, boredom and excitement. This device does not pose any risk of harm, cannot 'read your thoughts' and has been used as a computer interface in many experiments.

All participants will be asked to evaluate the same visualisations.

(4)   How much time will the study take?
We estimate that this study will take around 45 minutes to one hour:
1. Static Visualisation: 3 minutes to view, 5 minutes to give feedback.
2. Moving Visualisation: 5 minutes to view, 10 minutes to give feedback
3. Interactive Visualisation: 5 minutes to view, 10 minutes to give feedback

(5)   Can I withdraw from the study?

Being in this study is completely voluntary - you are not under any obligation to consent and - if you do consent - you can withdraw at any time without affecting your relationship with The University of Sydney.

You may stop the interview at any time if you do not wish to continue, the audio and video recording will be erased and the information provided will not be included in the study.

(6)   Will anyone else know the results?

All aspects of the study, including results, will be strictly confidential and only the researchers will have access to information on participants.

A report of the study may be submitted for publication, but individual participants will not be identifiable in such a report.

(7)   Will the study benefit me?

We cannot and do not guarantee or promise that you will receive any benefits from the study

(8)   Can I tell other people about the study?

Yes! Please forward our email address to them: contact@perceiving.info

(9)   What if I require further information about the study or my involvement in it?

When you have read this information, Phil Gough will discuss it with you further and answer any questions you may have. If you would like to know more at any stage, please feel free to contact Phil Gough (PhD candidate) at contact@perceiving.info

(10)   What if I have a complaint or any concerns?

Any person with concerns or complaints about the conduct of a research study can contact The Manager, Human Ethics Administration, University of Sydney on +61 2 8627 8176 (Telephone); +61 2 8627 8177 (Facsimile) or ro.humanethics@sydney.edu.au (Email).

This information sheet is for you to keep

A.4 Question forms used in user studies

A.4.1 Static Visualisation

Comparing Visualisations: Static Visualisation

These questions are not testing you, they are testing the infographic. There are no correct or incorrect answers.

Cognition

These questions are about how you describe the information in the graphic.

Using your own words, please describe the information the image is showing *

How clear was the visualisation? *

        1   2   3   4   5

Confusing ◯ ◯ ◯ ◯ ◯ Clear

How do you feel the information was represented, in a direct or abstract way? *

        1   2   3   4   5

Direct ◯ ◯ ◯ ◯ ◯ Abstract

When it comes to helping you understand information, how effective is this graphic? *

        1   2   3   4   5

Not effective ◯ ◯ ◯ ◯ ◯ Very effective

This graphic engaged my: *
Choose as many as applicable

☐ Attention
☐ Memory
☐ Understanding of Language
☐ Learning
☐ Reasoning
☐ Problem Solving
☐ Decision Making
☐ None of the above

I feel this graphic will affect me in terms of: *

Choose as many as applicable

- [ ] Attention
- [ ] Memory
- [ ] Understanding of Language
- [ ] Learning
- [ ] Reasoning
- [ ] Problem Solving
- [ ] Decision Making
- [ ] None of the above
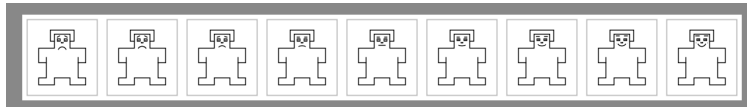
Affect

This section is about how you experience the visualisation through emotions and feelings.

Briefly describe how you were feeling during while reading the infographic

How would you describe your emotional state while reading the infographic

Pleasure

Please indicate which manikin most accurately describes your emotions or feelings while reading the infographic *
This manikin relates to whether this was a negative or positive experience

1 2 3 4 5 6 7 8 9

Unsatisfied ○ ○ ○ ○ ○ ○ ○ ○ ○ Satisfied

Arousal

Please indicate which manikin most accurately describes your emotions or feelings while reading the infographic *

This manikin relates to how relaxed or stimulated you feel

1 2 3 4 5 6 7 8 9

Passive/Calm ○ ○ ○ ○ ○ ○ ○ ○ Active/Aroused

Dominance

Please indicate which manikin most accurately describes your emotions or feelings while reading the infographic *

This manikin relates to how 'in control' you feel

1 2 3 4 5 6 7 8 9

Dependent ○ ○ ○ ○ ○ ○ ○ ○ Dominant

Submit

Never submit passwords through Google Forms.

A.4.2 Moving Visualisation

Comparing Visualisations: Moving Visualisation

These questions are not testing you, they are testing the video. There are no correct or incorrect answers.

Cognition

These questions are about how you describe the information in the graphic.

Using your own words, please describe the information the video is showing *

How clear was the visualisation? *

	1	2	3	4	5	
Confusing	○	○	○	○	○	Clear

How do you feel the information was represented, in a direct or abstract way? *

	1	2	3	4	5	
Direct	○	○	○	○	○	Abstract

When it comes to helping you understand information, how effective is this graphic? *

	1	2	3	4	5	
Not effective	○	○	○	○	○	Very effective

This video engaged my: *
Choose as many as applicable

- ☐ Attention
- ☐ Memory
- ☐ Understanding of Language
- ☐ Learning
- ☐ Reasoning
- ☐ Problem Solving
- ☐ Decision Making
- ☐ None of the above

I feel this video will affect me in terms of: *

Choose as many as applicable

- [ ] Attention
- [ ] Memory
- [ ] Understanding of Language
- [ ] Learning
- [ ] Reasoning
- [ ] Problem Solving
- [ ] Decision Making
- [ ] None of the above

Affect

This section is about how you experience the visualisation through emotions and feelings.

Briefly describe how you were feeling during while watching the video

How would you describe your emotional state while watching the video

Pleasure

Please indicate which manikin most accurately describes your emotions or feelings while watching the video *
This manikin relates to whether this was a negative or positive experience

1 2 3 4 5 6 7 8 9

Unsatisfied ○ ○ ○ ○ ○ ○ ○ ○ Satisfied

Arousal

Please indicate which manikin most accurately describes your emotions or feelings while watching the video *
This manikin relates to how relaxed or stimulated you feel

1 2 3 4 5 6 7 8 9

Passive/Calm ○ ○ ○ ○ ○ ○ ○ ○ Active/Aroused

Dominance

Please indicate which manikin most accurately describes your emotions or feelings while watching the video *
This manikin relates to how 'in control' you feel

1 2 3 4 5 6 7 8 9

Dependent ○ ○ ○ ○ ○ ○ ○ ○ Dominant

Submit
Never submit passwords through Google Forms.

Powered by   This content is neither created nor endorsed by Google.
                              Report Abuse - Terms of Service - Additional Terms

A.4.3   Interactive Visualisation

Comparing Visualisations: Interactive Visualisation

These questions are not testing you, they are testing the artwork. There are no correct or incorrect answers.

*Required

Cognition

These questions are about how you describe the information in the graphic.

Using your own words, please describe the information the image is showing *

How clear was the visualisation? *

	1	2	3	4	5	
Confusing	◯	◯	◯	◯	◯	Clear

How do you feel the information was represented, in a direct or abstract way? *

	1	2	3	4	5	
Direct	◯	◯	◯	◯	◯	Abstract

When it comes to helping you understand information, how effective is this artwork? *

	1	2	3	4	5	
Not effective	◯	◯	◯	◯	◯	Very effective

This graphic engaged my: *
Choose as many as applicable

- ☐ Attention
- ☐ Memory
- ☐ Understanding of Language
- ☐ Learning
- ☐ Reasoning
- ☐ Problem Solving
- ☐ Decision Making
- ☐ None of the above

I feel this artwork will affect me in terms of: *

Choose as many as applicable

- [ ] Attention
- [ ] Memory
- [ ] Understanding of Language
- [ ] Learning
- [ ] Reasoning
- [ ] Problem Solving
- [ ] Decision Making
- [ ] None of the above

Affect

This section is about how you experience the visualisation through emotions and feelings.

Briefly describe how you were feeling during while interacting with this artwork

How would you describe your emotional state while interacting with this artwork

Pleasure

Please indicate which manikin most accurately describes your emotions or feelings while interacting with this artwork *
This manikin relates to whether this was a negative or positive experience

1 2 3 4 5 6 7 8 9

Unsatisfied ○ ○ ○ ○ ○ ○ ○ ○ ○ Satisfied

Arousal

Please indicate which manikin most accurately describes your emotions or feelings while interacting with this artwork *
This manikin relates to how relaxed or stimulated you feel

1 2 3 4 5 6 7 8 9

Passive/Calm ○ ○ ○ ○ ○ ○ ○ ○ Active/Aroused

Dominance

Please indicate which manikin most accurately describes your emotions or feelings while interacting with this artwork *
This manikin relates to how 'in control' you feel

1 2 3 4 5 6 7 8 9

Dependent ○ ○ ○ ○ ○ ○ ○ ○ Dominant

Submit
Never submit passwords through Google Forms.

Appendix B

Infographics used in user studies

B.1 Infographics shown in the first user test

The first test presented the user with 3 infographics.

Changes in the global climate system

DECREASED
Net decrease in glacier volumes[1]

INCREASED
Middle atmosphere temperature

INCREASED
Water vapour

DECREASED
Net decrease in global sea-ice extent[2]

INCREASED
Air temperature over land

DECREASED
Polar ice sheets

INCREASED
Air temperature over ocean

INCREASED
Sea level

INCREASED
Sea-surface temperature

INCREASED
Ocean heat content

Indicators of a world experiencing a consistent pattern of warming.
[1] With regional variation (almost all glaciers worldwide losing mass but some gaining) but overall net loss.
[2] With regional variation (large loss in the Arctic, small net gain in the Antarctic) but overall net loss.

Figure B.1: An infographic shown in user test 1 showing changes in the global climate system.

Figure B.2: An infographic shown in user test 1 showing adaptation solutions for climate change.
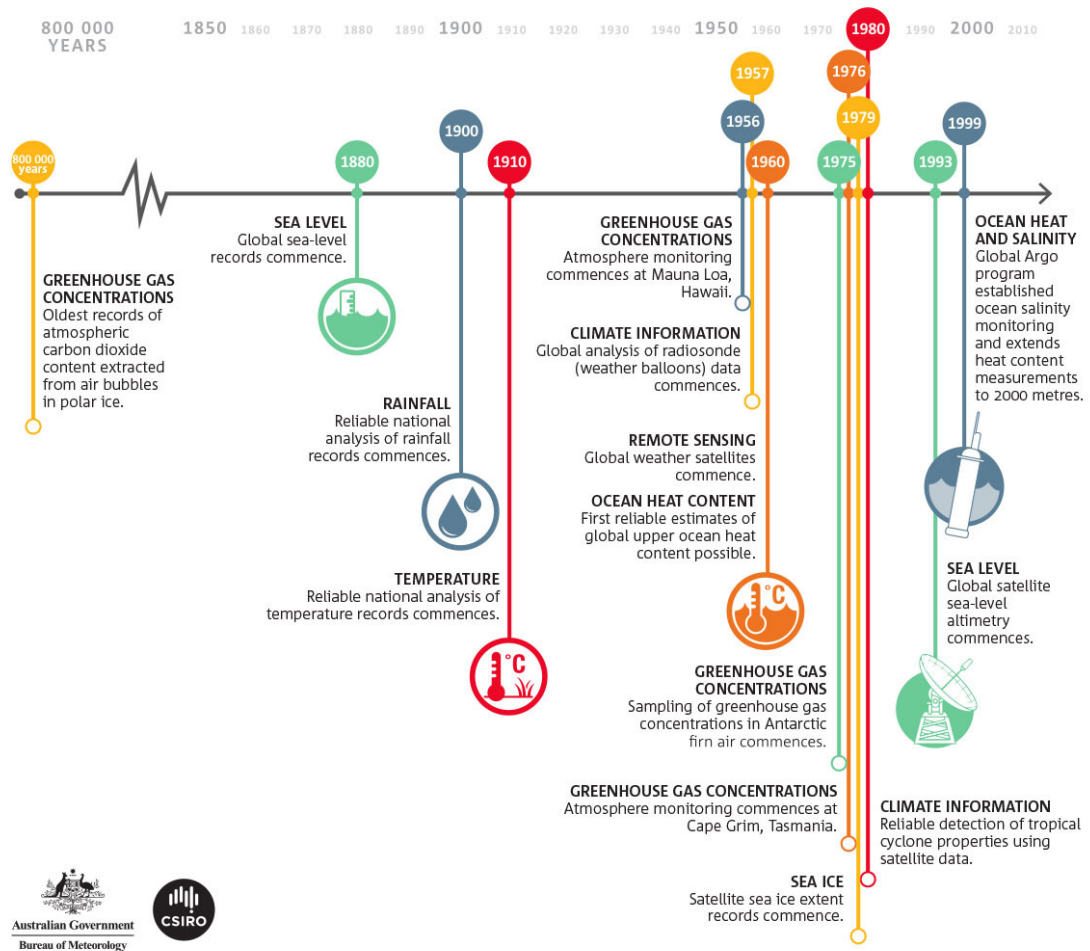
Figure B.3: An infographic shown in user test 1 showing a timeline for climate research.

B.2   Infographic used in the second user test
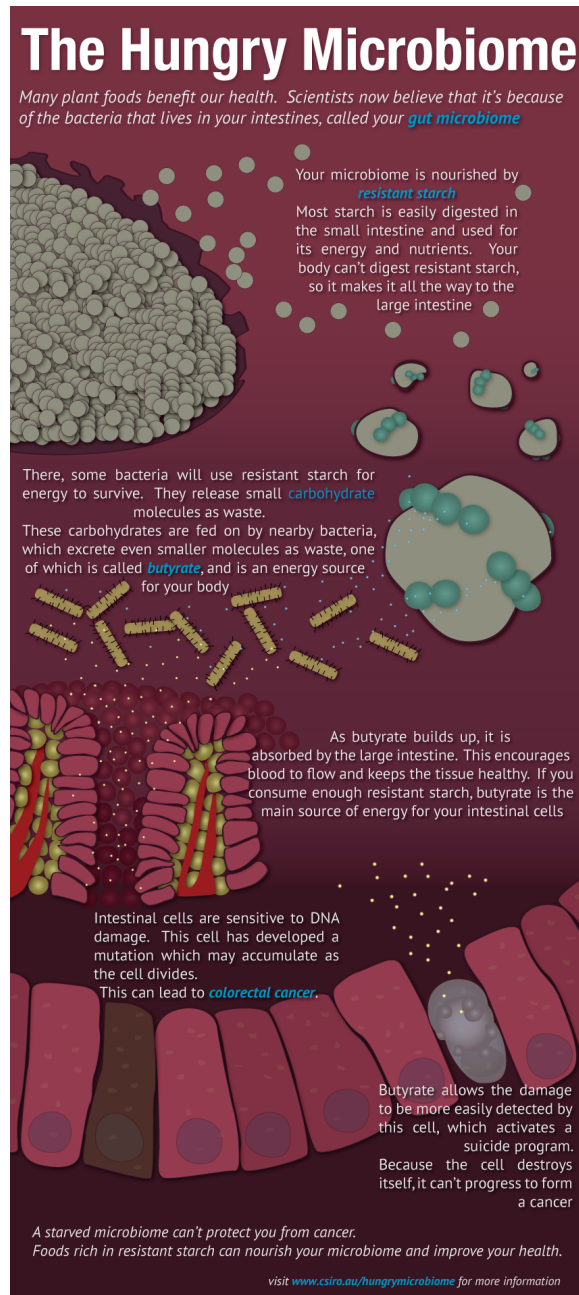
Figure B.4: The infographic version of *The Hungry Microbiome* shown in user test 2.

Appendix C

Research notes and data from user testing

Participant responses were recorded through a google form, shown as a spreadsheet output in section C.1.1 and section C.2.1 for user test 1 and 2 respectively.

Research notes were taken using a simple application made in Processing. The application allows the user to record through the computer's default audio input (a Zoom H4N audio recorder connected through USB was used for this experiment) and type notes simultaneously. It also logs data from the Emotiv Epoc headset, though this function was not used in the actual testing, as the EEG was not used. The application runs in Processing 2.x and can be downloaded from `https://github.com/philgough/EmotivLogger`.

C.1   Test 1

C.1.1   Participant Responses Test 1

Static Visualisation

Timestamp	Using your own words, please describe the information the image is showing	How clear was the visualisation?	How do you feel the information was represented, in a direct or abstract way?	When it comes to helping you understand information, how effective is this graphic?	This graphic engaged my:	I feel this graphic will affect me in terms of:	Briefly describe how you were feeling during while reading the infographic	How would you describe your emotional state while reading the infographic	Please indicate which manikin most accurately describes your emotions or feelings while reading the infographic	Please indicate which manikin most accurately describes your emotions or feelings while reading the infographic	Please indicate which manikin most accurately describes your emotions or feelings while reading the infographic
10/20/2014 12:08:21	The informations are very concise and systematic.	4	4	4	Attention, Learning, Problem Solving	Problem Solving, Decision Making	It wasn't interactive but it was interesting in a way. The informations being conveyed were presented directly. Although, I felt bored at the latter part.	calm but somewhat stimulated	6	4	6
10/20/2014 13:32:15	first image was showing possible future changes / designs to help with the effects of rising temperatures

the second image was showing the changes to rainfall etc. from Global Warming / heating

the third image showed a timeline of monitoring projects through history. | 3 | 2 | 2 | Attention | Attention, Memory | self-conscious about what I was reading. Because of this I felt slightly disconnected from the material due to a less-comfortable environment and knowledge of recording.

The first infographic was a little boring visually because of the colour scheme and the amount of text.

The second infographic was the most engaging and made me much more interested in comprehending the information it was presenting.

The third was also more visually interesting with the first, but felt cluttered and complicated which made me feel less interested. The content as well seemed less interesting and didn't provide further information. Normally if I came seeking information I would like to be able to continue investigating what certain things were or why, which I wasn't able to do through the inforgraphic or in this setting.

The other impact may be that I didn't seek out the information myself, it was presented to me, which affects my motivation and interest. | First - uninterested, reading because of this process. Second - much more interesting and engaging. Third - interesting but bored due to content | 4 | 5 | 6 |
10/21/2014 9:15:26	A short summary of a set of ideas/facts/events related to a topic.	5	4	4	Attention, Memory	Attention	Interested, open to learning information, curious as to what it had to say.	Happy to be reading some interesting information. But my mood wasn't significantly different once reading the information.	7	6	6
10/21/2014 11:25:15	The images are showing methods that may be taken to protect a settlement against climate change, what effect climate change is having on the environment broadly, and how the changing climate has been measured over time. These are three of the most important aspects of climate change, presented in a fairly flat and informative format.	4	1	4	Attention, Memory, Learning	Memory, Learning, Decision Making	I was feeling comfortable and familiar.	The infographics didn't really change my emotional state. Some infographics and media on the subject of climate change attempt to play with the viewers emotions and create a feeling of urgency in them. These infographics did not do that, they were purely informative.	6	5	8
10/21/2014 16:27:07	These schematics refer to the effects and milestones regarding climate change, as well as some possible actions to overcome the problem.	4	2	4	Attention, Learning	Understanding of Language	It depends. The first and the third caught my attention very easily. I was interested about the topic and I wanted to know more, particularly about some information in the infographic n1. However, I felt a bit overwhelmed by the second image. Even though the statements presented were clear, the use of colour seemed confusing and arbitrary.	Well, it's also complicated. Even though I understand you are assessing the images, I was concern about providing useful information. So, I can say there is a little stress factor involved.	6	7	8

Timestamp	Using your own words, please describe the information the image is showing	How clear was the visualisation?	How do you feel the information was represented, in a direct or abstract way?	When it comes to helping you understand information, how effective is this graphic?	This graphic engaged my:	I feel this graphic will affect me in terms of:	Briefly describe how you were feeling during while reading the infographic	How would you describe your emotional state while reading the infographic	Please indicate which manikin most accurately describes your emotions or feelings while reading the infographic	Please indicate which manikin most accurately describes your emotions or feelings while reading the infographic	Please indicate which manikin most accurately describes your emotions or feelings while reading the infographic
10/23/2014 11:39:48	All three images are showing scientific facts by using different visualising techniques. Each of them represents the correlated fact in its own visual arrangement and dependencies. The information they were showing in common was that the people have made aware of climate issues from long ago. The first image shows that a healthily operating society infrastructures such as the transportation tools are depending on a divers range of climate aspects. The second image shows a cycle of how different elements within the natural loop are depending on one another. The third one gives a timeline of the technical breakthroughs on climate related technologies and people's awareness.	4	1	4	Attention, Understanding of Language, Learning	Attention, Learning, Reasoning	The inforgraphics are very intuitive, I feel that I am not impressed.	Very calm, like general learning process such as reading a book.	7	4	5
10/23/2014 14:32:43	the images are showing information about solutions to climate change issues that are current on our plant, it aims to visualize the real world in the first image, in the second image, a less detailed information intensive image, and finally a timeline of events of when various climate change measures or data was recorded.	4	1	4	Attention, Memory, Learning	Reasoning, Problem Solving, Decision Making	I was feeling a sense of motivation and joy that I was able to learn something about the solutions to the changes in our climate.	happy	9	1	4
10/23/2014 15:49:24	It's about the environment, climate change, global warming, melting ice caps, and how we could potentially address the problem.	3	1	2	Attention	Learning	Like I was a student studying a diagram in a geological textbook.	My emotional state was complacent I guess. Neither positive or negative emotions were detected. I was also weirdly not emotionally effected by the infographics.	5	7	8
10/28/2014 13:31:10	All three images generally try and communicate strategies or events impacting climate change or government policy about conservation, built environment, disaster recovery etc.	4	2	4	Attention, Memory, Reasoning	Reasoning	It is hard to become truly affected by graphics and numbers regarding climate change even though I am interested in the area. Illustrations do a good job of conveying the data but remove some of the gravity of the situation, the people it will effect or the environments it will impact. So, informed but not necessarily moved.	The middle infographic does a good job of conveying the number of effects without going into too much granular detail about what specifics (most of the terminology I wouldn't grasp) mean or how they've changed. Maybe that was the one with most impact for me because rapid references to the many things either increasing or decreasing brings home the multifaceted way the environment is changing.	2	3	1
10/28/2014 15:21:28	The images all show information regarding one theme—Climate Change. The first identified a number of 'questions;' while the second focuses on 'trends'. The third, which is my favorite illustrates a historical trajectory within a certain time frame.	5	1	5	Attention, Memory, Understanding of Language, Learning, Reasoning	Attention, Memory, Reasoning	I felt these images are easy to read, and clearly structured.	I would say, comfortable and learnt something.	9	7	5

Moving Visualisation

Gough/Google Drive/PhD/thesis/"73C$_{Volumes_SpinDrive_Google_Drive_PhD_thesis_Appendix_Appendix_BTest1_moving-responses}$

Interactive Visualisation

Gough/Google Drive/PhD/thesis/"74C$_{Volumes_SpinDrive_Google_Drive_PhD_thesis_Appendix_Appendix_BTest1_interactive-respon}$

C.1.2   Researcher Notes

OBSERVATION NOTES TEST 1

USER 1: 20/10/2014 11:49AM

Static Visualisation

11.50.15.366 startedRecording
11.51.26.219 seems engaged
11.51.28.742 *sigh*
11.51.54.705 *sigh*
11.53.46.917 User may have been a bit frustrated from the
difficulty of putting the headset on - it didn't end up working
11.55.15.386 seems more interested in the second one…
11.55.43.227 3rd one
11.56.03.213 using mouse to navigate where she's reading
11.56.52.876 questionnaire
11.59.15.815 Re-reading the infographics on the 2nd question
12.00.38.659 Moves quickly through likert scale questions etc.
12.01.18.514 Affect section
12.01.56.347 keeps deleting and retyping answers… may have
trouble expressing herself verbally in that way
12.02.09.449 not trouble, but just it's different to what she's
used to
12.07.33.316 went back to add something to affect q2
12.08.27.954 done

Moving Visualisation

12.08.34.853 startedRecording
12.09.54.204 Has already seen the video
12.10.28.147 seems more relaxed than the infographic, leaning
back to watch instead of leaning in
12.12.41.746 shows she learned something new - had never heard
of buterate
12.13.20.674 *nodding*

Interactive Visualisation

12.21.43.638 startedRecording
12.25.14.428 Artwork doesn't seem to be behaving as it normally
would…
12.25.46.361 Doesn't use the swipe gesture
12.28.05.700 wasn't interested in the additional data about the
organisms

12.29.06.126 wanted to just hold one finger out in one place, so all the pollution would just be taken out before it reached the ocean
12.29.38.242 stoppedRecording

USER 2: 20/10/2014 1:12PM

Static Visualisation

13.12.14.478 startedRecording
13.13.11.602 1st infographic
13.13.37.467 comments on quality of image
13.13.59.871 laugh*
13.15.20.979 2nd infographic
13.15.30.479 1st is too much text
13.16.06.873 very high-level comparison
13.16.38.583 "Looks like less work to read" the 2nd one
13.17.14.138 3rd infographic
13.17.45.686 does want more info on demand
13.17.57.224 seems engaged with the graphics
13.18.13.615 hand gestures matching comments
13.18.36.161 looking further into information
13.19.20.589 this user may be a 'power user'
13.21.15.444 stoppedRecording

Moving Visualisation

13.32.55.491 startedRecording
13.33.29.827 seems more relaxed. like a passive engagement. Also leaning back like user 1
13.35.17.046 occasional laugh/smiling on changes in scene
13.36.28.070 tapping along with the music
13.36.28.570
13.37.34.769 stoppedRecording

Interactive Visualisation

13.41.03.131 startedRecording
13.42.19.987 engaging with text first - it would be interesting to see what would happen if he didn't have access to the text from the start
13.43.22.302 exploring the interaction
13.43.45.438 not realyl intersted in the actual visualisation at

the moment, more how to contraol it
13.44.46.235 Confused aout the toast
13.46.39.896 hasn
13.47.10.305 hasn't engaged with additional stats, even though
it would seem (from the infographics)
13.51.09.434 waaaaaaaay too many dots to see what is going on
13.54.27.006 more analytical investigation than the first user
13.54.57.563 she wanted to stop the pollution at one point,
rather than explore the "how does it work" of the artwork
14.00.41.442 stoppedRecording

USER 3: 21/10/2014 8:59PM

Static Visualisation

09.00.23.620 startedRecording
09.01.14.264 Seems engaged, leaning in as all the other users so
far
09.03.41.773 The user being in control and going at their own
pace allows more comments
09.03.53.063 seems consistent with other users so far
09.04.30.961 mentions sources: identifies as the power user
09.04.35.786 "more content"
09.05.17.132 "clear and understandable"
09.06.02.133 Engages, leans in, less explicit dialogue as he goes
through the info
09.08.06.764 pointing at the screen
09.08.28.352 points at the bottom of the screen

09.09.59.465 3 infographics, one questionnaire, should make that
clearer

Moving Visualisation

09.15.33.665 startedRecording

09.17.10.716 leans back, folds arms. Other participants have
done this too
09.17.21.624 seems passively engaged

09.21.01.355 using words like 'anxious' - more emotive than the
analytical approach to the infographics
09.21.01.863

```
09.21.04.085
09.22.13.307 Is the content likely to make someone more anxious?
perhaps the relationship with climate change is just as
provocative
```

Interactive Visualisation

```
09.24.07.515 startedRecording
09.24.30.910 "… question about the abstract/direct way"
09.26.04.267 stoppedRecording
```

USER 4: 21/10/2014 11:02PM

Static Visualisation

```
11.02.29.322 startedRecording
11.03.47.242 Noted the source - first user to do so
11.06.19.640 comments on utility for fist image
11.07.43.256 he's being quite objective - but is talking about
engagement
11.08.29.912 number 2
11.08.56.437 effectively representing
11.09.07.573 2nd one gets a more positive response
11.10.24.282 using words like "fear"
11.11.40.462 3rd
11.11.49.750 notes source of each infographic
11.12.44.653 seems very actively engaged
11.12.50.146 but relaxed, taking his time
11.14.53.224 guiding the viewer
11.17.33.688 perspective - giving more information
11.18.22.915 stoppedRecording
```

Moving Visualisation

- no notes taken

Interactive Visualisation

- no notes taken

USER 5: 21/10/2014 4:01PM

Static Visualisation

16.04.39.817 startedRecording
16.05.55.470 leans in like others…
16.06.16.112 reading 1st image
16.08.31.378 focussed in on one topic because of understanding
16.10.19.629 2nd image
16.10.44.342 "overwhelmed"
16.11.24.480 trying to make connection between colours and
groups
16.11.48.085 this thought stemmed from thinking about colour
16.13.00.263 leans in
16.13.10.789 move on to 3rd
16.13.56.318 comparing to 2nd one
16.14.44.775 leaneing in, reading closely
16.15.20.837 squiggle on line
16.15.28.739 pointed out by last user
16.16.26.089 1st
16.17.20.100 2nd one
16.18.19.714 stoppedRecording

Moving Visualisation

16.27.21.611 startedRecording
16.28.52.760 also has more passive body language
16.29.34.680 leaned in
16.31.33.245 "oh really" - indicating insigh
16.31.36.050 *insight
16.31.40.640 leans back
16.32.58.980 seeing yourself from the inside - interesting point
to make
16.33.03.633 stoppedRecording

Interactive Visualisation

16.37.09.248 startedRecording
16.38.48.187 keeping hand on the river
16.39.41.941 much slower to interact with the work than others,
carefully paying attention to what she is doing
16.39.51.097 and how it changes the work
16.40.57.718 holds out thumb instead of pointer as one finger
16.41.18.872 is cleaning the ocean, but it is very difficult
since there is a lot of locations spawning
16.42.34.160 doesn't use swipe gesture
16.43.34.758 holdeing her hand in one place near a waypoint, so

all of the pollution gets cleaned
16.44.22.149 keeps looking at the description, rather than at
the graph
16.45.23.481 some users seem to only focus on one area, either
the 'river' or the 'ocean'
16.46.17.215 stoppedRecording

USER 6: 21/10/2014 11:13PM

Static Visualisation

11.15.38.162 startedRecording
11.15.58.472 first infographic
11.16.18.662 leaning forward, hand supporting head, similar to
most users so far
11.16.51.621 1st infographic, he's gone over all three though
11.16.59.522 switching betwee them
11.18.33.641 2nd
11.20.36.896 most users lean in, even though they zoom into the
image, so maybe there's some body language psycology involved?
11.21.04.605 "the year when I was born"
11.21.24.437 making a connection between himself and the
information? or is this just curiosity
11.22.56.775 making connections between colours - looking for
meaning?
11.23.19.559 thinking about the science
11.23.44.686 the process of science
11.26.51.796 stoppedRecording

Moving Visualisation

11.39.57.471 startedRecording
11.41.19.355 leans back
11.41.22.043 folds arms
11.41.34.155 very similar in terms of behaviour to the other
users
11.41.34.667

Interactive Visualisation

11.49.10.982 startedRecording
11.50.14.894 hands not in the artwork while he started to read.
11.50.26.106 Goes straight to the instructions

11.51.27.850 arms folded. reading
11.51.57.623 found the 1 finger gesture
11.52.01.699 tried to grab
11.52.07.036 exporing what he can do
11.52.25.802 swipe
11.52.37.448 to hide sidebar
11.53.22.606 swiping up,
11.53.27.658 didn't get toast to go down
11.53.31.011 changed hands
11.53.45.421 also moved interaction from the river to the ocean
at the same time
11.54.04.739 false positive: he's grabbing to drop a settlement
11.56.23.459 cleaning a large bit of the pollution
11.56.57.298 keeps going back to the instructions
11.57.10.295 I think they need to be simplified
11.58.31.150 trying to swipe up again. found that he can swipe
the graph down
11.59.07.078 making connection with graph
12.00.04.227 stoppedRecording

USER 7: 21/10/2014 2:16PM

Static Visualisation

14.18.39.495 startedRecording
14.19.48.023 leans forward
14.19.53.208 hands supporting head
14.20.46.885 used the word 'leaflet' - is it somethign that it
meant to be printed
14.21.45.424 image 2
14.23.50.034 3rd image
14.24.09.275 "overwhelming" = probably too much visual
information
14.24.09.786
14.26.35.714 stoppedRecording

Moving Visualisation

14.32.50.574 startedRecording
14.33.29.712 leans back
14.33.50.486 looks more comfortable, takes a drink
14.38.31.571 more interested in the practical applications

Interactive Visualisation

14.43.28.706 startedRecording
14.44.22.606 not going directly to the text
14.44.26.548 more experimenting
14.44.40.808 he's got one finger out
14.44.59.373 this user has experience with the Leap motion
14.45.21.322 it shows in the way he is experimenting with what he can do
14.45.38.098 still hasn't looked at the text
14.46.51.542 has found the cleaning interaction
14.47.12.281 notices text
14.47.21.500 keeps his hand in the space at first
14.49.45.310 found swipe gesture towards the end
14.53.14.733 stoppedRecording

USER 8: 21/10/2014 3:40PM

Static Visualisation

15.42.05.562 startedRecording
15.42.52.883 leaning forward
15.42.56.532 hand supporting head
15.43.05.094 almost all users have had that posture
15.43.12.937 looked at source
15.44.23.609 found something new
15.44.26.779 and surprising
15.44.51.764 tried to highlight text, before JPEG comment
15.45.41.945 he has some expertise with infoVis, so it might be interesting to see what he expects, in contrast to the NEUs
15.48.05.466 He had just come from a meeting - he might be affected by this
15.49.27.703 stoppedRecording

Moving Visualisation

15.49.33.145 startedRecording
15.50.29.659 leans back, more relaxed posture
15.50.33.346 seems engaged
15.53.42.777 *nod*
15.55.00.982 abstract, but informative

15.56.16.434 why does he use the word funny?
15.56.58.565 has seen the video before
15.57.17.227 novelty of 3D animation style

Interactive Visualisation

15.57.51.776 startedRecording
15.58.46.160 doesn't use hand while reading the sidebar
15.59.42.034 has seen it in research visions
15.59.51.520 playing with toast
16.00.44.554 if the leap was in front instead of below
16.01.05.854 investigating the different areas that he can drop the nodes
16.01.27.474 waving hand around to cleap up
16.01.42.181 "it's fun"
16.02.49.942 seemed to enjoy the experience from his body language etc
16.03.00.833 very playful
16.04.14.440 interested in some technical issues
16.04.27.012 described the work as a "simulation"
16.05.16.833 he did seem to be playing
16.06.36.082 identifies the difficulty of 'cleaning up' as part of the game

USER 9: 21/10/2014 1:13PM

Static Visualisation

13.13.55.962 startedRecording
13.14.51.199 leans forward, comfortable, but engaged with the reading
13.15.39.028 gesturing to the screen
13.16.33.977 gestures towards the screen
13.16.52.847 interested in the relationship between the elements

13.17.22.771 leans back
13.17.27.616 2nd infographic
13.18.22.859 leans in to read, leans back after reading it, and gestures towards the screen
13.19.39.862 leans forward to read
13.20.07.345 'irking'
13.20.48.693 that was interesting
13.20.59.119 he hasn't mentioned the source though

Moving Visualisation

13.31.20.116 startedRecording
13.32.09.880 leans back
13.32.43.963 very passiv
13.32.47.011 *passive

Interactive Visualisation

13.44.03.404 startedRecording
13.45.03.448 I think he's looked at the graph
13.45.34.739 looks over to the text
13.45.58.006 hand is over ocean wile he reads
13.47.17.811 wants to "clean" the water
13.47.32.952 made connection with the cleaning metaphor
13.48.38.758 interested in "getting to the source" of what was causing the pollution
13.49.33.113 there's not enough pollution to see the change in the outline of the organism
13.51.28.437 is he "obliged" to clean the water?
13.51.34.067 does he feel compelled?
13.57.14.342 stoppedRecording

USER 10: 21/10/2014 3:09PM

Static Visualisation

15.10.13.891 startedRecording
15.11.10.344 2nd image
15.11.13.184 3rd images
15.11.26.042 leans forward
15.12.07.828 2nd image
15.12.23.195 3rd image
15.12.40.864 seems to be just reading the information
15.14.08.985 prefers one because she identifies with the use of it
15.14.41.661 stoppedRecording

Moving Visualisation

15.21.40.502 startedRecording
15.22.45.282 sits back, gets comfortable
15.26.45.399 stoppedRecording

Interactive Visualisation

15.31.57.223 startedRecording
15.33.31.301 exploring, rather than reading the sidebar
15.34.15.684 placing Lots of settlements, though hasn't made the
connection with the purpose
15.35.09.199 was grabbing to drop a new node
15.36.03.908 not looking for a connection with information that
is being presented
15.36.43.443 a few errors with it only detecting one finger when
the hand is there
15.37.27.481 is dropping as many settlements as she can - not
attempting, or hasn't found how to clean the pollution
15.38.02.882 didn't engage with the text at all so far
15.39.46.635 sees the analogy as trees around a river
15.40.21.271 … with snow
15.40.55.660 hasn't moved her hand fast enough to count as a
swipe gesture yet
15.41.24.215 if she's just exploring, it seems like there's not
much chance she would have found the information.
15.41.34.597 It will be interesting to read her comments
15.42.18.365 she didn't seem to notice the sidebar at all.
15.47.06.513 stoppedRecording
15.47.12.950 startedRecording
15.49.40.798 read text, found one-finger gesture
15.50.22.170 cleaning the pollution fromt he river/ocean
15.54.41.430 at some point she had hidden the graph and didn't
make the connection for 'swipe'
15.54.54.435 wants to be able to reverse the process
15.55.21.118 maybe a more direct representation of the human
settlement, such as a little house??
15.55.35.309 can I do that without it being lame

NOTES ON TEST 1

NOTES ON TESTING ITERATION 1

Static Visualisation (Infographics)

Notes from questionnaire

1. Describe the information in your own words:
   This was pretty simple, there are no surprises

2. How confusing/clear
   Average: 4

3. how direct/abstract
   Average: 1.9

4. How well does it help describe the information
   Average: 3.7

Open-Ended Questions
1. How you were feeling while reading the infographic
   1. One user commented that they may have been affected
      because it was presented to them, rather than something
      they found themselves.
   2. They were also paying attention to things like colour and
      what it represents.
   3. Some user commented that *it is hard to become truly
      affected by graphics and numbers… even though I am
      interested in the area*
      1. Interesting that they assume that they *should* be
         affected.
   4. One user noted that they were happy to be reading
      something interesting, though it didn't affect their
      mood. Another user made a similar comment, that it didn't
      change their mood, yet another found this strange.

Self-Assessment Mannikin
1. Average score of pleasure: 6.1
2. Average score of arousal: 4.9
3. Average score of dominance: 5.7

Interesting words/phrases:
Sense of **motivation** and **joy**

Interesting

Intuitive

like I was a **student**

informed but **not moved**

Comments on Likert Scores
The infographics were generally seen as clear, direct
representations of the information, but not particularly
helpful. It wasn't a particularly pleasurable experience, and
not particularly arousing, but users didn't really feel in
control either.

Think-Aloud feedback and Observer Notes
User 1
Gave most feedback through the questionnaire, rather than
talking.

User 2
Preferred 2nd to first infographic. Was looking at titles of the
first one.

2nd one was **less work**

Expected 3rd infographic to be interactive.

- Wanted to look further into information.
- Wants interaction, described *how* he wanted the interaction
  to work.
- Wants more than **just facts**

General comments on:

- Design factors in general
- colours
- pixelated/JPEG artefacts

User 3
Clear categories, skimmed through headings in #1.

Mentions Facebook feed a few times. He'd expect to find it on FB or follow links from Facebook posts. Image 1 would fit in a FB news feed, where #2 wasn't the same form-factor.

- Wanted to look further into visualisation
- Wants to connect colours
- Assumes social/sharable information
- Wants sources on more minimal presentations/more information available.

User 4
I think this was the only user to notice the sources of the infographics

"It takes a bit of **study**… to get **useful** information out of it"

Comments on design - image is dominated by the text, and the visual features are small.

Got lost on some of the graphic elements and their connection to the image.

Doesn't identify as the audience of #1 - suggests that it could be more direct and engaging.

Sees the point of #1 as to direct the audience to more information

2nd is more effective: communicates more with less information.

"Some of them put **fear** into the viewer" - a lot of people do respond to that. These were more **informative** and for someone who is a **more serious about studying the issues**, rather than someone who isn't really aware.

Identifies with disconnect between something like glacier sheets melting and the difficulty people would have with making the connection

3 REQUIRES A BIT OF READING TO GET MEANING FROM IT

Seems to be learning about the history of study. Timeline is an effective timeline.

"The study of climate change has been accelerating" - finds out this from the timeline

Connection between the modern or space age with increase in climate change research.

3 WAS WELL-PRESENTED AND ENGAGING. IT ISN'T GENERIC.

User 5
What does "sustainable fisheries management" mean?

- Is it longevity of the fisheries?
- Is it fishing less?

2 MADE THE USER FEEL OVERWHELMED

Focusses on individual words, has trouble interpreting some of the language, wants confirmation of meaning of things

Looking for categorisation through colour in #2

Interested in looking at more information

In general, they help the user "to contextualise what's going on with climate change"

User 6
Initial thoughts on #1 - colours, 'clean', mostly designer things. More real-world scenarios.

2 - DIDN'T KNOW WHERE TO LOOK, DOESN'T HELP THE USER AS MUCH. EASIER TO READ, NOT TOO MUCH INFORMATION OR DETAIL.

3 - OVERWHELMING WITH ALL THE DATES. THOUGHT IT WAS *OUTDATED* - BECAUSE THERE WAS MORE TEXT, LESS GRAPHICS

User 7

1 WONDERED WHERE IT WAS FROM AFTER THINKING ANOTHER COUNTRY WAS GOOD AT ONE TOPIC THAT WAS POINTED OUT, NOTICED CSIRO. SEEMED SURPRISED.

Seems to be investigating and comparing what is in the image.

Wants a **key** to show where colours come from in #3 "What is with these colourss?"

User 8

1 COMMENTS ON TERMINOLOGY AND HOW IT RELATES TO HIS EXPERIENCE, PARTICULARLY THE "BUILT ENVIRONMENT"

Well grouped

Comments on design issues

A lot going on, hard to take on what is in there at a glance. Will take a lot of time. Some dissuasion at the beginning. Broken down well though.

2 BY COMPARISON, HAVING NO ORDER/FLOW MADE IT INTERESTING

A key (for increase or decrease) is better than words

3 JUMPING AROUND FOR DATES IS SLIGHTLY IRKING

Saying it is reliable made him question whether it really *is* reliable

congested

Some terminology was not understood

User 9

1 SORT OF MISSED THE POINT

2 WHAT'S GOING ON

3 PREFERRED

Most comments through questionnaire

General Notes on Think-Aloud and Observer Notes
Most users leant forward for the infographics

Most users seemed to want more information available

Generally Positive comments

Direct your audience to more information

Users understand the context, you can't put too much info in

colours = categorisation, people will look for meaning and connections

Most of the infographics are seen as clear

Moving Visualisations (The Hungry Biome, 3D animation)

Notes from Questionnaire

1. Describe the information in your own words:
   Some people got a bit confused here. Nothing major.

2. How confusing/clear
   Average: 4.5

3. how direct/abstract
   Average: 2.6

4. How well does it help describe the information
   Average: 4.7

Open-Ended Questions
1. Generally very positive feedback.
2. Often relating to quite personal feelings about the information, and creates meaning for themselves.
3. Creating understanding of the relationship between the users actions and effects on themselves.
4. one user used the animation as a catalyst to visualise what was happening inside themselves

5. comments on the cohesion between sound and vision, specifically mentioning both the soundtrack and narration
6. specific mention of one scene, showing how resistant starch can prevent cancer.

Self Assessment Mannikin
Average Score for Pleasure: 7.4

Average Score for Arousal: 6.1

Average Score for Dominance: 4.1

Interesting words/phrases used
makes me **happy** to see a vis. of something invisible to the naked eye. Like learning about __another Universe__…

Grew **anxious** as my **awareness** of the reasons I should eat more healthy food became more clear. (but not excessively anxious)

Made me **worried** about not making good decisions…

the voiceover alone wouldn't have sufficed

really impressed with the **clarity** that the sequence of events was able to deliver

interesting and **vivid**

Compelling

engaged, excited, happy, focussed.

Comments on likert scores
It was a clear representation which was very effective in helping the users understand information. It wasn't really perceived as being either direct or abstract, there were some mixed results, since the representation itself can be argued for being both a direct or an abstract representation of what happens - even though it is scientifically accurate.

It was an enjoyable experience, some users didn't feel particularly aroused, but more relaxed, getting the information delivered to them. Users didn't particularly feel 'in control' or dominant, because it was a video, information was presented to them, rather than them exploring it at their own pace.

General notes on Think-Aloud Exercise
Most users didn't comment out loud. Instead they watched the video. One user stopped the video to make a comment (User 4)

Where butyrate is being pumped into the cell, after the description.

Several users showed insight – User 5 said "oh really!" when the suicide program was activated in the cell. User 1 commented that they had never heard of butyrate before. User 3 commented that he was **anxious** about what he was eating as a result, "it **freaks me out**, makes me feel like I've gotta eat some more healthy food", it is something they know, but the video explains *reason* for eating those foods.

Comments from user 4
Commented on how the molecular structures were obviously supposed to look very accurate - they had *gone to the trouble* of making it look like that, rather than just blobs. More abstract, but not a problem, you know what's going on with the illustration. It looks like what you would see under a microscope, but coloured.

Compared the message "eat healthy, and you won't get cancer" that he had heard from other people before. That message seems distant, and this video explains *why*

*I personally really enjoy knowing **why** I'm doing something - I feel kind of weird doing something unless I know what's happening, and what's the cause and effect.*

Seeing that cancerous cell being destroyed by… the good food you're eating is pretty important and engaging

communicates a better lasting message

Not a big deal that they didn't show a lot of specific foods that contain resistant starch, because that information is easy to find. The video was a (the user needs) **hook to engage you** and the rest is not difficult to find out, but you're not going to look for the information if you're not really engaged at all.

Interactive Visualisations (s18 rDNA, Interactive Installation)

Notes from Questionnaire

1. Describe the information in your own words:
   One user didn't notice the text at all, and totally misinterpreted the installation. On the other hand one user made a complete interpretation of the installation; rather than just demonstrating the relationship between the pollution and the organisms, the user established a connection involving human impacts and responsibility.

2. How confusing/clear
   Average: 3.1

3. how direct/abstract
   Average: 3.3

4. How well does it help describe the information
   Average: 3.1

Open-Ended Questions
1. Several comments on the Leap Motion. Some confusion because of a lack of understanding of how it works. This is a point which can be improved
2. Most of the users said that they felt entertained, and that it was an enjoyable experience
3. Users used words such as play and playful
4. Several users One user said they felt "like a kid", and thought it didn't matter if they weren't paying attention, but assumed they were subconsciously learning something.

Interesting words/phrases used
Curious and in **problem solving mode**

confused

[felt] very silly

frustrated with the accuracy

feeling a sense of **joy** and **playfulness**

what I've learned wasn't **entirely helpful** [what was described]

felt like a kid having fun with an installation

entertained, excited, engaged

Self-Assessment Mannikin
Average rating of Pleasure: 6.1

Average rating of Arousal: 7.2

Average rating of Dominance: 4.7

Comments on Likert Scores
No substantial swing towards first three points. This would be
an area to focus improvement.

It scored well in arousal, better than static and moving. Not
particularly strong on other scores.

Think aloud feedback and observer notes
User 1
Asked for direction, read the sidebar first. Read over the
instructions a few times.

Put finger in one place to clean all the contamination before it
gets to the sea. A few users did this.

Hasn't used LM before.

User 2
What is the input and how does it work? - Before he looked at
the leap motion.

Reads text before he puts hand on the screen. Just in case it
goes away.

Has to read text more than once to get the point.

Hasn't used LM before.

Didn't follow interaction system well.

Tried to connect to agriculture specifically, because of change of colours

What does the hand movement in 3D do to the simulation?

They don't want to hold their hand out all the time. Got tired. They said that the text might disappear if they put their hand in (from previous experience) so it might be interesting to use that.

Wants to remove the settlements

Feels he created chaos, because he put in as many settlements as he could at one point.

Paying more attention to the pollution, rather than the organisms living in the water

Gets the point that it's about pollution

Is he making a good/bad judgement?

It's the hidden stuff that they're showing that is really cool (particularly for the video)

Interested in a real example.

Less abstracted maybe?

Curiosity and simplicity, maybe it's good that it isn't too "serious"

Worth another listen. He talked a lot

User 3
Can't recover from errors well.

Noticed that organisms were effected by pollution

The toast bar was't that clear

User 4
Description was **too wordy**

Trying to figure out the scientific process behind the data

Too abstract - has to refer to sidebar to see what's going on.

Missed the point of the Toast, didn't make the connection.

Took to long to learn about the system

Figures out the difference between the organisms

Wants to compare before and after

difficult to compare organisms, possible, but difficult to compare how different organisms respond in different ways

does get the overall point of the work

can't really see the effect is has on the organisms

had to read info a few times, since it's quite abstract

important to have the text there

User 5
"Should I touch this" - leap motion

reading the info - "OMG, so many instructions"

from notes

- much slower to interact with the work than others, carefully paying attention to what she is doing and how it changes the work

- also placed hand near a waypoint, so that they can collect the pollution moving through one point

  can see the metaphor, but it is difficult to fix the problems

  wasn't easy to figure out - easily distracted
  user found some game element, laugh when they figured out to catch all the pollution by cleaning everything as it passes through one waypoint, then frustrated sound when they move their hand slightly and lets some in

User 6
Reads the instructions without hands in the space

found a false positive, was grabbing to drop a settlement

looked for all the ways he could interact, made sure he eventually made the swipe work, from the instructions.

User 7
This user had experience with LM

doesn't look at the text first

creates response, tries to repeat it

had to figure out that 1 finger was a separate interaction

seeing how many dots I can create to **feed** the blue stream

makes connection to graph and the organisms

notices text after 3 minutes

after instructions, tries to clean the water

explores with swipe gestures

User 8
had seen the installation at research visions

reads info

looks over info, "anyway, let's play with this" after thinking
about the gene

had a different mental model of the mapping (x,y,z planes) - his
model was that the leap was in the same plane as the camera,
i.e. the leap was in front of him, rather than below his hand

"Good thing I read, but if I saw this I probably wouldn't read
it, I probably would have just played with it

body language seemed playful, seemed to enjoy the experience

described the work as a **simulation**

User 9
connected the white colour with an increase in salinity, rather
than pollution, but then connected the interaction with
phosphorus

also confused x,y,z planes

made connection with the *cleaning* metaphor

describes it as a game having the pollution to *battle* keeps the
game engaging

User 10
This user didn't read the text at all. Added a LOT of
settlements, saw them as planting trees around a river, and the
dots as snow, didn't find the cleaning gesture at all

"I think the more I make, the more snow there is"

would like an explanation

2ND ATTEMPT
The user didn't notice the description, so I asked her to read
it and then have another go after she filled out the
questionnaire

laughed as she realised the analogy was about pollution of the river

Seems like I can do nothing to change it - no way to reverse the process

Was attracted by the image, didn't notice the text

General comments
Some users seem to focus on one part - either the river or the ocean

Most read the instructions while their hand was being tracked by the LM

only 1 user had experience with LM

Probably would have been a good idea to video record this

Usability Suggestions
3D representation of hand - unused (y?) axis could scale the pointer.

Improve learnability

Improve recoverability

Ideas based just on feedback
Use "game of life" simulation around a city. Similar for the pollution dumped into the river

The log version instead of the toast would work better

ANALYSIS ON TEST 1

OVERALL NOTES AND COMPARISON

Static

Clear, direct representations

Not that helpful.

A few users mentioned Facebook timelines, talked about sharing, and how they would find them

Didn't really move people, they didn't feel that they were compelling

Users wanted them to be interactive

They seem like a good way of leading people to a source of interesting information.

They, generally, didn't really care about the source of the data

Infographics do communicate information though

Too much information can make the user feel overwhelmed, or if it isn't presented well. Especially at a first glance

Generally positive comments from think-aloud exercise and observer notes

They lean in to read

Users find connection between colours, will look for meaning in colours

Good way to direct the audience to more information

Users leaned in, rested their head in their hand. It looked like they were studying, actively searching for information.

Moving

Very clear and helpful way of communicating information. Pleasurable experience

People related it to their personal feelings about the information, making their own understanding and meaning for themselves, and what was happening inside themselves

Users made exclamations that indicated moments of insight ("oh really!")

Users appreciated the reasons why they should be doing something - this is a good medium for doing this. Not inherently better than other methods though, static and interactive methods can do better. The video was described as a "hook to engage you" to explain the difficult concept (how eating good food helps your microbiome protect you from cancer) so the user can go out and find the information that is easy to get themselves (where do I get resistant starch?), but you're not going to find that information if you're not engaged at all.

Overwhelmingly positive comments

Users leaned back, often folded their arms, looked relaxed and passively paying attention.

Interactive

Generally an enjoyable experience, users also said that they felt aroused.

Feelings included a wide range of emotions, pleasure, curiosity, confusion, frustration, playfulness, excited, engaged, "child-like", "problem-solving mode", silly.

Some users understood it and made connections with human impacts on the river, but some didn't make any sense of it at all.

It would be good to improve it by giving more simple information sequentially, since, in general, they read the info before interacting with the work.

It would be also good to separate the didactic information from the information presented to the user in the work

Look out for false positives

General Comments

Users' expectations are high.
If something looks like it could be interactive, they will expect it to be, particularly for infographics. They were very quick to suggest how it should be.

Users' context is significant.
This is the difficulty of this kind of testing. The users related the infographics particularly to sharing and social media, including the format of the image.

Some users also assumed that they were something that is sharable, or that they wanted to immediately find out more information from a website that was included in the visualisation, particularly static visualisations.

Tell the user what they can't find out themselves
The success of the moving visualisation lies with the information they chose to share, and what to leave out. There are two questions addressed in this video:

1. *Why should I eat resistant starch*?
2. *Where do I get resistant starch*?

Question 1 is difficult for a user to answer on their own, even the information on wikipedia about the effect of butyrate on the body is difficult to decipher. The narrative-format of the video explains this information very clearly. But the video does not address the 2nd question. This isn't a problem, as it is very easy to find this information. This gives the a point with which they can engage and take their own steps to continue with that information. Engage the user with insight that is otherwise difficult to get, and let them solve the easy question for themselves.

Users appreciate accuracy
Investing the time in proper simulation and translation of data will make the user feel like their intelligence is being respected. Users noticed when things (particularly in the video) were meant to look very accurate, rather than just showing "blobs" - as if it was what would bee seen under a microscope. The user didn't have, or need any knowledge of the details about what was being shown, but was able to appreciate accuracy, and reacted positively to it.

In saying this, there wasn't a lot of interest in the source of the data; only one user seemed to actively look for the publisher.

Power-users are not the only users
Power users will follow links and find out information on their own if they are engaged.

C.2 Test 2

C.2.1 Participant Responses Test 2

Static Visualisation

Timestamp	Using your own words, please describe the information the image is showing	How clear was the visualisation?	How do you feel the information was represented, in a direct or abstract way?	When it comes to helping you understand information, how effective is this graphic?	This graphic engaged my:	I feel this graphic will affect me in terms of:	Briefly describe how you were feeling during reading the infographic	How would you describe your emotional state while reading the infographic	Please indicate which manikin most accurately describes your emotions or feelings while reading the infographic	Please indicate which manikin most accurately describes your emotions or feelings while reading the infographic	Please indicate which manikin most accurately describes your emotions or feelings while reading the infographic
3/12/2015 12:42:29	The image is showing a series of information describing a particular species of microbes, which live at every human being. At first this bacteria seems to be harmful, but it turns out that it developed a symbiotic co-relation with humans organisms, which is described in the further reading.	4	3	4	Attention, Memory, Reasoning	Attention, Memory, Learning, Reasoning	At first I felt strangely. It's a widely known truth there are organisms living in human bodies, but it's not really flattering or generally a good feeling. However, the further I went with reading the text, there was more and more discoveries being made, which changed my approach, from being a bit disgusted, to actually appreciating the symbiotic relations between humans and specific types of microbes.	At first I felt at unease. After having read more and more the feeling ultimately wore off and I became feeling relaxed and appreciative.	7	8	6
3/13/2015 12:18:49	I felt kinda grossed out by the infographic so I didn't really read it carefully enough to remember what it was about	2	4	4	Reasoning, Problem Solving	Reasoning, Problem Solving	I felt a bit grossed by the infographic, mainly the colours and shapes that the author used gave me an unease feeling.	grossed out, not engaged	4	5	7
3/13/2015 13:27:34	That resistant starches are essential for your large intestines for a few reasons. The infographic traverses through the process of how these starches are broken down in to the real important butyrates. It then goes onto explain that these butyrates are used for the bodies energy (I think) but more importantly aid the body in detecting bad cells - activating a suicide program which allows the cell to be destroyed.	2	3	2	Attention, Memory, Reasoning, Problem Solving, Decision Making	Attention, Memory, Learning	Fairly confused as there was little context I had as a non-medical person between the visuals and the text. I felt like there was something I was missing out on by not understanding what the graphics were communicating vs what the text was communicating.	Confused yet frustratedly interested. The content seemed to be trying to communicate important information to me, but I had very little context as to why it was important. In the end I had to come to the conclusion that these starches were necessary for my health.	3	7	3
3/17/2015 15:06:19	the information the image was showing was the process whereby our body moves starch to the large intestine in order to provide nutrients and nourishment - keeping us healthy and active	2	1	2	Attention	Learning	I felt as if i were reading a textbook, it was informative and direct and also heavily dependant on the text information it was portraying.	neutral	4	3	2
3/17/2015 15:44:04	the diagram is explaining exactly how the human body benifits from eating/consuming plant matter.	4	1	3	Attention, Learning, Problem Solving	Problem Solving	At first i felt overwhelmed as i did not really understand what i was reading, the visual somewhat aided me in my understanding of the text.	i was shocked when i reached the last paragraph as the word suicide stood out to me and i had to go back and re read exactly what i was reading to understand that it was a process happening to the cell not the person.	5	6	6
3/18/2015 12:19:49	Healthy eating can prevent colorectal cancer by nourishing the gut microbiome to which go on to produce butyl (wrong spelling) that are useful in detecting DNA mutation in cells.	4	1	3	Memory, Learning, Reasoning	Reasoning, Problem Solving, Decision Making	For the most past it was quite clear but areas that were parts I felt confused about such as what structures in the illustrations represented. Also, it felt like not all the information was a general summary and could not answer the questions I had from reading it.	Overall quite pleasant, information was in delivered in a bite sized manner separated by imaged.	7	7	4
3/18/2015 13:18:10	The information being shown in the image is describing the mechanism by which the cells within the gut are nourished and kept healthy. It describes the necessary components needed in order to maintain a healthy gut microbiome which leads to an increased protection against certain forms of bowel cancer.	4	3	4	Attention, Memory, Understanding of Language, Learning	Memory, Learning, Decision Making	I was engaged, which was helped via the format of the text being broken up into manageable chunks. The separation of the information made it less intimidating as I could process each section as needed while also taking in the related graphic which assisted my understanding of the text.	I was interested in the content as I am interested in science in general, particularly its ability to improve our lives. Gaining a greater understanding of a mechanism that can lead to cancer is something that I put great value in.	7	5	7
3/18/2015 15:19:00	The image is showing the environment within the human gut and the micro biology that exists. As well as processes of the use of starch.	3	3	4	Attention, Memory, Understanding of Language	Understanding of Language, Learning	It required my full attention to ensure I was remembering terminology and understanding raised concepts. I felt it was very text heavy but understood the pictures related to the paragraphs next to them	Felt like I was working, rather than appreciating the facts, as it required a lot of cognitive attention.	6	5	3
3/18/2015 16:14:46	The image is showing different molecules and how to prevent cancer. It also talks about the tissues that can be damaged and how it can be caused.	4	2	5	Attention, Memory, Understanding of Language, Learning, Reasoning	Attention, Learning, Reasoning	I was curious at first, since I had no knowledge about cells or anything to do with science. So reading through the whole static visualisation, I was getting a more clear idea of what information was presented.	Emotional State: Blank, more so curious as to what is being presented to me.	9	5	8
3/18/2015 17:30:46	How the body digests food and breaks it down in different areas and into smaller and smaller sizes	4	2	3	Attention, Memory	Memory	I was feeling informed in a straightforward way, I felt neutral and did have any reactions to the visualisation	neutral, I felt calm and as i would feel reading any other page in a textbook or area.	6	1	7

Moving Visualisation

Gough/Google Drive/PhD/thesis/"79C$_{Volumes_S pinDrive_G oogle_D rive_p hD_t hesis_A ppendix_A ppendix_B Test2_m oving-responses.pdf"Goug}$

Interactive Visualisation

Gough/Google Drive/PhD/thesis/"80C$_{Volumes_S pinDrive_G oogle_D rive_p hD_t hesis_A ppendix_A ppendix_B Test2_i nteractive-responses.pdf"C}$

C.2.2   Researcher Notes

OBSERVATION NOTES TEST 2

USER 1: 12/03/2015 12:20AM

Static Visualisation

12.21.46.314 startedRecording
12.23.25.781 Leaning forward, head in hand
12.24.22.241 uncomfortable about 'bacteria inside you' - so will
be interesting to see if that impression changes
12.25.59.115 Associates 'bacteria' with 'harmful' - changes this
impression
12.28.41.456 makes connection, but doesn't seem to have the
'aha' moment that the video gave
12.31.09.412 stoppedRecording

Moving Visualisation

12.42.58.107 startedRecording
12.43.36.606 leans back, folds arms

Interactive Visualisation

12.57.08.072 startedRecording
12.58.53.615 Using two hands… had not seen that before
12.59.33.199 notices the hint in the corner
13.00.23.049 just held hands out and missed the intro
13.00.26.132 changes to 1 hand
13.01.15.244 only has his hand in the water area… doesn't seem
to move it outside
13.03.38.659 missed the intro - so doesn't get it
13.03.58.290 maybe would be good to start over…
13.04.36.377 hasn't explored outside the water area much at all
13.06.54.577 leap motion isn't really reliably tracking
13.07.05.601 found he can add new settlements
13.07.32.809 cursour is underneath the waste
13.10.56.155 probably need a more obvious way of showing the
change from happy->sad
13.12.42.650 still finding the connection though - probably
would have made sense if the intro was more clear…
13.14.53.309 probably should have a start button, similar to the
add/remove settlements
13.15.27.910 also, maybe include something to say 'salinity' or
'pollution'

13.16.44.639 or have 2 different coloured graphs
13.18.46.681 reading into symbols I've used, but not making the saltwater/freshwater connection
13.31.05.212 stoppedRecording

USER 2: 13/03/2015 12:07PM

Static Visualisation

12.07.46.647 startedRecording
12.08.07.978 leans forward, using small screen on laptop
12.09.29.894 "gross"
12.09.50.726 visceral reaction
12.10.25.123 looks over the whole infographic before reading
12.10.48.664 actaully is getting it right
12.12.01.095 top 'red bean section'

Moving Visualisation

- no notes taken

Interactive Visualisation

12.33.42.527 startedRecording
12.34.29.559 I think I need 'next' buttons
12.37.13.493 5 fingers didn't work reliably
12.37.25.160 so he hasn't gone outside the water much
12.37.35.302 maybe it's because it's grey
12.39.51.650 maybe substitute hint for a list that lights up?
12.40.17.117 over land : 4 or 5 fingers
12.40.27.451 over water: 1 or two fingers

USER 3: 13/03/2015 1:03PM

Static Visualisation

13.11.50.652 startedRecording
13.15.48.594 exclamation of insight

Moving Visualisation

```
13.27.49.776 startedRecording
13.29.42.894 exclamations of insigh
13.29.45.338 t
13.31.45.548 "ok…"
13.33.20.696 made a similar observation to the discussion I had
with Chris
13.33.45.684 this does confirm some of the assumptions I'm
making about the *way* that information is communicated
```

Interactive Visualisation

```
13.44.57.482 startedRecording
13.48.17.830 very enthusiastic about cleaning pollution
13.49.41.443 the bug where they grow after shrinking should be
fixed
13.50.34.210 he was seated, so it seems that the leap motion
tracks his hand better
13.51.12.240 he's not moving outside the water muchat the start
13.53.00.275 the 'guy' he's talking about reacts to pH
13.55.40.871 very game-like approach
13.56.11.814 stoppedRecording
```

USER 4: 17/03/2015 2:54PM

Static Visualisation

```
14.56.38.703 startedRecording
14.57.36.652 leans forward
14.58.18.954 but hasn't zoomed in, so that may be why
15.01.16.928 seemed to look at an overview, instead of going
through and reading the text - has gone back to look at the text
again, and read closely
15.03.10.787 didn't notice any moment of insight; no somatic
reaction
```

Moving Visualisation

```
15.06.53.750 startedRecording
15.07.24.145 isn't leaning in
15.11.54.924 largely positive comments. Seemed very passive when
he was watching it, I didn't pick up on much in terms of
reactions.
```

Interactive Visualisation

15.16.55.821 startedRecording
15.18.29.626 buttons seem to be working well, it's giving the user a chance to explore the interface as well as the descriptions
15.20.15.688 refers to the hints
15.22.21.930 removed all of the settlements to then see what happened to the organisms
15.24.10.406 doesn't see any objective

USER 5: 17/03/2015 3:35PM

Static Visualisation

15.36.35.356 startedRecording
15.36.56.137 leans in
15.40.35.225 infographic allows the user to go back and re-read something - unlike video, if you miss something, you may not necessarily go back to re-watch it
15.40.54.304 though, I don't think any of the users have had that problem.
15.44.10.070 stoppedRecording

Moving Visualisation

- no notes taken

Interactive Visualisation

15.51.11.660 startedRecording
15.52.20.409 buttons were a good addition
15.53.46.166 still isn't moving hand over the land area much
15.54.00.801 inspecting the organism
15.54.12.519 *forgot to start the video…*
15.54.34.011 *started video*
15.54.42.563 removed the only settlement
15.54.52.805 seems confused, since there's no stated objective
15.56.48.084 perhaps there can be some kind of 'game' element - like a small sim-city type of thing, that way there is a stated objective
15.57.15.057 which will give users the goal of balancing the health of the organisms with the activity of people

USER 6: 18/03/2015 12:06PM

Static Visualisation

12.07.43.126 startedRecording
12.08.59.893 leaning in
12.09.31.496 pointing at the screen
12.09.54.878 2nd image…
12.11.01.567 moving onto the last part of the image
12.12.04.882 hand gestures to screen
12.13.10.547 stoppedRecording

Moving Visualisation

12.19.57.888 startedRecording
12.22.26.634 resting head in hands, but more relaxed
12.22.31.900 seems engaged
12.24.28.711 hand gestures to describe what was going on
12.25.05.384 stoppedRecording

Interactive Visualisation

12.30.02.713 startedRecording
12.30.59.035 I think this is at the point where it needs some sound
12.32.59.591 Before this test, I added the colours to the arc for the organism
12.33.54.247 4 and 5 finger interaction is still buggy
12.34.30.616 tried to hold hand out to catch pollution
12.34.44.250 didn't work, since the hand has to be moving
12.35.40.448 comparison to a game
12.36.11.811 maybe a simple pollution/economy/population score would make it engaging enough?
12.37.10.175 still difficulty finding errors - doesn't seem to know how many fingers are being held up
12.38.34.552 stoppedRecording

USER 7: 18/03/2015 12:59PM

Static Visualisation

13.00.36.310 startedRecording
13.01.13.767 lean in, head in hand
13.02.33.409 read through text, zoomed in, didn't seem to take a
whole overview
13.04.20.517 first and 2nd part of image

Moving Visualisation

13.18.30.704 startedRecording
13.18.47.774 leans back. Relaxed posture
13.19.06.373 seems passively engaged, has prepared to absorb
information
13.21.25.826 there doesn't seem to be the same realisation of
insight

Interactive Visualisation

13.31.06.771 startedRecording
13.38.28.536 he has kept the hand held out the whole time
13.45.26.380 doesn't seem to have picked up that there are 4
different types of organisms being shown
13.46.32.619 even though they're 4 different colours, shown in
different points

USER 8: 18/03/2015 12:06PM

Static Visualisation

15.09.42.263 startedRecording
15.10.18.444 leaning in, slightly, like he is studying
15.10.37.435 zoom in, and read, rather than overview

Moving Visualisation

15.19.22.019 startedRecording
15.20.55.525 sat back, but leaned in to stop the video

Interactive Visualisation

15.30.23.511 startedRecording
15.32.20.137 false positive: the simulation was only seeing one
finger extended
15.34.23.780 the text for the intro was changed for this version

15.42.07.987 makes tacit a good point about going back to the start to refresh the information
15.47.25.847 this version, they paid a lot more attention to the graph, probably because it's right next to the organism
15.50.53.179 doesn't seem to have commented about an 'objective'

USER 9: 18/03/2015 4:04PM

Static Visualisation

16.05.09.524 startedRecording
16.06.57.687 leaning in
16.07.07.446 similar body language to other users

Moving Visualisation

16.15.19.238 startedRecording
16.15.54.923 leaning back
16.16.18.203 passive body language
16.18.44.288 had an expression of insight when the plaque fibres were being formed

Interactive Visualisation

16.24.45.814 startedRecording
16.26.28.396 explored and also went over the introduction
16.30.13.507 the graph is much more important in this version

USER 10: 18/03/2015 5:19PM

Static Visualisation

17.19.53.443 startedRecording
17.20.16.250 Leans in
17.20.52.783 doesn't look at the whole infographic in overview, but focuses on each part
17.21.07.816 butyrate going into cells
17.22.45.164 last paragraph

Moving Visualisation

17.31.31.439 startedRecording
17.32.33.812 more relaxed, leaning forward

Interactive Visualisation

```
17.40.17.981 startedRecording
17.42.48.424 do people not know to hold the hand still??
17.42.57.598 that might explain the way some people couldn't do
it
17.47.27.792 stoppedRecording
```

NOTES ON TEST 2

NOTES ON TESTING ITERATION 2

Static Visualisation (Infographics)

Notes from questionnaire

1. Describe the information in your own words:
   Generally ok, picking up on different keywords, for example: most used
   "butyrate" instead of "resistant starch"

2. How confusing/clear
   Average: 3.3

3. how direct/abstract
   Average: 2.3

4. How well does it help describe the information
   Average: 3.4

Open-Ended Questions
1. How you were feeling while reading the infographic
   1. Visuals were helpful, as well as layout
   2. some users described going from not understanding to understanding
   3. one user was 'grossed out' (also by the video as well) by the biological
      information.
   4. generally had more difficulty following the story.
   5. some users felt overwhelmed (one also said that breaking up information
      meant that the information is less "intimidating")
2. How would you describe your emotional state while reading the infographic
   1. From grossed out/disgusted, confused, neutral to shocked (at the term
      "suicide" being used), and pleasant,
   2. Interested, overall quite pleasant
   3. Responses seem to be quite mixed
   4. 'grossed out' user also stated that they were disengaged

Self-Assessment Mannikin
1. Average score of pleasure: 5.8
2. Average score of arousal: 5.2
3. Average score of dominance: 5.3

Interesting words/phrases:
"understanding a mechanism that can lead to cancer is something that I put great value in"

User 1 noted that they went "from being a bit disgusted, to actually appreciating the symbotic relations between humans and specific types of microbes."

Confused yet frustratedly interested

Comments on Likert Scores
The infographics were generally seen as clear, direct representations of the information, but not particularly helpful. It wasn't a particularly pleasurable experience, and not particularly arousing, but users didn't really feel in control either. This feedback was very similar to the first round of testing - the biggest difference was the 2nd infographic was seen as more clear (0.7 difference). The rest was quite close.

Comparison to the video version of The Hungry Microbiome
Difference between infographic and video scores (infographic - video)

Averages:

1. How clear: –1.2
2. Direct: –0.3
3. Helpful: –1.3
4. Pleasure: –1.6
5. Arousal: –0.9
6. Dominance: 1.2

Median values were very similar for both, showing less deviation between the two styles, except for how "clear" each was. This is not likely to have much of an effect, since there's not a high number of 'odd' values, no outliers

Median scores were all identical, except

Direct/abstract: Experiment 1 more abstract by 1

Effective: Experiment 2 more effective by 0.5

The averages show that the video was seen as more clear and helpful, even though it was no more direct, more pleasurable/satisfying, a little more exciting, but gave the user less sense of control.

Some said that since they didn't have a medical background, it was difficult to follow, whereas on the video version, one users commented positively about the 'science' in the video.

It was noted, that even though there was some realisation, or insight gained, there was no 'aha' moment, or exclamation of insight. User 3 had an 'aha' moment, though this was the only user that had any indication that this was the case - even when other users stated that they learned something new.

Users could re-read the infographic, but none went back in the video. This makes delivery more important in a video context.

Think-Aloud feedback and Observer Notes
User 1
Seemed quite uncomfortable about the idea of bacteria inside of you. But by the end he understood that there was benefit to the relationship. Observer notes states that there was no exclamation of insight, like there was in the video. Is engaging with the infographic, but not really actively, doesn't seem excited. I think there's a different kind or level of engagement here.

Couldn't pronounce butyrate properly from seeing it written (which makes sense), where I assume someone watching the video would have been able to. This is a 2nd level difference.

Thinking about the similarities between the symbiotic relationship between himself and the bacteria and relating it to other natural systems, but not to himself.

User 2
bad audio recording? I think it switched to my laptop microphone, so you can hear when I'm typing, his voice is quite low.

Comments on colours and shapes, notes the 'fleshy' colours,

Is a bit grossed out.

Commenting on flow of infographic.
The observation notes says he actually came to the right to conclusion though

User 3

"not sure what a microbiome is" after reading hearing. "oh" after reading the first paragraph.

"some resistant starch use carbohydrates to survive… is that a good thing or a bad thing"

Interested in process

"I think resistant starches is a good thing, I'm not sure, at this stage"

Exclamation of insight when he reads about the suicide mechanism of the cancer cell.

"so later it tells me that butyrate is a good thing"

User 4

Comments on colours and other design matters, composition etc.

Looks over the infographic, then reads closely. Not the first

"I like it" and explains why.

no 'aha' moment

The survey response was that they felt 'neutral' and 'as if I were reading a textbook' They also leaned in as if they were studying

User 5

Missed something at the end, but is able to re-read information and make sense of it. Possibly was only skimming the text, as he went over it pretty quickly. The use of the word 'suicide' was the only prompt for him to really process the information in the infographic.

User 6

Also leaning in

Found it difficult to make connections between the objects in the infographic and what they represented, was that a starch blob or a bacterium?

Makes a connection between resistant starch and protection from cancer, but doesn't get the details of *how*

User 7
"Interesting"

Most comments are about design issues, what's helpful (grouping, flow, hilighted text etc).

Wasn't paying much attention to the graphics, mostly text, until he realised there was a link

No indication of insight or excitement about what was learned, if anything

User 8
Also zooms in and starts reading, rather than overview - this is only relevant, as the other infographics didn't have much 'overview' they didn't need to be zoomed in.

There's no real 'insight' from this for many users, even though the content is the same.

Mentions that it requires concentration **Did the video version require conentration?** or was it a different kind of engagement?

User 9
More vocal than some of the others

Interesting, it's a nice *story*, it's *informative*

Gets the connection, but there's no similar exclamation of insight

Talks a lot about design issues.

Similar 'studying' body language to other users

User 10
Reads closely, rather than skimming.

Largely visual comments

Only one who commented on the link.

"Familiar" with what he learned at school.

"Looks quite accurate, and sounds quite accurate"

General Notes on Think-Aloud and Observer Notes
They like the way the infographic breaks up the information into chunks and moves around the path. They generally liked the design.

Users often leant forward and 'studied' the infographic, like the original one, though some took more time, and others skimmed the information.

There was a mix of zooming in and reading, and taking an overview first.

Moving Visualisations (Alzheimer's Enigma, 3D animation)

Notes from Questionnaire

1. Describe the information in your own words:

2. How confusing/clear

   Average: 4.7

3. how direct/abstract

   Average: 1.6

4. How well does it help describe the information

   Average: 4.7

Open-Ended Questions
1. Picking up on certain phrases to do with the disease, similarly to how they did in experiment 1, esp "plaques"
2. Generally good descriptions of what the video is showing in terms of the description of the disease, but not much about the "conclusion" of the video, which was that scientists now can use a blood test to identify the onset of alzheimer's disease before symptoms
3. Some personal reflection, but not as vivid as the first one.
   1. "It is a subject I have a keen interest in, as it affects my family as well as

those of many friends"
2.

Self Assessment Mannikin
Average Score for Pleasure: 7.4

Average Score for Arousal: 5.3

Average Score for Dominance: 5.5

Interesting words/phrases used
- felt "discomforted, that this disease [may] happen to me and there's still no cure…" Learning about how the disease progresses "bothered me even more."
- Grossed out
- "I would have struggled to keep up had it just been audio or text"
- "Being able to have a greater understanding of what is happening to those suffering from the disease is of great value to me"
- I felt eager to see the end of the film to see the result, it left me wanting more
- Excited, curios, calm, focussed, pleasant, stressless, easy to understand, eager, drawn in, slight concern, hopelessness

Comments on likert scores
This video was seen as direct, not neither clear or unclear; pleasurable but not arousing, or exciting; not giving the user a sense of dominance or dependence. Likert scores generally matched up with the open-ended responses.

Comparison to scores for The Hungry Microbiome
The videos had a different response to the feeling of "dominance". There was a much wider spread of scores in *The Hungry Microbiome*, which is surprising, and may indicate that dominance when watching a video is entirely subjective, or the term is difficult to understand. The user doesn't really 'interact' with the video, so it may be misleading to put much weight behind this feedback. Experiment 1 had answers from 1 to 9, and experiment 2 had answers from 1 to 8, so I don't see how this can really tell us anything significant. What is more significant was that the answers matched up with the descriptions of the user's own report on their feelings (e.g., someone who used words like "eager" also put high scores for pleasure and arousal)

General notes on Think-Aloud Exercise
User 1

"Not very nice to know" that it can't be cured. "Feel pretty terrible that there is nothing you can do about it", but hopefully they can do something in the future.

Good to acquire new knowledge

Enjoyed the video itself

User 2
no comments made

User 3
"Very different from the infographic - the infographic had a purpose, where is this is something educational" The message from the infographic had a call to action, something for the user to do. Asked the obvious question, where do I get resistant starch, where as alzheimer's disease is just gonna happen, you can't stop it. "But there's a bit of hope"

"[the infographic] was more about 'you should do this… because it will prevent you from getting cancer', whereas this is 'this is how your body works, this is what could happen to you', and because they know this already, they can put more research into it and they understand it better, which is a hopeful thing."

Did have exclamation of insight. (but also did with the infographic)

User 4
Liked how they could show it "in a way that almost seemed tangible" and was 'consumable', and how it didn't have a lot of text - this user commented that the infographic was heavily dependent on text

User 5
No comments made

User 6
Really good, quite clear, even changes of scale.

User 7
"it was great"

"I think I would definitely struggle to understand [the visualisation… if it was just audio"

"…seeing it all in motion, and how it get carried out, is probably one of the only ways I would be able to take that all in, certainly in that space of time." - even compared to if it was text

User 8
Felt more engaged, and felt that the visual/narration helped them understand more effectively than reading text.

It was confusing to try to keep up with the terms introduced in the video.

Can understand the concept, since they can see it, even though feeling a bit lost with more new terminology is introduced. (commented on this in the feedback)

Concept was understandable, but terminology 'gets lost' - did get the point that there was a blood test that can detect the disease.

User 9
Also had exclamation of insight at the same point (when plaques are being formed) as the previous user.

"It was clear"

There was a story

Compared to image: video was more informative

User 10
Exclamation of insight, and brought up that point in the comments after (when plaques were forming, and zoomed out)

"Nice, really clear visualisation, really good video"

"It was really informative"

"I'll understand more about alzheimer's from it"

Very enthusiastic

General notes

Users seemed pretty relaxed, similar, but not exactly the same body language as the first video. This one was shown on a 60" plasma, instead of a HD projector, but is a similar scale when viewing distance is taken into account.

Some users explicitly stated they preferred the video format to the infographic.

Comparison to *The Hungry Microbiome* Video
Users were very positive about both videos, and expressed that they thought that the videos were more efficient (easier to understand in the same amount of time) at explaining the concepts. Neither videos were of the style of the highly technical videos, but even some of the terminology in *Alzheimer's Enigma* could get lost, as stated by some users. A few users also had a moment of insight around the point where the explanation of plaques built up outside the cell by forming the fibres. This was the 'climax' of the story, but another sequence was added on to the end of the video, and it doesn't seem to make sense to have it there. Most of what people expressed about their understanding from video was about the disease, not that there is now a test for it.

The major difference was that there was a separation between the users and the context, or, rather, in *The Hungry Microbiome* the users were expressing deep, personal connections to the data, which didn't happen with *Alzheimer's Enigma*. It was that it was something to learn about, even though it affects a lot of people. Perhaps it is because everyone eats, but not everyone has alzheimer's, or is concerned that it will happen to them. But some users say that it has affected their family, so maybe this isn't the best reason?

Another reason may be that there is a perception that Alzheimer's disease is not as bad, or not preventable (at least you can do something about bowel cancer according to *THM*), so as *THM* says what the user can do (eat resistant starch), it gives something the user can engage with on a more personal level, rather than *AE*, which doesn't have.

It is interesting that there was no similar personal connection between this *AE* and the user, because in *THM* users stated that they were imagining it happening inside their own body. There was no suggestion of this kind in *AE*.

THM has the climax of the video (the mechanism of how you are protected from cancer by eating resistant starch) followed by a short call to action, and then finishes, on a high note.

AE has a climax (returning full-circle with plaque fibres in the brain), without a call to action, but another sequence which takes users away from the information, which feels like a footnote (by the way, there's a test that we can do which can see it decades in advance) on the last page of a novel.

The users seemed to be engaged with the medium, but after watching *AE* did not express that they were engaged with the message as much as with *THM*.

One thing of note was that in *THM*, several users expressed that they felt the video engaged or would influence their decision making, where as this was not selected with *AE* - since after watching it, there was nothing to *do*.

Interactive Visualisations (s18 rDNA, Interactive Installation)

Notes from Questionnaire

1. Describe the information in your own words:
   Users generally described the data accurately. The introduction probably helped that.

2. How confusing/clear
   Average: 2 1/3 - Pretty clear

3. how direct/abstract
   Average: 3.8

4. How well does it help describe the information

   Average: 3
   Scores seemed to be pretty similar to the original version. I think the response was better because the user was forced through a short introduction.

Open-Ended Questions
1. Description of what was being visualised generally pretty good.
2. "Overall the representation was pretty cool"
3. Novelty through the interface was noted, but also frustration with it.
4. Interactivity made the user want to figure it out, like using the system was a pay-off for dealing with some of the issues.
5. A few users said that they were confused when they started. But they kept going with it, so there might be something more in that.
6. Users found it 'fun' and 'engaging'

Interesting words/phrases used
- "At first I was confused what I was dealing with, but after I learned how it works I started to rationalise and comprehend the whole nature of this project. In the end however I think I felt indifferent"
- fun, exciting, curious, engaged, confused, interested

Self-Assessment Mannikin
Average rating of Pleasure: 7

Average rating of Arousal: 7

Average rating of Dominance: 7

Comments on Likert Scores
Very similar to the first, with the exception that users felt more dominant, more in control.

Think aloud feedback and observer notes
User 1
Used 2 hands, I think that was the only time that happened. Eventually changed to one hand.

Didn't really pay attention to the intro, and doesn't really get what's going on.

Takes almost 10 minutes to figure out that you can add a settlement

Gets the pollution effect, but maybe note the fresh/salt water effect

User 2
Stayed inside the water area most of the time

Comments on usability issues

User 3
"It's some kind of game"

Wanted to stop the pollution coming into the river.

Spent a lot of time cleaning the pollution

[By this point I had found some bugs that needed fixing]

User 4

Added some interface fixes to slow down the introduction. This means the user can't accidentally skip the information at the start.

Removes all settlements to see what happens to the organisms.

"I just don't understand what it wants me to be doing"

"...am I amining to achieve anything?"

Added lots of settlements, removed them, then just added a few

User 5

Constructs understanding by reasoning out the introduction and the interaction.

"From what I read prior to doing this activity..." describes pollutants flowing through the estuary.

"I would say that I understand the least, *but*, if I were to read something" and confirm what they were thinking, it would be easier to link the information and the actions

Added a few and removed them, leaving one

User 6

Compared cleaning the pollution to fruit ninja - maybe that is a kind of 'game' approach I could use?

Focussed on keeping the water clean. Didn't add many settlements

User 7

The system stopped working at some point and had to restart.

This user seemed confused about an objective too.

Added lots of settlements, then cleaned it all, and removed settlements, then added one or two.

User 8

Playing around with the interface before going through the entire introduction.

Exclamaition of insight, when he finds the scales

Uses these to make the connection between the organisms and their type. Though it was still confusing.

Also changed between adding lots of settlements and removing them and exploring the effect on the simulation

User 9
Explored the introduction before going to the simulation

Had difficulty adding the sttlements, so it was restarted twice

User 10
Also had difficulty adding settlements.

Explored cleaning with first settlement, then added a lot of settlements, observed that pollution increased, then removed all of the settlements, because it was too hard to clean. Removed all settlements then explored graphs with just one settlement active at a time.

General comments
A few users asked if there was an 'objective' or goal, but didn't seem disappointed that the

Usability Suggestions
Users don't necessarily hold their hand over the leap motion - a light or something might help that.

Updates after user 3 were good.

Some sound could help.

Users liked being shows what you can do.

Ideas based just on feedback
Something with an objective might be more interesting, adding a "fruit ninja" element to the mix might be good.

ANALYSIS ON TEST 2

OVERALL NOTES AND COMPARISON
Static

Users generally found the infographic to be helpful and clear, but had generally neutral feelings about its performance. Users didn't seem to be particularly excited about them. There seems to be little difference between the responses for the first and second ones.

Many users reported that the infographic engaged their attention, memory, and learning (for both this seems to hold true). The second one also engaged their understanding of language, perhaps because of the terms used. Few said it will affect them in terms of decision making, so it may be that this is not a good way to help people make decisions? But they did feel that they engaged with something, and learned from it, and might remember something about it, which would not be out of line with other research into infographics.

They also behaved as if they were studying; many leaning in. What users seemed to value was the access to information. Users were able to give a pretty good general description, in their own words, of what was going on. Some were better than others, and they picked up on different keywords to the video: infographic was 'butyrate', video was 'resistant starch'

Only one user had an 'aha' moment, where many did in the video version. I think this is worth mentioning because may people say the main focus of visualisation is 'gaining insight'.

Many users zoomed in to start reading, without taking an overview of the whole infographic before doing so, but it was a bit of a mix. Many also commented that it required a lot of concentration, rather than just attention. They liked the way that text was broken up.

I feel as the infographics are a bit 'take it or leave it'. They don't seem to have anything compelling going for them. In terms of their production cost, they are probably an effective means of communicating science to the general population, but I don't see how it will engage people enough, that they're going to really change anything they do. This goes down to context for users and objectives at the communicators' end.

Moving

Responses are very positive, as with the first experiment. Much more than the infographic. It provoked curiosity, and no users said anything about having to concentrate to follow the information. They were able to parse the information and describe it in their own words fairly well.

There was a few notable differences in the response to the two videos:

1. Personal Reflection was limited
    1. *AE* viewers made personal connections with the data, but not to the same extent, or as vividly and explicitly as the users who watched *THM*.
    2. There was less personal reflection and identification with the data overall - even though both related to human anatomical processes.
    3. Perhaps it was because the content was different, if brain processes are less familiar to the non-expert user than digestion. Maybe they find it easier to identify with that information and relate it to themselves.
2. Narrative structure in the two videos was different:
    1. *THM* - Scientific explanation, climax (cell with DNA damage commits suicide), call to action, credits.
    2. *AE* - Scientific explanation, climax (plaque is formed around the cell, returning the video to the start), explanation of tests which help early detection, credits.
    3. The difference is that there is no call to action in the second video, and a segment after the climax in the narrative.
    4. One user commented that it was about learning information, rather than about something they could do. This implied that they didn't see any way that they could go and find something to potentially protect them from developing Alzheimer's disease.

Interactive

This version was much clearer, and had abetter interaction system, but still was confusing at the start. Forcing the users to select their way through the introduction was a good change after the 3rd user.

It was a playful and enjoyable experience for most of the users, the interface making it 'fun' and 'engaging'.

The final version should have a narrative, or objective. Users commented that it is game-like, so it might be a good idea to explore that a bit more.

The final version should also include what I have learned from the other approaches - applying them to my own practice.

Data
How does this new knowledge benefit the viewer?
Broader understanding of human impacts on the environment.

What about this data is relevant, or important to the viewer?
Impact of human activity. How things are in balance in the environment.

What information is inaccessible to the user?
What different kinds of organisms live in these environments, and how they react to different conditions. Also how strong the reaction is, where the reactions to pollution occurs (at what concentration).

The gradient between the fresh/salty water and the clean/polluted water

What information is easily accessed by the user?
Pollution is bad, how to clean up or change habits to reduce impact.

What myths can be addressed?
Pollution kills everything? Actually some organisms thrive in polluted water.

User Needs
This is an installation that may be useful for a museum or art gallery, so there is no impetus for the user to engage. Novel information and interaction systems may be useful to get the user to interact with the installation.

The user needs had a level of curiosity, but no explicit stated objective in this situation. The objective of museums is to share scientific, cultural or other artefacts for the education and enlightenment of the general public. With no explicit objective it leaves the message open for artistic exploration.

http://australianmuseum.net.au/blogpost/museullaneous/what-are-museums-for

This project may be useful for museum contexts where there is an education program or education focus, particularly on biology, or river systems. (See the Australian Museum and NSW Art Gallery websites)

The message

Does pollution kill?

This work will address this question through an engaging interactive experience.

It will address this by comparing the **natural** gradient of salinity in an estuary to the **man-made** gradient of phosphorus (pollution), to show how some organisms thrive in salty or fresh water, and some flourish in clean or polluted water.

Appendix D

List of Exhibitions

D.1   Creative Work Submitted for Examination

18S rDNA (2016)

Interactive Projection.
    OpenFrameworks
    Microsoft Kinect
    A video demonstration of the interaction is also available at `https://youtu.be/OyIGzpOlgZU`

D.2   Other Creative Works Undertaking During Candidature

Science Of The Unseen (2016)

Co-curator, online exhibition organised by ACM SIGGRAPH Digital Arts Community.
    Exhibition is hosted online by ACM SIGGRAPH at `science-unseen.siggraph.org`

Altered Books: Digital Interventions (2015)

Collaboration with Xavier Ho to produce abstract representations of public domain books.
    Processing
    Python with NLTK

Founders Circle (2014)

Generative video work created as an ambient animation for an event held for the Founders Circle at The University of Sydney.
    Digital Video
    Processing
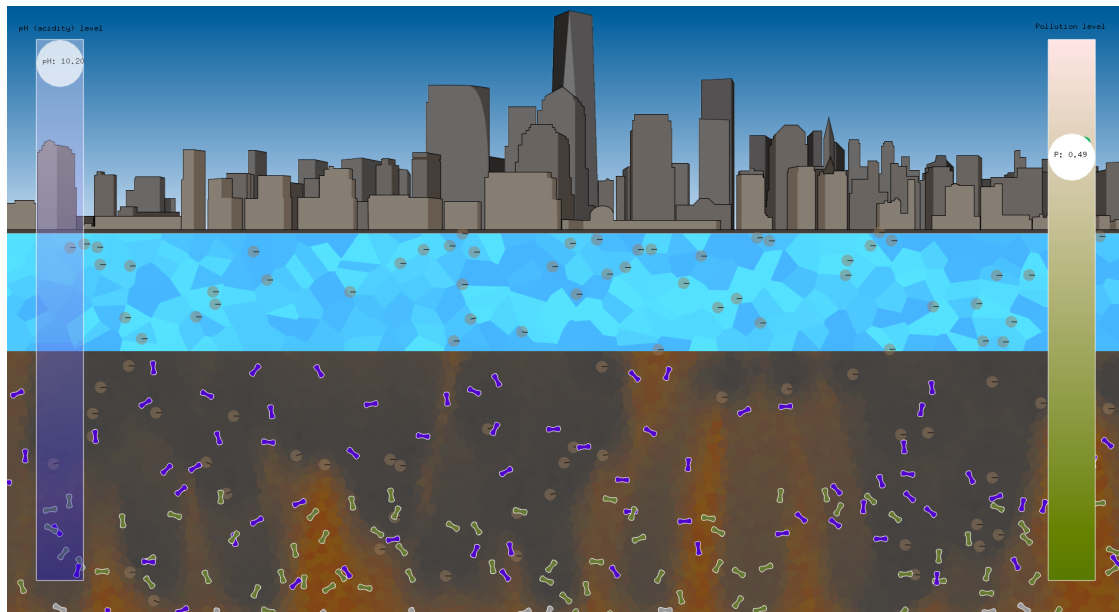   Custom Poisson Point distribution library for processing.
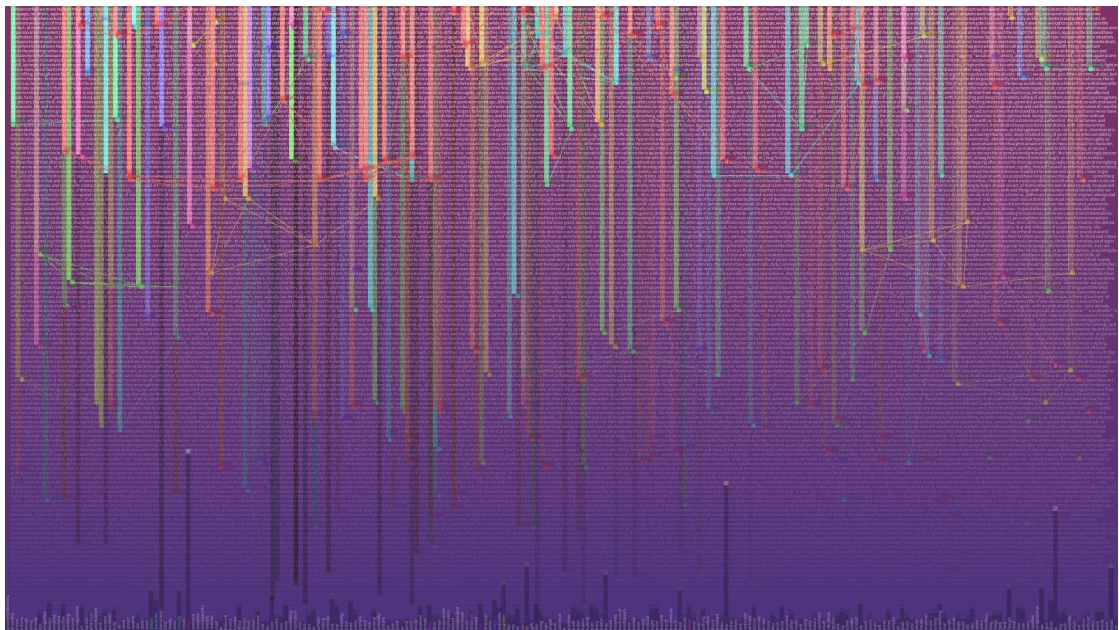
Figure D.1: *18S rDNA* (2016)

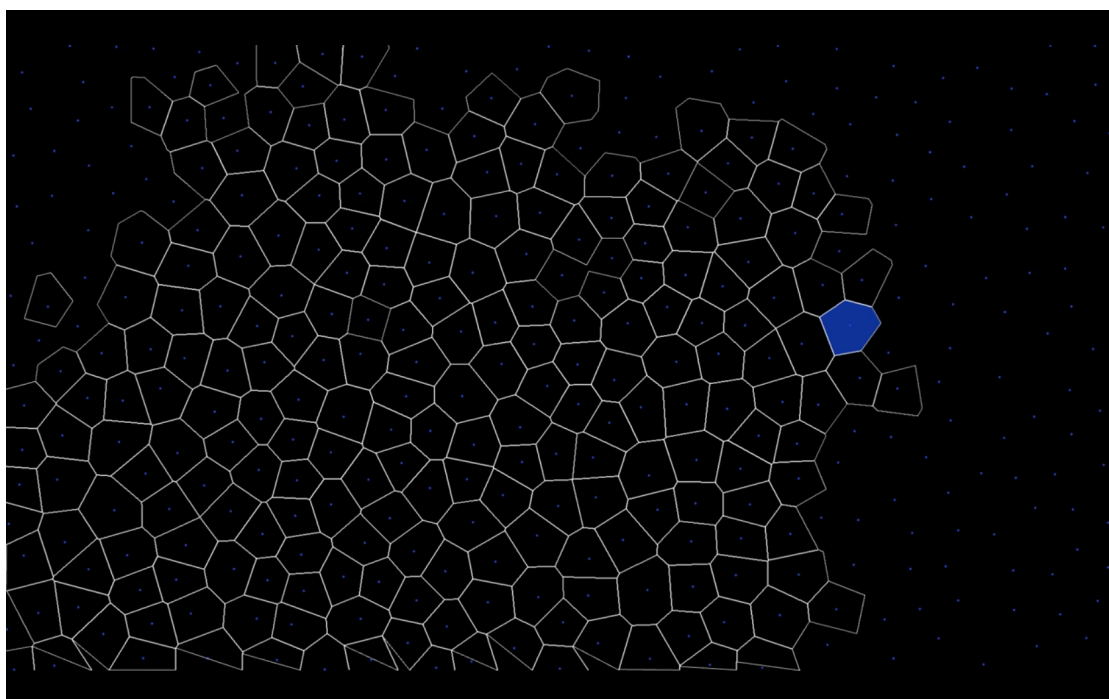Figure D.2: *Altered Books: Digital Interventions* (2015)

Figure D.3: *Founders Circle* (2014) Animation

Collaborative Mapping **(2014)**

Kate Dunn, John McEwan and I created this interactive artwork as part of the Expanded Architecture exhibition in Sydney, October of 2014. It is inspired by collaborative works between Harry Seidler and various artists that were undertaken during the design of several prominent buildings around Sydney, and Australia.

> Large-scale, interactive projection mapped onto the wall of the atrium at Grosvenor Place, Sydney.
> Microsoft Kinect
> Processing.

Personal Care? **(2013)**

Static data visualisation created in collaboration with Xavier Ho, based on the experimental data from [100]. Shown at OzViz 2013 in the CAVE2 at Monash University, Melbourne.

> High Resolution CAVE2 (27320 x 3072 pixels)
> Processing
> Photoshop

Figure D.4: *Collaborative Mapping* (2014)

Figure D.5: *Personal Care* (2013)

Appendix E

List of Publications

List of all publications and selected presentations during PhD.

E.1   2016

Roberts, J., Gough, P., (2016) Communicating Statistical Uncertainty to Non-Expert Audiences, Accepted extended abstract at Big Data and Visual Analytics (BDVA'16), IEEE.

Bown, O., Tomitsch, M., Gough, P., (2016, Forthcoming) Learning Design Through Facilitating Collaborative Design: Incorporating Service Learning into a First Year Undergraduate Design Degree Course. In *Collaboration and Student Engagement in Design Education*. IGI Global, Hershey, PA.

Gough, P., (2016). *[ACM SIGGRAPH Theater Events] Science of the Unseen: Digital Art Perspectives*, Panel, ACM Siggraph 2016, Los Angeles.

E.2   2015

J. Bullard, M. Ley, J. Hagedorn, R. Desaymons, W. Griffin, J. Terrill, Q. Hu, S. Satterfield, and P. Gough, (2015) Direct Comparisons of 3D Hydration Experiments and Simulations, in *Proceedings of the 6th Advances in Cement-based Materials: Characterization, Processing, Modeling and Sensing*, Manhattan, Kansas, July 20, 2015.

Hagedorn, J., Bullard, J., Desaymons, R., Griffin, W., Terrill, J., Ley, T., Hu, Q., Satterfield, S. and Gough, P., (2015) HydratiCA: A Parallelized Numeric Model of Cement Hydration, Poster presented at *Extreme Science Engineering Discovery Environment 2015 Conference (XSEDE'15)*, St. Louis, Missouri, July 26-30, 2015.

Gough, P., Dunn, K., & de Bérigny, C. (2016). Climate Change Education through Art and Science Collaborations. In L. Wilson, & C. Stevenson (Eds.) *Promoting Climate Change Awareness through Environmental Education* (pp. 16-36). Hershey, PA: Information Science Reference. doi:10.4018/978-1-4666-8764-6.ch002

Dunn, K., Gough, P., (2015) Collaborative Mapping. In *Bauhaus Edition: Expanded Architecture — Temporal Spatial Practices*. Bauhaus Dessau and Spurbuchverlag, Bamberg.

Gough, P., Dunn, K., Bednarz, T., Ho, X., (2015) Art and Chartjunk: A Guide for NEUVis. *International Journal of Software and Informatics*, 9(1), 61-72.

Gough, P., (2015). *Comparing Visualisation Approaches to Communicating Science to Non-Scientists*, Presentation at SIGGRAPH 2015 Conference, Los Angeles.

E.3   2014

Gough, P. (Accepted for publication, November 2014). From the Analytical to Artistic: A Review of Literature on Information Visualization. *Leonardo*, 141105103503000. http://doi.org/10.1162/LEON_a_00959

de Bérigny, C., Gough, P., Faleh, M., Woolsey, E., (2014). Tangible User Interface Design for Climate Change Education in Interactive Installation Art. *Leonardo* 47:4, (pp 451, 456).

Gough, P., Ho, X., Dunn, K., & Bednarz, T. (2014). Art and Chartjunk. In *Proceedings of the 7th International Symposium on Visual Information Communication and Interaction - VINCI '14* (pp. 171–177). http://doi.org/10.1145/2636240.2636852

Gough, P., De Berigny Wall, C., & Bednarz, T. (2014). Affective and Effective Visualisation: Communicating Science to Non-expert Users. In *2014 IEEE Pacific Visualization Symposium* (pp. 335–339). Yokohama: IEEE. http://doi.org/10.1109/PacificVis.2014.39

Gough, P., 2014, *The Missing Link Between Design and Science: Creating a Design Understanding for NEUVis*, Presentation at OzVis 2014, QUT, Brisbane

Gough, P., 2014, *The Chartjunk Debate for Dummies*, Presentation at Computational and Simulation Sciences and eResearch, Annual Conference, CSIRO, Melbourne,