Entanglement:

An investigation into the effective union of contemporary art and science communication

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Supervisors: Professor Heather Galbraith, Dr Marcus Moore

Technical Advisor: Stuart Foster

By

Claire Hughes

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Figure 1. Claire Hughes, *Entangled* Screenshot.

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Richard (Dick) Taylor
Heather Galbraith
Marcus Moore
Stuart Foster
Massey University

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I dedicate this work to my husband Dick Taylor.

Video clips of *Entangled (*2018) and *Matter Matters* (2017) can be found at:

https://vimeo.com/344684177

https://youtu.be/31VkfcDJSAo

Webpage: https://clairehughesart.wordpress.com

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Abstract

Virtual reality (VR) technology is increasingly providing opportunities for new contemporary art experiences. This creative practice research has been developed to provide one such contribution. It offers innovative employment of the immersive capabilities of VR to engage with and convey complex scientific theories, and to stimulate changes in mental processes to unlock these concepts. The research highlights empirical similarities between art and science to propose that creative aspects of art can be considered proximate to the creative qualities required to understand quantum theories.

In order to reveal this, the body of research engaged specifically with quantum entanglement, because of its well documented existence[1] combined with the more challenging considerations of *how* 'communication' can occur at a quantum level. By providing metaphoric immersive experiences of quantum entanglement, a contribution of 'scientific communication' is made as defined by the evocation of awareness, enjoyment, and interest, questioning of opinions and providing new perspectives of understanding.[2] This research posits that there is a fertile, effective terrain to explore in the union of the fields of contemporary art and science communication.

Considerations of constructivist theories of knowledge and the concept of paradigm shifts[3] are used whereby new insights into knowledge processes can be experienced through VR art. Here, simulacra, cognitive dissonance and the technological sublime afford a framework to create experiences of conflicting realities. It is due to the immersive strengths of VR which are exploited and subverted through my designs that these experiences can be facilitated for the viewer.

The culmination of this research is *Entangled,* a VR art installation which provides interplays between virtual and physical spaces while also offering entry-points to contemplate and understand quantum theories. Critical analysis of this project is supported by focus group and questionnaire responses. These findings prove how viewers perceived the project as an aesthetic art work and that by recognising scientific underpinnings, an effective engagement and participation in elements of scientific communication occurred at varying levels.

[1] References to the proven existence of quantum entanglement are provided in section 1.6.

[2] This definition of scientific communication is expanded in section 1.1.

[3] Paradigm shifts are times when the familiar framework has to be profoundly changed. This is discussed in detail in section 1.3.

The work provided new perspectives on the properties of quantum entanglement. This facilitated cognitive and experiential awareness providing opportunities for viewers to encounter conflicting knowledge systems. The challenge in this creative practice research was to create aesthetic experiences that contravene common sense reasoning and provide insights into the type of thought processes and experiential perception that is required to deepen and expand our understanding of our physical reality. In the present era of an evolution of super-technologies, now past its nascent stage, *Entangled* offers exposure to the types of interfaces that this thesis asserts will increasingly be encountered when comprehending our reality in the 21st century and beyond.[4]

[4] Quantum entanglement is only one possible area that will cause our experience of reality to change radically. For example biotechnologies, nanotechnologies, artificial intelligence (AI) and human/AI interfaces to name some.

Introduction

The focus of this creative research is the development of artworks that can allow bodily experiences of metaphoric quantum entanglement and the opportunity to experience a conflicting change of knowledge systems. The research aims to exploit new capabilities of virtual reality (VR) to provide bodily and cognitive experiences within exhibited art works, that audiences in New Zealand rarely encounter in gallery, museum or entertainment sectors. The audience of my work has various unique encounters, both in physical and virtual spaces and I argue that these aesthetic encounters can help to explain and embody scientific theories and principles of quantum entanglement.

"Working out another system to replace Newton's laws took a long time because phenomena at the atomic level were quite strange. One had to lose one's common sense in order to perceive what was happening at the atomic level."[5] Richard Feynman

"For creativity, the focus shifts to generating novel interpretations and novel categorizations … In this regard, it has been shown that these structural and functional similarities, which are very helpful in commonsense reasoning, become a major impediment to creativity."[6]

Indurkhya and Ojha

The illusive topic of common sense was famously discussed over many years by philosopher Ludwig Wittgenstein and logician Alan Turing.[7] Today 'common sense' is a key topic in

[5] Richard Phillips Feynman, *QED : The Strange Theory of Light and Matter*, Alix G. Mautner Memorial Lectures (Princeton, N.J. : Princeton University Press, c1985, 1985), 5.

[6] Bipin Indurkhya and Amitash Ojha, 'An Empirical Study on the Role of Perceptual Similarity in Visual Metaphors and Creativity', *Metaphor and Symbol* 28, no. 4 (2013 2013), 234.

[7] Juliet Floyd, 'Turing on "Common Sense": Cambridge Resonances', in *Philosophical Explorations of the Legacy of Alan Turing: Turing 100*, ed. Juliet Floyd and Alisa Bokulich, Boston Studies in the Philosophy and History of Science (Cham: Springer International Publishing, 2017): 103–49, https://doi.org/10.1007/978-3-319-53280-6_5

discussions on artificial intelligence, where it is considered to be the missing critical factor.[8] Many attempts have been made to define common sense and I take Lui et al's definition from their paper, *ConceptNet — A Practical Commonsense Reasoning Tool-Kit* that sums up common sense as the, "millions of basic facts and understandings" that people accumulate.[9] As suggested by physics Nobel Prize winner, Richard Feynman, there are occasions when common sense needs to be queried in the sciences. Consider Einstein's theory that time slows down near the speed of light. This defies common sense because we have understandings of time as a constant. But mathematical proof and experimental measurement have proven Einstein to be correct.[10] Many studies have investigated methodologies to mitigate the conventional constructs of common sense reasoning to create original contributions. Methodologies such as divergent or lateral thinking and making the familiar strange are suggested to remove the impediments of common sense reasoning to allow creativity.[11] [12]

I contend that in order to understand the complexities of quantum physics creative thinking is important.[13] Research indicates that changes in thought processes will be required to understand current and new theories of our physical reality.[14] While scientific areas such as climate change and medical vaccinations receive comparatively large funding for

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[8] David Gunning, 'Machine Common Sense Concept Paper', *ArXiv:1810.07528 [Cs]*, 17 October 2018, http://arxiv.org/abs/1810.07528 .

[9] H. Liu and P. Singh, 'ConceptNet — A Practical Commonsense Reasoning Tool-Kit', *BT Technology Journal* 22, no. 4 (1 October 2004): 211, https://doi.org/10.1023/B:BTTJ.0000047600.45421.6d.

[10] Atomic clocks have been flown around earth and have shown a time difference to clocks on the ground. Papers such as J. C. Hafele and Richard E. Keating, 'Around-the-World Atomic Clocks: Observed Relativistic Time Gains', *Science* 177, no. 4044 (14 July 1972): 168–70, https://doi.org/10.1126/science.177.4044.168.

[11] Non-linear techniques such as brainstorming.

[12] Indurkhya and Ojha, 'An Empirical Study on the Role of Perceptual Similarity in Visual Metaphors and Creativity', *Metaphor and Symbol 28 no. 4,* 234.
In particular are de Bono's thinking hats which require different types of thinking. Schellens et al state that these are useful for creating new ideas. Tagging thinking types in asynchronous discussion groups: effects on critical thinking T. Schellens , H. Van Keer , B. De Wever & M. Valcke

[13] See Appendix 6 for definition of quantum physics.

[14] Richard Phillips Feynman, QED : *The Strange Theory of Light and Matter*.

Emily Marshman and Chandralekha Singh, 'A Framework for Understanding the Patterns of Student Reasoning Difficulties in Quantum Mechanics', 2015, https://doi.org/10.1103/PhysRevSTPER.11.020119.

Frederick Reif, 'Understanding and Teaching Important Scientific Thought Processes', *Journal of Science Education and Technology 4*, no. 4 (1 December 1995): 261–82, https://doi.org/10.1007/BF02211259.

communication of findings, quantum physics is often deemed too 'difficult' to communicate. Feynman stated that with quantum physics, "It is my task to convince you *not* to turn away because you don't understand it."[15] Similarly, this body of work aims to generate an awareness of the importance of complex scientific theories to better communicate understandings of our physical world. It is my conviction that just as humans had to grapple with scientific discoveries of Newtonian physics, electricity and x-rays to enable a wide acceptance of this technology; it is now a pivotal time to create awareness of quantum capabilities because of new developments in areas such as quantum computing, artificial intelligence, nanotechnology and biotechnology. This increase in modern capabilities does not just involve learning about new theories, I argue it requires new knowledge systems to live and thrive in the 21st century and beyond.

My research asks questions about the potential for VR production to draw on scientific findings and make accessible tangible information about scientific theory and processes through immersive, visual, and spatialised means. This experience prioritises a holistic encounter, where computer-generated imagery, within a virtual reality spatialised environment, operates in conjunction with spatialised sound and an interactive interface, whereby the viewer influences and directs their passage through the environment. A background to VR technology is provided which emphasises its strengths in setting up immersive spaces and its appropriateness as a medium to the questioning of reality.

Given the potential to create new internal logics and behaviours within the constructed VR environment, VR provides a pertinent medium to address the new knowledge required for quantum theories. Quantum entanglement is chosen as the specific theory to communicate science because entanglement is a form of communication in itself. The mysterious, intangible properties of this well-evidenced theory are introduced in this research and the importance of the implications of the theory is presented as a basis for investigating how such theories can be communicated experientially. New Zealand and international case studies are presented to illustrate overlaps and establish gaps within historical and contemporary art practice within the largely unexplored territory defined by the overlap of art, VR, science communication and quantum entanglement.

[15] Richard Phillips Feynman, *QED : The Strange Theory of Light and Matter*, 9.

The aims of my research are communicated in the following research questions:

1. How can immersive art experiences provide insights into complex scientific theories, in particular quantum entanglement?
2. What is the correlation between a creative art work and science communication in generating awareness of our physical reality?
3. Can virtual reality art play a role in providing new contributions to paradigmatic shifts in knowledge?
4. If so, how might VR also be utilised to allow audiences ways to better comprehend, embrace and understand such scientific discoveries?
5. Finally, what is unique about creative art and the creative thought processes which can then provide for innovative *experiences* of these above dynamics?

This written component is a supporting document to the creative VR output. The document is no substitute for immersive 3-dimensional experience in a VR environment, and the images of the VR work included here are only indicative. Methodologically, I sought testament from individuals who experienced *Entangled* through focus groups and questionnaires. This provides direct assessment of the types of effects a VR environment has on people in relation to the aims of my research.

Albert Einstein commented, "I am enough of the artist to draw freely upon my imagination. Imagination is more important than knowledge. Knowledge is limited. Imagination encircles the world." [16] This body of research, inspired by scientific theories that have been conceptualised and evidenced (or calculated within a realm of probability), also takes a lead from Einstein's assertion of the value of stimulating the imagination, and it does so within a specific framework, with a purposed intent. This intent, to engage and educate, arguably differentiates my investigations from many other artists interested in science, who operate in a predominantly speculative mode, or more directly question the authority of scientific findings and/or where scientific priorities and processes are critically challenged. I position my work within a union between contemporary art and science communication. I am very aware that this research occurs at a particular period of the development of the discipline of science communication, and at a time where more artists are investigating aspects of science, and the bourgeoning field of collaborations between artists and scientists is growing (and relevant

[16] 'Albert Einstein: "Imagination Is More Important Than Knowledge" | The Saturday Evening Post', accessed 26 January 2018, https://www.saturdayeveningpost.com/2010/03/imagination-important-knowledge/.

examples are considered in this document). I am positioning my enquiry as an individual arts researcher working within a contemporary art context, with previous scientific training and a strong interest in physics. I share aspirations with some larger, highly funded collaborations, however, I have chosen a more focused and achievable scale of research to enable a flexible and individually driven creative process. It will be shown that by modelling the 3-D scenes and writing the computer code myself, that opportunities were afforded that contribute to creating original visual elements.

This document presents the main theories that are used to support my investigation and inquiry. A definition of science communication is established which focuses on engagement to provide awareness, enjoyment, interest and the opportunity to form opinions and understanding. The deficit model is compared with the contextual model of science communication and while I argue that both have a role, this research sits within the contextual model of experience and dialogues.

Art and Science Communication are positioned within the epistemological framework of testing the limits of knowledge to understand our physical reality. It is suggested that both art and science operate in terms of empiricist and rationalist theories which opens the way for this research to function in each of these domains. Communication theories for art and science are presented as a complex set of relationships with the weighting towards experiential theories of learning. VR technology is examined through a postphenomenological lens to draw out the relationships between the viewer, the technology and the world.

Virtual reality (VR) technology is described by VR artist Jacquelyn Ford Morie as creating, "a paradigm shift in what humans are now able to experience."[17] In my work I define and explore what the significance of paradigm shifts entails in art and science.[18] Piaget's constructivist theory of knowledge is used to examine paradigm theories and shifts in thought processes.

To convey complex and invisible relationships, a theory of metaphors is presented which incorporates the use of visual metaphors. Patterning is discussed as a relational system in art, science and mathematics. Theories of presence and embodiment enable focused attention to

[17] Morie, Jacquelyn Ford, 'Performing in (Virtual) Spaces: Embodiment and Being in Virtual Environments', *International Journal of Performance Art and Digital Media*, no. 23 (2007): 123, https://www.academia.edu/355899/Performing_In_Virtual_Spaces_Embodiment_and_Being_In_Virtual_Environments.

[18] Paradigm shifts are times when the familiar framework has to be profoundly changed. This is discussed in detail in section 1.3.

the strengths of VR to provide an immersive experience of entanglement. Research into simulacra, dissonance and the technological sublime provide the theoretical platform for a strategy of creative practice that is designed to provide insights into the uncomfortable experience of two conflicting simultaneous thoughts.

I have developed a VR artwork with metaphoric entanglements that can be experienced bodily and cognitively. These entanglements entwine objects and events so that they appear to have the capacity to communicate with each other, which is the basis of quantum entanglement. While this is experienced at a scale much larger than quantum particles, it is a metaphoric expression and does not imply that quantum entanglement occurs at this scale. I follow the research that proposes that quantum entanglement occurs only at a quantum level.[19]

New contributions to contemporary installation art are provided by furthering experimentation in the design of VR environments as well as combining these with interactions with the physical space. Additionally, by creating interactions between the physical and virtual spaces, it will be shown that metaphoric entanglement is taken to a new level of experience. Intertwined images, animations and events, along with identical projections are used in both spaces. The scene the viewer sees within the VR headset is projected onto the gallery space and a webcam draws what is seen in the gallery space to the VR experience. As in quantum entanglement where 'communication' between fundamental particles can happen light years away, this work uses the barrier between the physical and virtual spaces to signify the unknown connections between the two entangled events. The barrier is not only achieved because the headset takes over the vision, but because of the strength of VR to create the illusion of presence in the VR surroundings. Here, my research is far from merely being illustrative of science, but through the intersection of a phenomenology of contemporary art installations and the state of art medium of VR, I attest that it provides a new contribution to art and science communication.

To provide the experience of the type of shift in thought processes that may be required to understand such areas as quantum entanglement, I have set up the opportunity for the viewer to experience conflicting situations. Purposeful disruptions in the form of changes in visual scenery, locking the view, changes in movements, tempo and sounds have been created to

[19] Quantum entanglement is discussed in hundreds of documents as being at a quantum scale. I discuss Karen Barad in section 2.6, as someone who proposes scaling of entanglement to a macro size and provide references of opposition to her position.

interrupt the feeling of being part of the virtual reality. I argue that each time the viewer is transported from the virtual space to the awareness of the physical space, they are experiencing two separate realities at the same time. I contend that this very conflicting situation involves the type of thought that belies common sense and provides an insight into the platform required to comprehend quantum physics.

The main body of the written component of this research is presented in two chapters: chapter 1 establishes the theoretical framework and chapter 2 analyses the art investigations. Section 1.1 offers a working definition of science communication. Section 1.2 introduces the shifts in thought processes and knowledge acquisition that can occur in art and science. Pedagogical theories of learning have enabled a more thorough examination of paradigm shifts. To take these theories into creative practice, methods of representing research findings are explored in section 1.3. In section 1.4 contemporary relevance of this research and challenges of working in the digital field are investigated through contemporary art practice. Section 1.5 gives a detailed account of the scientific theory of entanglement, its importance and implications. I offer a comparison with science fiction, computer gaming and international art to position my work in a niche area that overlaps yet provides a fresh perspective.

Simulacra, dissonance and technological sublime are defined in section 1.6 which leads to a more in-depth discussion of VR technology in section 1.7 and its strengths in setting up immersive spaces and conflicting situations. Section 1.8 provides a focused discussion on the capabilities of VR in presence and embodiment. This leads to the final section in this chapter which delves deeper into technology, presenting it as a mediator between the viewer and the world through a study of postphenomenology. This positions this research as using technology to provide new perspectives and insights into our physical reality.

Chapter 2 applies the theories discussed in chapter 1 in regard to the main body of artworks that have been undertaken as the practical component of this research. I introduce two earlier works which were part of the PhD research: *Why Anything?* (2016) and *Matter Matters* (2017), which show developments towards the primary focus of *Entangled* (2018). The earlier works are extensively documented and their development outlined in Appendix 1. *Why Anything?* explored computer animation and projection to scope a range of science topics and the implications of these theories. It will be shown that this was illustrative and required refining. The second project, *Matter Matters* was an animation focused on one scientific theory, that of quantum entanglement, which was projected onto a 6m high water screen as part of the Lux

Light Festival in Wellington harbour. The aim of this was to investigate scale of size, immersion and to create an entertaining event that pushed the lighter side of scientific communication.

The final VR work, *Entangled,* is a culmination of the research. This work is analysed by addressing five separate aspects and sequences within it. This analysis includes and is informed by focus group feedback and questionnaire results. Iterations that address challenges and decision-making are added to provide insights into the process. These analyses bring together the aims and achievements in this body of my research. Firstly, the main landscape of the VR scene in *Entangled* is established with respect to the definition of 'apparatus' and two specialised forms; the Klein bottle and the spacetime curve are detailed. The role of the spacetime curve and the scaling of the Klein bottles are unpacked in the following two sections. Analyses of shadows and interplays between the virtual and physical space complete this chapter.

The written component is rounded out by a section synthesising my findings and offering a conclusion. The appendices also include supporting material and previous practical investigations towards this body of creative research.

Chapter 1 Theoretical Framework

1.1 Art and Science Communication

There is immense intrigue in the possible relationships between the practices of contemporary art and science communication and the potential productive intersections between their conceptual premises and methods of communication. This research has a declared aspiration to foster a richer understanding of the implications of scientific theorem on our understanding of our physical world.

It is important to firstly position the very broad and often contested domains of art and science within the philosophical field of epistemology. I then offer a definition of science communication that provides the focus for this research with respect to contemporary art. The importance of science communication will be discussed and the growing prominence of this field and New Zealand's involvement will be presented. The two principal approaches to science communication will be introduced and explained; the deficit model and the contextual model and I shall argue that while there is room for both approaches, it is more appropriate to situate this research in the framework of contextual dialogue.

Epistemology

Art and science are both branches of epistemology, a complex field of philosophy which investigates the theory and limits of knowledge. Epistemology asks questions such as: how do we understand what it is we know? and what is real? Here, I follow the thought articulated by Alberto Vanzo, that sources of knowledge can be derived by rationalism or empiricism or both. Rationalism is the formation of knowledge with logical reasoning without direct sensory experience, and empiricism is that knowledge of the world which stems from direct experience, through our senses.[20] [21] [22] I attest that science and art can operate within either of these areas and that a synthesis of these knowledge systems is a productive space for enriching viewer experiences. Theoretical physicists are commonly typified as rationalists,

[20] Alberto Vanzo, 'Empiricism and Rationalism in Nineteenth-Century Histories of Philosophy', no. 2 (2016): 253, https://doi.org/10.1353/jhi.2016.0017.

[21] Jan Willem Lindemans, *Epistemology or the Theory of Knowledge*, accessed 15 April 2018, https://www.youtube.com/watch?v=12Zzn73v72I.

[22] Jan Willem Lindemans, Element 99, *Rationalism Vs Empiricism*, accessed 21 April 2018, https://www.youtube.com/watch?v=m1g8wjsEQyw.

coming to the epistemological questions by reasoning and rigorous and logical thinking. However, experimental physicists may test theories and develop new theories by active intervention, observation, or measuring data.[23] [24] Contemporary art I attest is predominantly positioned as empirical as it provides knowledge of our world through our senses, however, it also involves rationalist knowledge that the artist and the viewer bring to the work with cognitive skills to interpret it.[25]

It is useful to briefly examine the rationales for education in art to provide a clearer view of the epistemology of art. The slant towards education is in line with science communication which aims to build up engagement in scientific issues to increase understanding. Richard Siegesmund, in his paper, *Why Do We Teach Art Today?* summarises the literature as providing three main arguments for art in education: expressionist, reconstructivist and scientific rationalism.[26] He argues that the Expressionist puts free expression as the main aim of art education with the psychological and social benefits arising from this. Reconstructivists posit that art is a tool for reconstructing society rather than reproducing it and that art is not a discipline in itself; it is a tool for other disciplines.[27] I therefore propose that I do not sit within this area. I position my research as closer to art which is scientific rationalism. This locates art as a distinct discipline with the role of widening knowledge. Richard Siegesmund presents recent philosophers who have proposed that within art, perception can be an integral part of cognition.[28] He quotes Nelson Goodman as saying "…the arts must be taken no less seriously than the sciences as modes of discovery, creation, and enlargement of knowledge".[29] This positions my research as the meeting of art and science as two epistemological branches

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[23] Jan Willem Lindemans, *Philosophy of Science: Epistemology Applied*, accessed 19 April 2018, https://www.youtube.com/watch?v=NJ6EcfJjPLk.

[24] Jan Willem Lindemans, Element 99, *Rationalism Vs Empiricism*, accessed 21 April 2018.

[25] Enric Pol, 'Symbolism a priori - Symbolism a posteriori', *Universitat de Barcelona*, 1998.

[26] Richard Siegesmund, 'Why Do We Teach Art Today? Conceptions of Art Education and Their Justification', *Studies in Art Education* 39, no. 3 (1998): 197, https://doi.org/10.2307/1320364.

[27] Richard Siegesmund, 'Why Do We Teach Art Today?, 197.

[28] Richard Siegesmund, 'Why Do We Teach Art Today? , 197.

[29] Nelson Goodman, 1978, **quoted in** Richard Siegesmund Why Do We Teach Art Today? Conceptions of Art Education and Their Justification, *Studies in Art Education 39*, no. 3 (1998): 102. https://doi.org/10.2307/1320364.

sharing the aim of increasing knowledge by perception and cognition; utilising both rationalism and empiricism.

Art and science question the 'truth' of knowledge and below I discuss trust in terms of science. I use the definition of truth to be either the correspondence position of aligning the theory with what we observe in reality, or the pragmatist view that it is truth if it is useful.[30] Lindemans suggests that physicists see reality differently to how we see it in daily life, for example physicists may see the world as particles and be asking questions about the truth of particle theory.[31] My research seeks to question the truth of reality as we see it in everyday life. I do this by presenting the scientists' view of reality, as a means to broaden perspectives of our physical world, stimulate dialogues and provide experiences related to the processes that may be required to make the shifts in understanding.

I investigate the field of science communication to test where a productive and effective synthesis with contemporary art could be located. Science communication is a dialogue that can engage a wide range of audiences into any area of science. I draw from a paper by Burns, O'Connor and Stocklmayer, *Science Communication: A Contemporary Definition:*

"SCIENCE COMMUNICATION (SciCom) may be defined as the use of appropriate skills, media, activities, and dialogue to produce one or more of the following personal responses to science (the vowel analogy)

> **A**wareness, including familiarity with new aspects of science
> **E**njoyment or other affective responses, e.g. appreciating science as entertainment or art
> **I**nterest, as evidenced by voluntary involvement with science or its communication
> **O**pinions, the forming, reforming, or confirming of science-related attitudes
> **U**nderstanding of science, its content, processes, and social factors"[32]

[30] Jan Willem Lindemans, *Epistemology or the Theory of Knowledge*, accessed 15 April 2018, https://www.youtube.com/watch?v=12Zzn73v72I.

[31] Jan Willem Lindemans, *Philosophy of Science: Epistemology Applied*, accessed 19 April 2018, https://www.youtube.com/watch?v=NJ6EcfJjPLk.

[32] TW Burns, DJ O'Connor, and SM Stocklmayer, 'Science Communication: A Contemporary Definition', PUBLIC UNDERSTANDING OF SCIENCE 12, no. 2 (April 2003), 191.

"The significance of awareness should never be underestimated. For science, it provides the foundations of knowledge, broadens the mind and opens up personal and public opportunities that did not previously exist."[33]

Communication of science includes interaction between anyone in society, including scientists, people already well informed, those who are interested but not informed and those who are not aware that they are not informed.[34] Jesse Shore, a past president of the Australian Science Communications, is quoted as saying that in science museum curation, "The goal is to identify and communicate the fundamentals of the subject which are relevant to the uninformed, have enough variety to intrigue the informed and reinterpret the content with freshness and humour to surprise and entertain the specialists."[35] Such sentiment is pertinent to my aims, to provide positive awareness, engagement and interest, with layers of understanding available and elements of humour and playfulness. I am mindful that terms such as 'playfulness' may not seem serious, however, in this context, playfulness is derived from Jane Webster's and Joseph Martocchio's description, as providing the individual the opportunity for spontaneous interaction, invention and imagination.[36] Nina Lieberman assists and further describes the manifestations of playfulness as curiosity and inventiveness and an important link between imagination and creativity. The personal traits of the person influence the ability to interact playfully and conditions such as confidence with the media also determine the level of playfulness that may occur. [37] [38]

Creative means of communicating science and such qualities of 'playfulness' explained above featured strongly in the programme of the 2018 Australian Science Communication conference, which I attended in Sydney (12-15 November 2018). An art exhibition was presented for the conference (discussed in section 1.5 on contemporary art), workshops were

[33] TW Burns, DJ O'Connor, and SM Stocklmayer, 'Science Communication, 196.

[34] TW Burns, DJ O'Connor, and SM Stocklmayer, 'Science Communication.

[35] TW Burns, DJ O'Connor, and SM Stocklmayer, 'Science Communication, 196.

[36] Jane Webster and Joseph J. Martocchio, 'Microcomputer Playfulness: Development of a Measure With Workplace Implications', *MIS Quarterly* 16, no. 2 (June 1992): 201–26, https://doi.org/10.2307/249576.

[37] Jane Webster and Joseph J. Martocchio, 'Microcomputer Playfulness.

[38] Josefa Nina Lieberman, *Playfulness : Its Relationship to Imagination and Creativity*, Educational Psychology Series (New York : Academic Press, 1977, 1977).

provided on 'designerly approaches to science communication', 'extended play with social media', making games, story-telling skills and writing science poetry, along with the presentation of a comedic science play and encouragement for science communicators to attend comedy workshops.[39] The emergence of creative exhibitions partnered with major conferences is a trend across disciplines and conference committee members indicated that this creative approach was a new development in Science Communication conferences. Such initiatives may begin to overcome a barrier in communicating science that is summed up by Alexander Aitkin, in his PhD thesis, *Playing at Reality*; "scientific culture is not popular because the essential nature of science – the models and practices that make it up – cannot be communicated via conventional media in a manner that is interesting to the average person."[40] He contends that science should be as popular as other activities and provides a foundation for computer games to fulfil this role. The 2017 NZ Prime Minister's Award for Science Communication was won by Damian Christie. The judges commented that his previous work was told "with humour and curiosity".[41]

Initially science communication operated on the basis that more knowledge would increase scientific literacy, "the more the public know science, the more they'll come to love it".[42] Filling this knowledge gap by a top-down dissemination of information, the deficit model is considered to be responsible for public knowledge and confidence in science plateauing at around 40% in the US since 1973.[43] Simis et al have shown that the profusion of the deficit model is an easy option and that the methodology gains influence in policy decisions.[44] Many speakers at the Australian Science Communication Conference emphasised the importance of leaving behind the deficit model of learning science which often involves teaching from

[39] SciCom conference, 2018. http://2018conf.asc.asn.au/schedule-detail/.

[40] Alexander Lewis Aitkin, 'Playing at Reality: Exploring the Potential of the Digital Game as a Medium for Science Communication', October 2004, https://openresearch-repository.anu.edu.au/handle/1885/46051, Abstract 4.

[41] '2017 Prime Minister's Science Communication Prize Winner | The Prime Minister's Science Prizes', accessed 7 November 2017, https://www.pmscienceprizes.org.nz/2017-prime-ministers-science-communication-prize-winner/.

[42] Miller, S. https://journals.sagepub.com/doi/abs/10.3109/a036859 , January 2001, 116.

[43] Korownyk, C. *et al.* "—what they recommend and the evidence to support their recommendations: a prospective observational study." *BMJ* 349 (December 2014): g7346. A review of Dr Oz showed almost half his advice conflicts with scientific literature.

[44] Simis M.J. et al., 'The Lure of Rationality: Why Does the Deficit Model Persist in Science Communication?', 25, no. 4 (01 2016): 400–414, https://doi.org/10.1177/0963662516629749.

textbooks and lecturing students. David Harris, a speaker at this conference, states that the "deficit model thinking is the root of societal mistrust of science."[45] However, I posit that there will always be a role in attempting to build up public knowledge and mediums such as VR will have a vital future role to play. This is backed up by Steve Millar who emphasises that not only is there still a deficit in public knowledge, but that there always will be because of the intensive ever-developing research required by scientists to establish their knowledge.[46] Additionally, the continued success of the populist speakers, who operate in filling the gap in knowledge, such as Neil deGrasse Tyson, Brian Cox, Lawrence Krauss etc., have provided popular traction for science and indicate that there is a place for this type of dissemination of knowledge.

My work sits closer to the contextual model of science communication, which is based on creating dialogues between science and the public. This model requires an 'active' public which I hold as an aim of my work. The contextual model has been particularly successful in engaging the public in areas of climate change, global warming, vaccinations and genetically modified foods as the model aims to provoke debates with ethical and political concerns at the forefront.[47] However, while engagement has increased, misconceptions and antagonism to science also prevail.[48] The 2015 Harvard Public Opinion Project found that only 56% of respondents trusted scientists to do the right thing most of the time, 34% some of the time and 10% never trust scientists at all.[49] This distrust and rejection of science, for some people has a political, cultural or religious basis[50] and similar challenges for art because of social, cultural and political influences.

There are many issues to overcome with the contextual model. Millar states that an important part of understanding science is for the public to realise that scientists argue about discoveries

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[45] David Harris, 'Notes and Thoughts – Sciartica', accessed July 2018, https://sciartica.net/category/notesandthoughts/.

[46] Miller, S, https://www.researchgate.net/profile/Steven_Miller .

[47] TW Burns, DJ O'Connor, and SM Stocklmayer, 'Science Communication: A Contemporary Definition', *12*, no. 2 (April 2003).

[48] Cary Funk, 'Mixed Messages about Public Trust in Science', *Issues in Science & Technology* 34, no. 1 (Fall 2017): 86–88.

[49] 'Young Americans' Growing Distrust of Science | Harvard Political Review', accessed 02 November 2017, http://harvardpolitics.com/hprgument-posts/young-americans-growing-distrust-science/.

[50] TW Burns, DJ O'Connor, and SM Stocklmayer, 'Science Communication.

and this process needs to be more transparent.[51] Peer reviews of published articles aim to filter the highest quality research and publications of scientific results and theories provide discourse, but these are not necessarily the final solution.[52] Millar proposes that by conveying this as an important aspect of science, the public will understand that science being wrong can be part of the process as theories are developed amongst the wider scientific community.

The importance of science communication has evolved from anti-science attitudes and the need to provide a more positive outlook to ensure funding.[53] The use of the atomic bomb in WW2, the Cold War that followed and the escalation of nuclear arms set trust in science backwards.[54] After WW2, the media in the UK showed periods of hope and admiration for science followed by disillusionment and even hostility.[55] This was exacerbated in both the UK and US by scientists withdrawing from public engagement. Funding for science was put in a vulnerable position, highlighted in the Bodmer Report (1985) which legitimised the promotion of science and gave the message to scientists that they have a duty to communicate findings.[56] Grants and prizes were made available to popularise science and media training courses were initiated at universities aimed to improve scientists' skills in communicating.

Governments, corporations, health and military have their own motivations for funding scientific research and its communication and scientists have been accused of exaggerating findings for their own opportunities.[57] Survey results suggest there is concern about whether scientists and governments will keep the public safe,[58] and indicate concern that boundaries

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[51] Miller, S, https://www.researchgate.net/profile/Steven_Miller.

[52] J. Matthias Starck, 'Introduction', in *Scientific Peer Review: Guidelines for Informative Peer Review,* ed. J. Matthias Starck, Essentials (Wiesbaden: Springer Fachmedien Wiesbaden, 2017), 1–1. https://doi.org/10.1007/978-3-658-19915-9_1.

[53] Miller, S, https://www.researchgate.net/profile/Steven_Miller.

[54] John Krige, 'Atoms for Peace, Scientific Internationalism, and Scientific Intelligence', *Osiris* 21, no. 1 (2006): 161, https://doi.org/10.1086/507140.

[55] Miller, S, https://www.researchgate.net/profile/Steven_Miller.

[56] Miller, S, https://www.researchgate.net/profile/Steven_Miller.

[57] Peter Weingart, Anita Engels, and Petra Pansegrau, 'Risks of Communication: Discourses on Climate Change in Science, Politics, and the Mass Media', 9, no. 3 (1 July 2000): 261–83, https://doi.org/10.1088/0963-6625/9/3/304.

[58] *Read 'Trust and Confidence at the Interfaces of the Life Sciences and Society: Does the Public Trust Science? A Workshop Summary' at NAP.Edu*, accessed 5 June 2018, https://doi.org/10.17226/21798.

are blurred between science and government and businesses.[59] Increased media opportunities are providing platforms for misleading information with powerful personalities presenting unsubstantiated claims. For example, American pseudoscience promoter, Dr Oz,[60] runs a daily TV show which has been shown to present information that conflicts with scientific and medical research in nearly half of his advice. [61]

Weingart et al highlight risks in communication of science and propose that these risks need to be presented as part of science communication.[62] They maintain that to combat communication issues, more debate and transparency is required and the assumption of communication flowing from science findings to political decision-making and to the public must be confronted with analysis at each stage with its own issues of communication.[63] Analysing this is beyond the scope of this PhD, however, it is important to note that the aim is for more frequent communication, not less.

Science engagement gains extensive government and business investment with the aim of regaining the public's trust in science.[64] Millions of dollars are provided worldwide for education, employment of science communicators and high level awards such as the Descartes prizes for science communication of 275,000 Euro annually.[65]

NZ has a strong history in providing science communication with The Association of Scientific and Technical Communicators (NZ) running from 1987 until 1996 followed by the Science Communicators Association of NZ, SCANZ, which was established in 2004. SCANZ provides

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[59] James Wilsdon and Rebecca Willis, *See-through Science: Why Public Engagement Needs to Move Upstream* (Demos, 2004).

[60] Dr Oz is a Turkish American Mehmet Cengiz Öz

[61] Korownyk, C. *et al.* "Televised medical talk shows—what they recommend and the evidence to support their recommendations: a prospective observational study." *BMJ* 349 (December 2014): g7346. A review of Dr Oz showed almost half his advice conflicts with scientific literature.

[62] Peter Weingart, Anita Engels, and Petra Pansegrau, 'Risks of Communication: Discourses on Climate Change in Science, Politics, and the Mass Media', *9,* no. 3 (1 July 2000): 261–83, https://doi.org/10.1088/0963-6625/9/3/304.

[63] Peter Weingart, Anita Engels, and Petra Pansegrau, 'Risks of Communication: Discourses.

[64] 'A Learning System for Science Engagement: Part 1', Sciblogs, accessed 17 September 2017, https://sciblogs.co.nz/curious-and-curiouser/2016/02/05/a-learning-system-for-science-engagement/.

[65] 'European Commission - PRESS RELEASES - Press Release - From the Lab into the Limelight: EU Announces Nominees for the Descartes Prize for Science Communication', accessed 7 March 2018, http://europa.eu/rapid/press-release_IP-07-131_en.htm.

newsletters, workshops, conferences and seminars with their stated aims of promoting science communication with a professional emphasis, promoting awareness, celebrating achievements and encouraging dialogue, discussion and debate of ethical, policy, economic and social issues related to science and technology.[66] Hands-on science museums were established in NZ with Discovery World in Otago in 1991 and Science Alive! in Christchurch (1992).[67] An early focus on art and science collaborations is the Artists to Antarctica started in 1957 which is still running. Other art and science projects include *Are Angels OK* (2005) a collaboration of physicists and writers; *The Waking Incubator* (2010), an artist/scientist collaboration and the *International Year of Chemistry* (2011) which resulted in a large knitted periodic table.[68] The Science Communication NZ Prime Ministers prize of $100,000 is awarded annually to stimulate new projects from established scientists and/or communicators of science. The Royal Society of NZ awards, prizes and scholarships, such as the Callaghan Medal for science communication for "raising public awareness of the value of science to human progress".[69] Some prolific people currently active in Science Communication in New Zealand include Damian Christie, as mentioned previously and scientists Shaun Hendy, Michelle Dickenson (Nanogirl) and Siouxsie Wiles, to name a few. In the last three years Creative New Zealand has provided an average of $42.2million dollars for direct arts funding, capacity building and advocacy.[70]

[66] 'SCANZ - Science Communicators Association of New Zealand', SCANZ, accessed 23 August 2018, https://www.scanz.co.nz/.

[67] Jean Fleming and Jeremy Star, 'The Emergence of Science Communication in Aotearoa New Zealand'. https://www.researchgate.net/publication/318573059_The_emergence_of_science_communication_in_Aotearoa_New_Zealand.

[68] Jean Fleming and Jeremy Star, 'The Emergence of Science Communication.

[69] Jean Fleming and Jeremy Star, 'The Emergence of Science Communication, 11.

[70] 'Creative New Zealand'. Accessed 25 February 2019. http://www.creativenz.govt.nz/.

1.2 Learning Models and Paradigm Shifts

The definition of science is complicated and contested. There is some consensus in terms of basic principles, but there are many varying viewpoints and anthropological and philosophical stances. Modern theories of scientific process take into account the human mind as a contribution to the truth of scientific discoveries and verifications. Therefore social, political and cultural values influence findings. A further complication is that scientific data can be influenced by the framework that is used to collect it. Historically science was considered infallible and provided 'truths' of the world, however, when Einstein's relativity turned Newtonian physics upside down, the success of the cumulative build-up of scientific knowledge was challenged.[71]

Broadly, science has been defined by The Panel on Public Affairs of the American Physical Society as: "Science is the systematic enterprise of gathering knowledge about the world and organizing and condensing that knowledge into testable laws and theories."[72] These laws and theories are created by identifying patterns, which at times can be very complex and a part of science requires peer review and modification of theories. However, a more in-depth investigation is required to explain the processes involved in quantum theory.

I align with the definition presented by Dr. Hoyningen-Huene, Professor of Philosophy and Ethics of Science at the University of Hannover, Germany. People have often defined science by what they describe as the 'scientific method', however, Hoyningen-Huene states that today one single scientific method does not exist. His research has shown that over the past 100 years scientific theories have been developed involving four main scientific methods: inductive processes and generalisations; deductive testing of generalisations; systematic process and paradigm theory.[73] Inductive and deductive scientific processes are what we are familiar with in secondary schooling. Induction theory takes singular, particular facts which are usually able to be measured and then generalises them into a theory; this is a bottom-up process. When it is done with a sufficiently large number of observations, in different conditions and no

[71] mehranshargh, *Hilary Putnam on the Philosophy of Science (1977)*, accessed 19 December 2018, https://www.youtube.com/watch?v=kH785oawwkk.

[72] The Panel on Public Affairs of the American Physical Society **quoted in** Science Communication: A Contemporary Definition T. W. Burns, D. J. O'Connor and S. M. Stocklmayer, 2003, 185.

[73] P Hoyningen, *Introduction to Philosophy of Science. Lecture 1, Part 1*, accessed 15 March 2018, https://www.youtube.com/watch?v=tP8teUgZcBY.

contradictions are found, generalisations are considered justifiable.[74] Deductive theory is similar, still requiring observation and data, however, it is a top-down process, where theories are designed first and then tested by measurement of data. Systematic process considers that what makes science different from other kinds of knowledge is the systematic approach, which can account for cumulative build-up of knowledge by the inductive and deductive theories and non-cumulative developments which have been observed in science. The fourth method is paradigm theory, which is relevant to understanding quantum science.

Paradigm theory was developed by Thomas Kuhn in his book *The Structure of Scientific Revolutions* (1962). He defined scientific paradigms as "universally recognized scientific achievements that, for a time, provide model problems and solutions for a community of researchers".[75] Paradigms are exemplary solutions that have been widely accepted, giving implicit information that is capable of being explored rather than a strict set of rules.[76] New knowledge is built up by small increments from the paradigm.

There can be times when a paradigm does not account for experimental or observational data and when the consensus is that there are too many anomalies in a paradigm, resulting in a new framework, a paradigm shift. [77] Kuhn called this period a scientific revolution, as it is a time when competing frameworks are evaluated aiming for new paradigms that cannot be understood from the old conceptual framework. [78]

This inability to understand vocabulary and methodologies between new paradigms is termed, incommensurability. The initial definition, "to have no common measure"[79], has been

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[74] Moncy Vilavinal John, 'POSTMODERNISM AND SCIENCE', Published Article or Volume, Breakthrough - A Journal on Science and Society, 1 May 2011. http://www.breakthrough-india.org/current_issue.html. This links to Karl Popper's falsifiability theory that theories are scientific because of the capability of being shown to be false, however Kuhn disputes this.

[75] Thomas S Kuhn, *The Structure of Scientific Revolutions: 50th Anniversary Edition.* University of Chicago Press, 2012, preface xiii.

[76] P. Hoyningen, *Kuhn's Paradigm Theory III: Normal Science*, accessed 23 November 2017, https://www.youtube.com/watch?v=IVo5ip-0n4Y.

[77] Vilavinal John, 'POSTMODERNISM AND SCIENCE'.

[78] P. Hoyningen, *Kuhn's Paradigm Theory IV: Revolutionary Science, Revolutions, Incommensurability*, accessed 25 November 2017, https://www.youtube.com/watch?v=3-zw6kFSJqA.

[79] The term incommensurability goes back to ancient Greek mathematics where measurements that did not have a common measure were termed this.

reformed many times within the discussion of the philosophy of science. Kuhn along with Paul Feyerabend brought the theory of incommensurability to the fore in 1962 because of the implied challenge to rational thinking in science. This was because paradigm shifts are not the cumulative scientific building of facts *towards* gaining truth, but large shifts *away* from the anomalies in a current theory. These involved changes that operate so differently that Kuhn stated, "In a sense that I am unable to explicate further, the proponents of competing paradigms practice their trades in different worlds"[80]

Incommensurability lacks a common measure, which because of structurally different laws and theories limits understandings between them. [81] Kuhn (and Ludwick Fleck before him) defined three domains that incommensurability operates under: "a change of problems and standards, a change of concepts used to state and solve them, and a change of world-view in which they arise."[82]

It is the experience of different frameworks that my research investigates. For example, the difference between Newtonian physics and Einstein's relativity involves concepts such as mass, length and time operating in different manners which are incommensurable to each other because they operate completely differently in each framework. Similarly quantum theory compared with Newtonian physics, has resulted in changes of concepts, standards and a change in world-view. American physicist, Mario Rabinowitz states, "Quantum mechanics (QM) clearly violates Newton's First Law of Motion."[83] This is because they are incommensurable. He also details that quantum theory has not been able to operate in the macro world to describe gravity even after eight decades of extensive attempts.

Eric Oberheim and Paul Hoyningen-Huene, 'The Incommensurability of Scientific Theories', *The Stanford Encyclopedia of Philosophy* (Fall 2018 Edition), Edward N. Zalta (ed.), https://stanford.library.sydney.edu.au/entries/incommensurability/.

[80] Kuhn, Thomas S. *The Structure of Scientific Revolutions*, 149.

[81] Oberheim, Eric and Paul Hoyningen-Huene, 'The Incommensurability of Scientific Theories', *The Stanford Encyclopedia of Philosophy* (Fall 2018 Edition), Edward N. Zalta (ed.), URL = <https://plato.stanford.edu/archives/fall2018/entries/incommensurability/>.

[82] Oberheim, Eric and Hoyningen-Huene, Paul, "The Incommensurability of Scientific Theories", Section 4 paragraph 2.

[83] Mario Rabinowitz, 'Is Quantum Mechanics Incompatible with Newton's First Law?', *International Journal of Theoretical Physics* 47, no. 4 (April 2008): 936–48, https://doi.org/10.1007/s10773-007-9519-7. Abstract 1.

The underlying model of the paradigm theory is Piaget's constructivist learning model. Within this model, forming knowledge involves absorbing information and building it into existing knowledge structures.[84] [85] [86] Piaget called these structures our schema; systems that organise knowledge stored in our memory.[87] [88] Piaget based his theory on the equilibrium of assimilation and accommodation. Assimilation involves a person taking on new knowledge and integrating it into their pre-existing knowledge. Accommodation is the process which changes the existing knowledge structures to be in line with the new information. [89] The discrepancy between the assimilation of the new knowledge and the old structures requires accommodation to create the equilibrium. Piaget considered that change in knowledge structures is an iterative process only occurring if the new knowledge is close to the existing structures, allowing the person to accommodate it. This constructivist model sits within the understanding of scientific knowledge which often involves reworking existing knowledge with new developments and modification of these structures. [90]

Piaget describes paradigm shifts as times when the familiar framework has to be profoundly changed.[91] The disequilibrium is too great and so accommodation is less likely to occur because there is an incomplete fit with existing schema.[92] [93] This conflict is called cognitive

[84] Ernst von Glasersfeld, 'An Exposition of Constructivism: Why Some Like It Radical.', *Journal for Research in Mathematics Education* 4 (1 January 1990): 19–45, https://doi.org/10.2307/749910.

[85] Jean Piaget, Bärbel Inhelder, and Helen Weaver, *The Psychology of the Child* (Routledge & Kegan Paul, 1969).

[86] Catherine C Schifter, Maria Cipollone, and Frederick Moffat, *Piaget, Inhelder and Minecraft*, 2013, http://archive.org/details/ERIC_ED562248.

[87] Richard C. Anderson, Jean Osborn, and Robert J. Tierney, *Learning to Read in American Schools: Basal Readers and Content Texts* (Psychology Press, 1984).

[88] Christopher B. Bingham and Steven J. Kahl, 'The Process of Schema Emergence: Assimilation, Deconstruction, Unitization and the Plurality of Analogies', *Academy of Management Journal* 56, no. 1 (7 May 2012): 14–34, https://doi.org/10.5465/amj.2010.0723.

[89] Jack Block, 'Assimilation, Accommodation, and the Dynamics of Personality Development', *Child Development* 53 (1 April 1982): 281, https://doi.org/10.2307/1128971.

[90] Block, 'Assimilation, Accommodation.

[91] Timothy Koschmann, 'Paradigm Shifts and Instructional Technology', *Book Chapters*, 1 January 1996, https://opensiuc.lib.siu.edu/meded_books/4.

[92] Dimitris Mavroskoufis, 'The Use of Cognitive Dissonance / Conflict as a Tool for Critical Teaching', accessed 7 October 2018, http://www.academia.edu/8453597/The_Use_of_Cognitive_Dissonance_Conflict_as_a_Tool_for_Critical_Teaching.

dissonance and is a very powerful motivator as it can lead to the changing of conceptual structures. [94] Cognitive dissonance is discussed in more detail in section 1.7 along with its application within my work to provide experiences based on this theory.

New concepts of physics are mostly invisible in our everyday life and this provides a challenge for the lay-person to see the relevance of quantum physics, or gain the opportunity to form the change in thinking required to understand such theories. Classical physics of forces, gravity and time explain the basics of how we interact with our physical world, however, as will be discussed later in this chapter, quantum physics is poised to change our understanding of the world. This means it is an opportune time to investigate the communication of this information, because I align with research that new understandings of physics require a change in conceptual thinking, not just knowledge accumulation. This need is backed up by a three year study by pedagogy researchers, Hadzidaki et al, who set up an instructional model using a qualitative approach to teach classical physics and quantum theory to students not specialising in science. They outline their process as, "two *totally independent conceptual systems"*, which were presented showing 'crisis' points where the older conceptual systems had to be abandoned.[95] They concluded that there is a need for this type of instruction to allow insights into "radical modifications into human thought."[96]

I argue that the experience of conflicting conceptual structures opens a space for creative art research using forms of language and imagery that offer modes of engagement and experiential encounters, to present different perspectives and ideas in science communication.

Quantum physics is a prime example of a paradigm shift because the classical framework cannot explain quantum theory.[97] [98] [99] As physicist, Brian Greene states ''But of all the

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[93] Rosalind Driver and Gaalen Erickson, 'Theories-in-Action: Some Theoretical and Empirical Issues in the Study of Students' Conceptual Frameworks in Science', *Studies in Science Education* 10, no. 1 (1 January 1983): 37–60, https://doi.org/10.1080/03057268308559904.

[94] Dimitris Mavroskoufis, 'The Use of Cognitive Dissonance.

[95] George KALKANIS, Pandora HADZIDAKI, and Dimitrios STAVROU, 'An Instructional Model for a Radical Conceptual Change towards Quantum Mech...: Discover', *Science Education (Salem, Mass.)* 87, no. 2 (2003): 257–80, 257.

[96] KALKANIS et.al. 275.

[97] Kuhn, Thomas S. *The Structure of Scientific Revolutions*.

[98] Marshman and Singh, 'A Framework for Understanding the Patterns of Student Reasoning Difficulties in Quantum Mechanics'.

discoveries in physics during the last 100 years, quantum mechanics is far and away the most startling, since it undermines the whole conceptual scheme of classical physics.''[100] [101]

The required change in schema is one of the main reasons why people have difficulty with quantum physics; we have to change our whole view and our existing ideas of logic.[102] This is extremely difficult, especially if there is no motivation or even any awareness that it is needed. As quoted by Feynman earlier, the new phenomena at quantum level are strange and require common sense to be left behind. Marshman and Singh state that even upper level tertiary students encounter difficulties in understanding quantum physics because of the significantly different paradigm.[103] Their prior knowledge, cultural background, goals and motivation and even prior physics knowledge can create barriers in forming a new framework. Additionally using learning methods developed for old paradigms can cause misunderstandings in the new framework.

A main conceptual element for my work is articulated by Marshman and Singh, who propose that to learn quantum, people will benefit from Piaget's theory of, "cognitive conflict that makes them understand that there is a mismatch between their naive, everyday model and

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[99] Valia Allori states that most scientists describe quantum to be a paradigm shift however she presents a case for quantum mechanics to be in the classical framework.
Valia Allori, 'Quantum Mechanics and Paradigm Shifts', Published Article or Volume, Topoi, 2015, http://link.springer.com/article/10.1007/s11245-014-9295-y.

[100] B. Greene, *The Fabric of the Cosmos : Space, Time, and the Texture of Reality* (New York : A.A. Knopf, 2004, 2004, 197).

[101] Virtual reality technology is also described as creating paradigm shifts in fields such as: human resource development; engineering; medicine; education; museums.
Elisabeth E. Bennett, 'The Coming Paradigm Shift: Synthesis and Future Directions for Virtual HRD', *Advances in Developing Human Resources 12*, no. 6 (01 2010): 728–41, https://doi.org/10.1177/1523422310394796.
Sanyuan Niu, Wei Pan, and Yisong Zhao, 'A Virtual Reality Integrated Design Approach to Improving Occupancy Information Integrity for Closing the Building Energy Performance Gap', *Sustainable Cities and Society* 27 (1 November 2016): 275–86, https://doi.org/10.1016/j.scs.2016.03.010.
Navid Farahani and Corey E Monteith, 'The Coming Paradigm Shift: A Transition from Manual to Automated Microscopy', *Journal of Pathology Informatics, Vol 7, Iss 1, Pp 35-35 (2016)*, no. 1 (2016): 35, https://doi.org/10.4103/2153-3539.189698.
VR Content Editors: The Signs Of A Paradigm Shift In The Learning Industry', eLearning Industry, 4 November 2018, https://elearningindustry.com/vr-content-editors-signs-paradigm-shift-learning-industry.
Rebecca Leuchak, 'Imagining and Imaging the Medieval: The Cloisters, Virtual Reality and Paradigm Shifts', *Historical Reflections* 23, no. 3 (1997): 349–69.

[102] mehranshargh, *Hilary Putnam on the Philosophy of Science (1977)*. https://www.youtube.com/watch?v=kH785oawwkk. Accessed 3 January 2019

[103] Emily Marshman and Chandralekha Singh, 'A Framework for Understanding the Patterns.

what the laws of physics predict in a particular context."[104] While this will create disconnected and internal inconsistences at first, instruction will assist in assimilating and accommodating to strengthen new theories and critical thinking.[105] [106] It is the experience of cognitive conflicts that I am using in the VR work to create an experience of the type of change of thought processes that may be required to understand our physical reality.

Margaret Dolinsky is an artist who has used projected imagery to change cognitive processes through sensory experiences which are on the boundary of awareness. [107] [108] She investigates the edge between not noticing something and noticing it; "a fleeting moment of categorical breakdown,"[109] where, "we must regroup our thinking, reposition our self and reintegrate the worlds within and around us."[110] I suggest this is similar to the disruptions in *Entangled,* however while I am aiming to create these moments as an experience of conflicting mental processes, Dolinsky is interested in the change of perception between the familiar and unfamiliar.

Experience provides an additional perspective on the acquisition of knowledge, providing a subjective personal meaning for abstract concepts through concrete involvement with the stimulus.[111] Teaching science in schools changed in the 1960s when Dewey proposed 'discovery' learning (later to be named 'inquiry' learning) where the emphasis of information learned was replaced with experiencing the "logical thinking processes by which new knowledge is acquired."[112] Jean Piaget's constructivist theory states that knowledge is formed

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[104] Emily Marshman and Chandralekha Singh, 'A Framework for Understanding the Patterns, 27.

[105] Marshman and Singh, 'A Framework for Understanding the Patterns.

[106] Stella Vosniadou, 'Exploring the Relationships between Conceptual Change and Intentional Learning', accessed 17 April 2018, 48. https://www.researchgate.net/publication/251736849_Exploring_the_Relationships_between_Conceptual_Change_and_Intentional_Learning.

[107] Dolinsky has worked with CAVE projects, explained more fully in investigations of Char Davies.

[108] Margaret Dolinsky, 'Transformative Navigation: Energizing Imagery for Perceptual Shifts', *Technoetic Arts: A Journal of Speculative Research*, no. 1 (2009): 49, https://doi.org/10.1386/tear.7.1.49_1.

[109] Margaret Dolinsky, 'Transformative Navigation, 49.

[110] Margaret Dolinsky, 'Transformative Navigation, 49.

[111] David A. Kolb, *Experiential Learning : Experience as the Source of Learning and Development* (Upper Saddle River, New Jersey : Pearson Education Ltd, [2015], 2015).

[112] Steven J. Rakow and Bloomington Phi Delta Kappa Educational Foundation IN., 'Teaching Science as Inquiry. Fastback 246', 1 January 1986.

cognitively from the person's direct experience.[113] [114] Experiential aspects of presence and immersion are discussed more fully with respect to VR technology in section 1.8

1.3 Methods of Representing Research in Creative Practice

But what to make of all this explanation of science and paradigmatic thought for creative research and a creative VR work? In what ways is science and art commensurate? The different ways in which research findings are made representable emerged as a necessary and critical ingredient in my studies. Located through my designs of scientific empirical data, aesthetics and visual metaphors is, I believe, an expression of art *for* science communication. Encountered with *Entangled* is the conveyance of quantum entanglement; it is an expression of incommensurability through metaphors, and therein displayed is the conviction for grappling with new paradigmatic shifts in knowledge.

In *Information and Noise and et Al* (2007) Su Ballard draws parallels between art and information science, the following quotation concerning the aesthetics of art foregrounds findings discussed in the latter half of this thesis:

> "Like art, information science remains concerned with the material spaces of transmission – whether conceptual, social or critical. In the context of art something is made to be seen, understood, viewed, or presented as a series of relationships that might be established between individuals, groups, environments, and sensations. Understood this way, art is an aesthetic relationship between differing material bodies, images, representations and spaces."[115]

Uncertainty can be a tremendous impetus and influence for a creative artist. Making it be seen and understood an altogether more difficult task. The relationships formed to provide experiences of entanglement in *Entangled* are not providing literal interpretations or a direct visualisation, but instead use visual metaphors, movement and spatialised sound to generate

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[113] Schifter, Cipollone, and Moffat, *ERIC ED562248*.

[114] Sara Druyan, 'Effect of the Kinesthetic Conflict on Promoting Scientific Reasoning', *Journal of Research in Science Teaching* 34, no. 10 (1 December 1997): 1083–99, https://doi.org/10.1002/(SICI)1098-2736(199712)34:10<1083::AID-TEA7>3.0.CO;2-N.

[115] Su Ballard, 'Information, Noise and et Al', 2007, 9. https://ro.uow.edu.au/creartspapers/197/.

the experiences. I propose that it is important to offer these experiential modes of scientific communication to the public, even though complex, abstract concepts can be difficult to communicate. As Werner Heisenberg, the father of the uncertainty principle says, "If we omitted all that is unclear we would probably be left with completely uninteresting and trivial tautologies."[116]

In his paper, *Interpreting Art through Metaphors,* Michael Parsons observes that the meaning from artworks often comes from metaphors.[117] I agree with the stance that visual metaphors operate in a similar manner to verbal or written metaphors, while taking the visual aspect as being "recognized perceptually".[118] Visual metaphors require the viewer firstly to process the perceptual features such as colour, texture and shape to establish the concept of the object and then form relationships between the two domains that are being compared. US Researcher, Robert St. Clair, states that the use of visual metaphors goes back as far as Indigenous groups who have used them to share their cultures and dominate medieval art.[119] St Clair states that since Kuhn's model of thought processes researchers have realised that metaphors infuse all forms of knowledge.

An example of metaphoric mapping within *Entangled* involves one element of scientific entanglement (which is discussed more fully in section 1.6); the concept that entanglement occurs between pairs of very similar particles. I have taken scientific entanglement as the primary domain and pairs of objects that occur in the physical or gallery space as the secondary domain. I have mapped the property of pairs, two similar objects, onto entanglement to provide the information that entanglement is about two similar pairs of particles. More complex metaphors will be discussed in chapter 2 in the analysis of *Entangled.*

One of the aims of creating visual metaphors is to offer audiences the opportunity to think in a creative manner. As noted above, this is important in art, however it is also well documented

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[116] Heisenberg, Werner *(1971).* "Positivism, Metaphysics and Religion*",* in Ruth Nanda Nanshen. Werner Heisenberg, *Physics and Beyond - Encounters and Conversations. World Perspectives. 42. Translator:* Arnold J. Pomerans*. New York: Harper and Ro, 213.*

[117] Michael Parsons, 'Interpreting Art through Metaphors', *International Journal of Art & Design Education* 29, no. 3 (October 2010): 228–35, https://doi.org/10.1111/j.1476-8070.2010.01621.x.

[118] Noel Carroll, 'Visual Metaphor', in *Aspects of Metaphor* (Springer, 1994), 190.

[119]Robert N. St. Clair, 'Visual Metaphor, Cultural Knowledge, and the New Rhetoric', 2000, https://jan.ucc.nau.edu/~jar/LIB/LIB8.html.

as required in science to produce solutions through insights that are unexpected. [120] [121] [122] The 'logical' processes that are required for classical science are replaced by other 'thinking processes' to understand quantum theory.[123] As quoted in the introduction of this research, common sense can be a hindrance to creative processes. [124] [125] Common sense uses known facts and understandings and operates in a logical manner. For creativity, Edward de Bono proposed that 'lateral thinking' is required as distinct from the linear generation of logical thinking.[126] De Bono defined lateral thinking as a different mode of thinking which requires restructuring of patterns and provocation of new ones, which he calls 'insights'.[127] However, lateral thinking still involves a systematic process,[128] as the pattern changes do not occur from nowhere.

Mathematics is often referred to as the language of science as well as the "science of patterns."[129] [130] Patterns are central to the design and matrix of my work. "The mathematician seeks patterns in number, in space, in science, in computers, and in imagination."[131] So do the

[120] Robert L. DeHaan, 'Teaching Creative Science Thinking', *Science* 334, no. 6062 (2011): 1499, https://doi.org/10.1126/science.1207918.

[121] A. Carl Leopold, 'Act of Creation: Creative Processes in Science | BioScience | Oxford Academic', accessed 27 September 2017, https://academic.oup.com/bioscience/article-abstract/28/7/436/263622?redirectedFrom=fulltext.

[122] Mark A Runco, *Creativity : Theories and Themes : Research, Development, and Practice*, Educational Psychology (Amsterdam ; Boston : Elsevier Academic Press, ©2007, 2007),

[123] Richard Phillips Feynman, *QED : The Strange Theory of Light and Matter.*

[124] Common sense was defined in the introduction as the "millions of basic facts and understandings" that people accumulate. Creative processes were defined as being original, incorporating novel ideas but with the use appropriate reasoning to ensure it is not just random ideas.

[125] Indurkhya and Ojha, 'An Empirical Study on the Role of Perceptual Similarity in Visual Metaphors and Creativity'. *Metaphor and Symbol* 28, no. 4 (2013 2013): 233–53.

[126] Other authors have presented similar ideas, for example, Arthur Koestler uses the word bisociation to distinguish creative thinking from routine thinking. Arthur Koestler, *The Act of Creation* (London, Hutchinson [1964], 1964).

[127] Edward De Bono, *Lateral Thinking : A Textbook of Creativity* (London : Penguin Books, 1990, 1990), 9.

[128] Edward De Bono, *New Thinking for the New Millennium* (London : Penguin, 2000, 2000).

[129] Lynn Arthur Steen, 'The Science of Patterns', *Science* 240, no. 4852 (29 April 1988): 611–16, https://doi.org/10.1126/science.240.4852.611, 616.

[130] Burns, O'Connor, and Stocklmayer, 'Science Communication', 191.

[131] Lynn Arthur Steen, 'The Science of Patterns'.

rationalist and the empiricist scientists, who are looking for patterns to generalise from, to form new theories and to backup existing theories. I posit that to communicate science is to communicate the concept of patterns and as Steen says, "Generalization leads to abstraction, to patterns in the mind. Theories emerge as patterns of patterns, and significance is measured by the degree to which patterns in one area link to patterns in other areas."[132]

I created patterns throughout the artwork; relationships that have a pattern and events that are tied together visually and metaphorically. I take scientific and mathematical patterning into a visual art realm with the use of techniques of repetition of shape and line to offer the experience of new connections, correlations and relationships. For example, patterning is established visually with the spacetime curve, which is a diagrammatical representation of the relationship between space and time. In the animation the spacetime curves form new patterns, such as the shape of wormholes.

UK artist, Madi Boyd investigates visual patterning to explore the qualities of perception as she creates immersive physical spaces with multi-sensory projection installations.[133] A recent work, *Digital Forest* (2018), projects an abstracted forest video onto screens, creating patterns within the 3-D space to investigate multi-sensory perception and the restorative capabilities of installation art. Boyd worked with cognitive scientist, Polly Dalton, to establish elements that have been shown to influence restorative attention in the forest, such as light, scale, geometry, sounds, changes in depth perception and complexity and reproduced these in her installation.[134] Boyd states that she purposefully exaggerated the patterning in the forest scenes by the abstraction of the videos and the optimisation the fractal dimensions to recreate the restorative elements of the forest. [135] Use of layered threads, gauze and satin as 'screens' for the projections activated the space and immersed the viewers, also offering them the opportunity to interact and change the patterning. Forest sounds were provided by composer

[132] Lynn Arthur Steen, 'The Science of Patterns'

[133] Madi Boyd, 'Professional Development Bursary Blog – Work so Far..', accessed 9 November 2018, https://www.a-n.co.uk/blogs/professional-development-bursary-blog-work-so-far/page/2/.

[134] Madi Boyd, Polly Dalton, and Nye Parry, 'Digital Forest', Digital Forest, accessed 9 November 2018, http://digitalforest.org.uk/.

[135] Boyd defines this as "The fractal dimension gives a guide to the complexity of a scene as it is a ratio for the complexity of detail in a pattern as it changes with the scale at which it is measured. A fractal dimension of approximately 1.4 shows a low to intermediate level of complexity, which, as mentioned before, in a natural scene, would have offered the best chance of survival for early humans, and so today still produces the highest level of attention restoration."
Madi Boyd, 'Professional Development Bursary Blog – Work so Far..', accessed 9 November 2018, https://www.a-n.co.uk/blogs/professional-development-bursary-blog-work-so-far/page/2/.

and sound artist, Nye Parry, using 32 speakers suspended above the viewers to enhance the spatial dispersion.

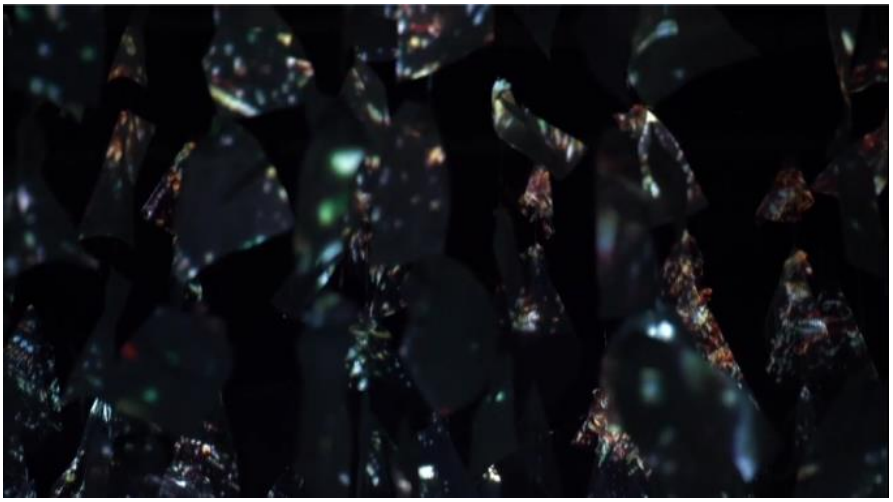

Figure 2. Madi Boyd and Nye Parry, UK, *Digital Forest,* 2018.
Screen capture from https://vimeo.com/277805428

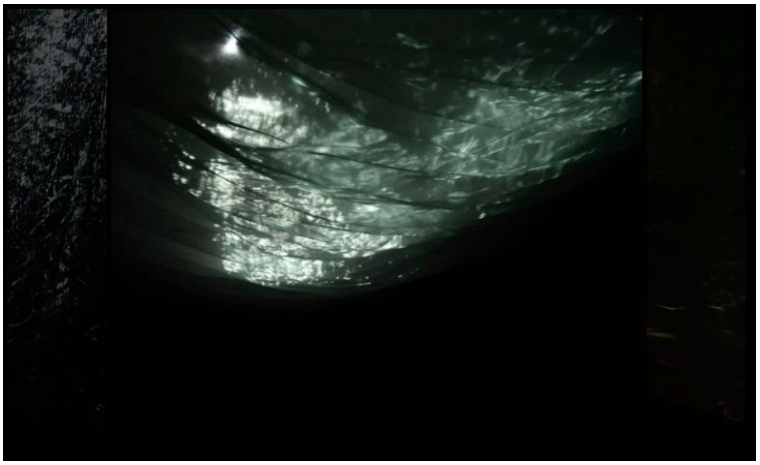

Figure 3. Madi Boyd and Nye Parry, UK, *Digital Forest*, 2018.
Installation photo from https://digitalforest.org.uk/

A psychological experiment was set up by Boyd and Dalton to run in parallel with the immersive art installation, by incorporating an attention test to establish whether her installation had the same effects as the forest on restoring attention. The results as yet are unavailable although comments reported from gallery attendees indicate viewers found it

relaxing[136] and as the reviewer Andrea Yanez reported, “There is a levity here in this still moment, a need to weave between the leaves, playing, touching; carefree and calm.”[137] Boyd’s work created illusions of areas of canopies, dense forest and rain, these changes in experience to me relate to Char Davies work *Osmose* which is discussed in section 1.8. I observe that the *Entangled* installation operates in a different manner to Boyd’s, with periods of patterning to stimulate creative thinking, while still exaggerating and abstracting.

Much of the inventiveness in *Entangled* is derived from the use of VR allowing the viewer to have the opportunity to interact with the work and in doing so form their own relationships. They can determine on their own positions, making choices as to whether objects fall around them or through them. They can walk through planes that in real life are impossible to transverse, play with shadows and experience the view of their own body as it passes through them, providing unexpected experiences. De Bono states that lateral thinking and humour are both ‘pattern-switching’ processes. Both require a change from a predictable, expected pattern to an unexpected one. In an interview with The Guardian in 2007, de Bono said, "What the joke displays is a switch in perception. This is important in changing the way we think.”[138]

Based on Shore’s museum curation with respect to scientific communication discussed in section 1.1,[139] I aim to create art that communicates a fundamental awareness and engagement with science, and which provides elements of intrigue for those who are informed, and offers freshness and humour to entertain. For example, the shadows formed in the gallery space are related to the shadows I have constructed in the VR to create a metaphoric entanglement between the real and the virtual spaces. There is a straightforward relationship when the shadows outside and in the VR both act in the same manner, such as the formation of darkness where light is blocked and the shadows shifting as you move around in relation to a light source. However, the relationship breaks down when the VR shadows

[136] Madi Boyd, ‘Professional Development Bursary Blog – Work so Far

[137] Madi Boyd, Polly Dalton, and Nye Parry, ‘Digital Forest’.

[138] Angela Balakrishnan, ‘Interview: Edward de Bono’, *The Guardian*, 23 April 2007, sec. Education, https://www.theguardian.com/education/2007/apr/24/highereducationprofile.academicexperts.

[139] Shore was quoted earlier as aiming to, “communicate the fundamentals of the subject which are relevant to the uninformed, have enough variety to intrigue the informed and reinterpret the content with freshness and humour to surprise and entertain the specialists.”

Jane Webster and Joseph J. Martocchio, ‘Microcomputer Playfulness: Development of a Measure With Workplace Implications’, *MIS Quarterly 16*, no. 2 (June 1992): 201–26, https://doi.org/10.2307/249576.

behave differently from shadows in the physical world. The Klein bottle shadow comes through the wall and shadows of people appear without their bodies being visible and at times are more like silhouettes. When the relationship of known, predictable dynamics breaks down, there is a disruption between prior knowledge and new experience. This can provide an opportunity for a dislocation for those unfamiliar with VR and an opportunity for people more familiar with the technology to test the new information. Other creative relationships within *Entangled* are discussed in more detail in chapter 2 and an analysis of an earlier work in this body of research, *Matter Matters,* will show the intentional use of imagination and inventiveness to invite engagement.

1.4 Contemporary Practice and Challenges

This section situates my practice at the intersection of art and science communication by focusing on select examples of contemporary art. It also serves to identify some broad challenges that have surfaced in my research. I provide indications of new developments in the overlap of art and science and discuss challenges in operating at the intersection of these disciplines. An analysis of works in the 2018 Australian Science Communication art exhibition is provided as a recent example of art within this arena. I highlight differences in New Zealand practice between my area of interest and current trends in art communication, suggesting that the majority of current work in science communication in New Zealand is environmentally-based. Some challenges I have encountered while operating a niche area in a small country are then presented. This section finishes with an overview of European initiatives in art and science (where the majority of particle research institutes are located) with the consideration of two works about quantum physics which have been successful in recent prestigious, international awards. I will introduce how my work achieves some similar qualities with different methods and aims. This leads into the following section where I define my specific scientific foci in greater depth and discuss a range of particular art practices to provide original contribution at the intersection of art and science communication.

As noted earlier, the notion of a recognised field or discipline called Science Communication is relatively recent (in the 20th century), while the interplay and mutual interest in the relationships between art and science have a considerably longer history. *Leonardo* is an international peer-reviewed journal that provides two-way links between art and science.[140] It

[140] 'MIT Press Journals', MIT Press Journals, accessed 4 April 2018, https://www.mitpressjournals.org/.

was amalgamated with *The International Society for the Arts, Sciences and Technology,* whose vision statement is to enhance communication amongst artists, scientists and engineers to support "sustainable environmental practices, spreading global scientific and artistic literacy, creating technological equity and encouraging freedom of thought and imagination." In 2017 *Leonardo* created a forum for debate on a PhD degree in art, design and 'artscience'. They acknowledge that world-wide, most universities are only in the planning stages of the art and design PhD courses.[141] New Zealand's forward-looking development of practical-based PhDs and my focus on art *and* science communication, position this research at an opportune time to provide an original contribution.

STEM to STEAM

Art has been positioned and acknowledged as enriching the fields of science, technology, engineering and mathematics (STEM), through the call for a re-collaboration of the acronym to STEAM. The basis of STEM is to encourage "innovators, educators, researchers, and leaders who can solve the most pressing challenges facing our nation and our world, both today and tomorrow."[142] New Zealand has recognised job growth in these areas and the need for "innovative thinkers". [143] John Maeda, US graphic designer, computer scientist and innovator on the computer platform *Second Life* points out that to get the creative and innovative qualities that STEM aspires to, the arts need to be incorporated. Maeda, who is president of the Rhode Island School of Design in USA, developed the first STEAM programme to include the 'A' for the arts into the STEM model. Maeda says that "there is great power in both fields taken separately and more in both fields put together."[144] I align with Maeda's position, that it is not the job of artists to present the results of science but as he says, art's role is to, "enrich the questions that are being asked."[145]

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[141] 'Call for Papers: PhD in Art and Design', Leonardo/ISAST, 8 January 2017, https://www.leonardo.info/opportunity/call-for-papers-phd-in-art-and-design.

[142] 'Science, Technology, Engineering and Math: Education for Global Leadership | U.S. Department of Education', accessed 30 May 2018, https://www.ed.gov/Stem.

[143] Michelle Curran, 'So Why the STEM Push? — EducationHQ New Zealand', accessed 7 January 2019, https://nz.educationhq.com/news/33914/so-why-the-stem-push/, paragraph 3.

[144] John Maeda, 'STEAM | ARCADE | Dialogue on Design', accessed 23 February 2018, http://arcadenw.org/article/steam.

[145] John Maeda, 'STEAM | ARCADE, paragraph 8.

David Harris, Australian artist and prominent science communication practitioner, is adamant that art should not be "the handmaiden" of science, but should bring alternative perspectives.[146] I would posit that Harris and I have both produced works that on a spectrum could sit closer to 'illustrating' science, yet the majority of our work has an aesthetic sensibility and a conceptual independence of inquiry and these factors primarily position our practice in the art world domain. An example of Harris' work that I see as closer to illustration of science is *Cymatic Water Table* (2015)[147] which uses sound to make water vibrate to create waves. While this is reminiscent of science demonstrations and could be comfortably located in a science museum, the physical structure of the apparatus and the creation of what he describes as "spider-web-like" formations means it could also be positioned in an art gallery.[148] The conceptual issues that Harris propounds of confronting the deficit model of science communication while not minimising the art are more clearly articulated in works such as *Waving Back* (2018).[149] This work has sensors detecting spectators' movements which trigger tree limbs to wave back as if in conversation with the person, a playful aspect to the work. The symbiotic relationship between humans and nature is more detached from the illustration of science because it facilitates the capabilities of art to convey conceptual issues.

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[146] Harris, David. 'CLOT Magazine | In Sci-Art, Art Should Not Merely Be a Servant of Science, David Harris', 2016. https://www.clotmag.com/contributors/david-harris-2.

[147] 'Cymatics Definition and Meaning | Collins English Dictionary', accessed 7 May 2018, https://www.collinsdictionary.com/us/dictionary/english/cymatics.

[148] David Harris, 'Cymatic Water Table (2015)', sciartica, 28 November 2015, https://sciartica.net/portfolio/cymatic-water-table/.

[149] Harris has proposed a 'manifesto' on the deficit model. https://sciartica.net/portfolio/against-the-deficit-model

Figure 4. David Harris, Australia, *Cymatic Water Table,* 2015.
https://sciartica.net/works/cymatic-water-table/

Figure 5. David Harris, Australia, *Waving Back,* 2018.
https://sciartica.net/works/waving-back/

Figure 6. David Harris, Australia, *Neutrino Flux,* 2014.
https://www.sciartcenter.org/david-harris.html

David Harris curated an art exhibition as part of the 2018 Australian Science Communication Conference selecting a range of works from Australia (10), New Zealand (3) and international artists (9), including some cross-disciplinary collaborations. Excluding one larger group collaboration, the majority of artists or scientists were female (76%) and all had university qualifications, with nine either with, or studying towards PhDs and four with both science and art qualifications. The works were predominantly digital images, photographs, or projected 2D digital animations (81%) however they did include drawings, paintings and felting. Fourteen of the twenty-one works were about the natural world and it appeared to me that six featured microscopic images that had been enhanced or distorted. From the documentation provided it would seem that none of the works was about quantum physics.

However, Harris has created a number of artworks based on quantum physics such as: Particle Wind Chime; Edges of Color (about quantum randomness); and Stigler's Law of Eponymy (which uses cosmic ray data). *Neutrino Flux* (2014) is a work where the viewer interacts with a detector that triggers a light display that is based on data from the Antarctic IceCube neutrino experiment.[150] Relevant to my previous discussion of science communication, Harris describes how this installation will be experienced differently depending on the viewer's understanding of science. While he considers that a viewer with little scientific knowledge may be "intrigued" by the spatial and visual effects, he considers that a scientist may notice the references to the IceCube experiment and deduce that they are travelling through the installation as a quantum neutrino.[151]

A group of New Zealand artists and scientists collaborated to produce a play called *Into the Uncanny Valley* (2012) which addressed many aspects of quantum physics. It was described as having, *"*jaw dropping visual and sound design", although was termed as, "like an entertainingly performed physics lecture at times." [152] The discipline of theatre and the narrative structures employed, clearly differentiate this project from the research I am undertaking.

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[150] 'IceCube Neutrino Observatory', accessed 19 December 2017, https://icecube.wisc.edu/.

[151] Emma Snodgrass, 'David Harris', SciArt Center, accessed 17 February 2018, https://www.sciartcenter.org/david-harris.html.

[152] 'Into the Uncanny Valley', accessed 3 June 2018, http://www.joebleakley.com/faustroll.htm.

Figure 7. Collaboration, USA, Jennifer Martin in *Into the Uncanny Valley,* 2012. http://www.joebleakley.com/uv31.htm

A recent New Zealand performance project that addresses quantum physics is *Nonlocality* (2017-2018), a series of works by Mark Harvey, a New Zealand contemporary dancer, performance artist and video artist. Harvey teamed up with physicist Shaun Hendy to create a series of works based on the intersection of psychology and quantum physics, while also addressing Harvey's interests in issues such as "architectural, geological, geographic, psycho-social, and political currents."[153] Nonlocality is a physics term which is very closely related to entanglement. The 'principle of locality' states that objects can *only* be influenced by their immediate surrounds; however quantum entanglement is an example where nonlocality occurs.[154] Harvey created six performance pieces that included many theories of physics while also responding to other exhibitions at the Physics Gallery in Christchurch during the year. For example, "*Length Contraction* (2017) dealt with changes of length due to changes in velocities near the speed of light, while referencing Charlotte Drayton's modifications of the gallery

[153] 'Length Contraction: A Performance-Talk by Mark Harvey | The Physics Room', accessed 4 February 2018, http://www.physicsroom.org.nz/events/length-contraction-a-performance-talk-by-mark-harv.

[154] D. Rohrlich and S. Popescu, 'Nonlocality as an Axiom for Quantum Theory', 1995.

space in her exhibition and *Like stepping from concrete to carpet*[155] *Gas* (2018) referenced entanglement with videos of two gas fires playing in separate locations at the same time. Harris also uses properties of gas to question psychological and political dynamics that are not part of the quantum reference.[156] We work in different modes and our aims are clearly different, but his interest in including quantum physics and the humour in many of his projects provides a salient overlap.

Globally, and particularly in New Zealand, a current focus in science communication is on environmental concerns.[157] [158] *Leonardo* internationally situates environmental science as one of its main aims and many projects are based around climate change and sustainability.[159] Janine Randerson, a New Zealand media artist and international exhibitor and author, who has been published in Leonardo, often uses projections and captured data in her artworks to focus on ecological systems in the environment and climate crisis. *Anemocinegraph* (2006) compares micro and macro systems of weather collection, which translates scientific data into artworks that push away from the scientific collection as she redesigns her own version of apparatus to question the role of science. A strong thrust in environmental issues currently comes from University of Otago, with its courses, conferences, and exhibitions. *Performing Ecologies Conference* (2018) features Jenny Rock, environmental artist and marine biology researcher alongside performance designer Dorita Hannah in *The Performance of the Real*, which presents environmental provocations on ecology topics such as environmental activism, morality, Indigenous paradigms and dystopic futures.[160] Ian Clothier, New Zealand artist who has exhibited internationally, curator, academic, Director of Intercreate Research Centre and an

[155] 'Length Contraction by Mark Harvey: A Performance-Talk', accessed 4 February 2018, https://allevents.in/christchurch/length-contraction-by-mark-harvey-a-performance-talk/1128903423905745.

[156] 'Gas | The Physics Room', accessed 4 February 2018, http://www.physicsroom.org.nz/exhibitions/gas.

[157] Madeleine Bunting, 'The Rise of Climate-Change Art', *The Guardian*, 2 December 2009, sec. Art and design, https://www.theguardian.com/artanddesign/2009/dec/02/climate-change-art-earth-rethink.

[158] 'Entering the Century of the Environment: A New Social Contract for Science: Discover', accessed 12 November 2017, http://eds.b.ebscohost.com.ezproxy.massey.ac.nz/eds/detail/detail?vid=1&sid=0675e071-f826-49b9-9fb1-ddac29145406%40sessionmgr102&bdata=JnNpdGU9ZWRzLWxpdmUmc2NvcGU9c2l0ZQ%3d%3d#AN=edsjsr.2894024&db=edsjsr.

[159] 'Our Mission', Leonardo/ISAST, 3 October 2016, https://www.leonardo.info/mission.

[160] University of Otago, 'Performing Ecologies Conference', University of Otago, accessed 3 March 2018, https://www.otago.ac.nz/news/events/otago691570.html.

influential contributor to the New Zealand art and technology scene is currently creating art in the environmental field and commented that from his experience a more compelling case for funding is made in New Zealand if digital work is relevant to environmental concerns.[161] He commented that New Zealand shows sensitivity to Indigenous cultures in issues of the environment and that whenever his collaborations intersect the environment they always include Indigenous groups as they provide deeper philosophical context. SCANZ engages with tangata whenua and Te Ao Māori and in terms of contemporary visual art practice, Kereama Taepa creates the only discernable Maori VR contemporary artwork in New Zealand.

My area of interest differs from more commonly explored environmental issues and the context of colonising forces within societies where Indigenous peoples have been subjugated. It is pertinent to acknowledge that my heritage is European, and that I am a first generation New Zealander. My parents, both of European descent, were born and educated in India and two of my siblings were born in India. My parents' accents and customs were a hybrid of English, Indian and New Zealand contexts, but within my art practice I do not draw on this cultural hybridity within the context of British colonial expansion and rule. My education spanning the fields of art and science, and my interest in technology are more prominent influences on my research. Within these intersecting spheres of interest I acknowledge the complex, and often conflicted contextual conditions that have enabled major developments in art, science and technologies (relating to governmental, military and economic agendas).

As a New Zealand-based artist working in the digital and VR fields I have encountered certain challenges. While the internet has opened up the world globally, financially we are still at a disadvantage in New Zealand when it comes to working with technology. Auckland-based digital artist and educator, James Charlton, has experienced 200-300% mark-ups on electronic components in New Zealand. To enable constant access to the VR equipment during this doctoral study, I purchased an expensive high-functioning computer, graphics card and VR headset.

Because of the small size of New Zealand I have found dialogues limited within my field. Formal discussions around art's relationship with science communication are still relatively restricted, and priorities of discourse have recently been focused on the important issues of diversity and community in science, these being strong themes within the 2018 New Zealand Science Communication conference. I could find little direct relevance within this conference

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[161] From an interview between this researcher and Ian Clothier.

to the themes explored in my research. James Charlton has noticed that the small size of New Zealand is amplifying the problem of dialogues in niche areas. For example, to his knowledge there is only one solely digital art gallery in the country. Engagement with new media has been slim in recent times for many New Zealand public museums and galleries, or restricted to video projections often involving spatialised sound and/or some form of sensor triggered activity, but rarely engaging with more recent, immersive technology platforms. The VR meet-up groups and symposia I have been aware of in New Zealand are highly orientated towards gaming and instructional training outputs. Unfortunately some networks (such as Aotearoa Digital Arts and SCANZ), after having a period of intense energy and productivity, largely driven by individuals volunteering their time and episodic project-based funding, have become quieter in their activities.

Charlton's observations, which were taken into consideration during his PhD study in the UK and involvement with such festivals and research gatherings as Transmediale in Berlin, make it clear that internationally there are larger opportunities and greater resources available. In the USA, UK and Europe there are greater infrastructures and whole institutions that are focused on electronic art and/or on art and science interrelating. For example, the Wellcome Collection in the UK allows the creation of interesting concepts for shows and increased dialogues[162] and the NTT InterCommunication Centre in Tokyo opened in 1997 aiming to connect artists and scientists. Korea, China, Taiwan and Brazil, have more recently opened new media institutions.[163]

While many opportunities are offered worldwide, competition is stiff. For example, Ars Electronica, formed in 1979 and which is based in Linz, Austria, has leading international artists, institutions and large production teams, often with government assistance behind them, competing for recognition.[164] Arts at CERN has been operating since 2011 and now

[162] 'Wellcome Collection | The Free Museum and Library for the Incurably Curious', Wellcome Collection, accessed 29 November 2017, https://wellcomecollection.org.

[163] Oliver Grau, *Virtual Art : From Illusion to Immersion*, Leonardo (Cambridge, Mass. : MIT Press, ©2003, 2003).

[164] An example of the extent of financial, technical and other support is evidenced by Ars Electronica Hybrid Art winner, K-9 Topology by Maja Smrekar which was supported by: Ministry of Culture of the Republic of Slovenia, Municipality of Ljubljana - Department for Culture, European Commission – 7th Framework Programme (KiiCS) // Curatorial and production team: Jurij Krpan (SI), Sandra Sajovic (SI), Petra Milič (SI) // Expert collaborators: Andrej Strehovec (SI), Marko Žavbi (SI), Institute of Biochemistry, Faculty of Medicine, University of Ljubljana (dr. Alja Videtič Paska (SI), dr. Tilen Konte (SI)), Department of Forestry, Biotechnical Faculty, University of Ljubljana (dr. Miha Krofel (SI)), Mia Zahariaš (SI), Manca

provides 4-6 residencies a year, including the Collide International Residency Award to allow artists to work intensively with particle physicists who are part of the CERN (European Organisation for Nuclear Research) laboratory, the home of the Large Hadron Collider. "Collide proposes to transform the way art and science encounters are understood, and to challenge new modes of dialogue and enquiry." [165] However, as an indication of the competition, Arts at CERN provides a guest artist programme only for invited artists who have an "extensive internationally recognized career".[166]

Semiconductor and Markos Kay are two artist practices that have been recognised on the international stage in a similar area to my work, however, both operate in different modes with different aspirations. Markos Kay is a UK-based digital artist, educator and recipient of an honourable mention in 2018 Ars Electronica. Kay works with CERN to generate representations of a number of quantum processes by setting up visual computer simulations, similar to scientific simulations. In *Quantum Fluctuations* (2018), these result in abstract, animated patterning to represent quantum collisions involving many particle properties, capturing the randomness of particle interaction. His work has been described as taking science and uncovering the "beauty, complexity and simplicity just like art,"[167] which I would suggest sums up some of the qualities that art can bring to science communication. With the aid of CERN scientists, Kay communicates their combined ideas of what the processes in particle physics could look like. These are very literal representations, more in the category of illustrating their imaginations, rather than giving the viewer the opportunity to be involved in the process. These are presented as a 2-dimension film which I find unusual for a simulation of 3-dimensional properties.

Kemperl (SI), Lojze Jazbinšek (SI) // Light design and technical support: Jure Sajovic (SI), Scenart (SI) // Photo: Borut Peterlin (SI), Miha Fras (SI), Sunčan Stone (SI).

[165] 'Guest Artists', Arts at CERN, 5 January 2017, https://arts.cern/programme/guest-artists.

[166] 'Guest Artists'.

[167] 'PRIX ARS', accessed 3 October 2018, http://prix2018.aec.at/prixwinner/27961/.

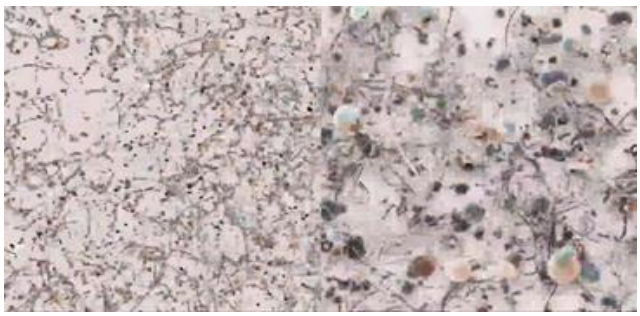

Figure 8. Markos Kay, UK, *Quantum Fluctuations,* 2018. www.mrkism.com This image is used with permission. It remains copyright property of Markos Kay. All rights reserved, not for copying or further distribution.

Semiconductor is UK-based, Ruth Jarman and Joe Gerhardt, who have won many prestigious awards and fellowships with their electronic and science-based artwork. *Halo* (2018) was commissioned and funded by the Swiss venture, Audemars Piguet, and curated by the Mónica Bello, Head of Arts at CERN, who they had worked with on a prior residency at CERN. Semiconductor take data directly from CERN and use intermediary software and hardware to create new graphics, sounds, and lights to communicate the data by new representations.

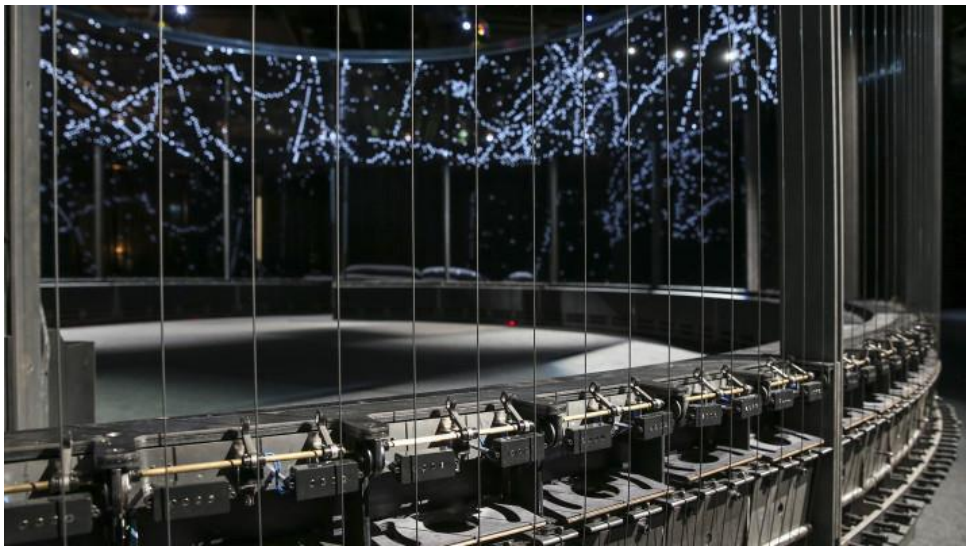

Figure 9. Semiconductor, UK, *Halo,* 2018. http://semiconductorfilms.com/art/halo/ This image is used with permission. It remains copyright property of Semiconductor. All rights reserved, not for copying or further distribution.

Halo encircles the audience with a 10m diameter circle of screens with point lights that respond to the data, and piano strings surround the space. The inputted data activates the mechanism for hammers to strike the strings so the sound being heard is not only within the circle but throughout the nearby environment. The sound the audience hears is not the direct sound from CERN but the mediated sound of the constructed instrument, "transcending the scientific aims of the data".[168] I would agree with the description that Semiconductor's installation, *Halo*, is bringing "to life the precision and complexity of particle physics and art."[169] The translation between the science and the artwork communicates the science by creating new abstract representations; their research, "interrogating science as a language and the development of knowledge."[170] Describing their installation *Halo,* they say, "this is the technological sublime", conveying that *Halo* is the exemplar of it. [171] My work also addresses the technological sublime as discussed in section 1.7. While these aspects and the immersive nature of this work link with my practice, and it addresses the topic of particle physics, Semiconductor's installation provides a different point of view to mine as it makes the scientific data available to the senses whereas my work aims to confront the thought processes required in understanding quantum-level entanglement and question the extension from micro to macro environments.

Investigations have enabled me to create parameters in my research project that focus on an individual creative output, with a targeted collaboration in sound composition, rather than trying to establish a bigger collaborative team. In the following section I will discuss quantum entanglement in more detail. This will enable me to concentrate my attention on how artists have approached the particular quantum properties that I am investigating.

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[168] Dana Mortada, 'Audemars Piguet Unveils HALO By Semiconductor At Art Basel 2018 - A&E Magazine', 24 May 2018, http://aeworld.com/lifestyle/art/audemars-piguet-unveils-halo-by-semiconductor-at-art-basel-2018/.

[169] Dana Mortada, 'Audemars Piguet Unveils HALO.

[170] 'Semiconductor Wins Collide@CERN Ars Electronica Award - Ars Electronica Blog', 13 August 2015, https://ars.electronica.art/aeblog/en/2015/08/13/semiconductor/.

[171] Audemars Piguet, *Art Basel 2018 - Behind the Scene of "HALO" by Semiconductor*, accessed 6 May 2018, https://www.youtube.com/watch?v=pWrNczgtBdg.

1.5 Entanglement

"Spooky action at a distance" Einstein[172]

Einstein's description of quantum entanglement articulates the mysteries of the 'communication' between vastly separated quantum particles. Explanation of this, including how the principles form the basis of my art investigations to communicate and provoke destabilisation of common understandings of the physical world, is presented here. By first outlining the scientific theory of entanglement I will show its far reaching impact and prolific nature and its potential role in enriching understanding of the physical reality around us. Secondly, two significant aspects of entanglement are discussed: quantum computing and encryption. I also investigate examples of current artistic practices drawing on genres of science fiction, myth, fantasy, spiritual science and illustrative science and highlight how these are in stark contrast to my research and the intent of the practice. An analysis of two contemporary works demonstrates how artists have previously addressed the properties of entanglement and I position how my approach differs. The chapter concludes with a case study of the Australian academic artist, Jonathan Rehwoldt's investigation of entanglement.

Humankind has for thousands of years attempted to discover the smallest particles of existence. As far back as around 420 BC, 'Atomists' believed that tiny atoms were the smallest building blocks. John Dalton (1766–1844), provided the model for the 'modern atom' based on chemical reactions. Smaller parts of the atom, electrons, were not discovered until 1894. New Zealander, Ernest Rutherford (1873–1937) is considered to be the founder of nuclear physics; his work with radioactive elements led to the discovery of the positive nucleus of the atom and splitting the atom. In 1913 Niels Bohr detected the positive nucleus and this was followed by the discovery of the neutron and proton that made up the nucleus. Back in 1801 Thomas Young had devised the double slit experiment, which used a single pulse of light to show that light could create interference patterns of waves.[173]

[172] Juan Yin et al., 'Bounding the Speed of `spooky Action at a Distance'', *ArXiv:1303.0614 [Quant-Ph]*, 4 March 2013, http://arxiv.org/abs/1303.0614.

[173] 'Thomas Young | British Physician and Physicist', Encyclopedia Britannica, accessed 21 December 2017, https://www.britannica.com/biography/Thomas-Young.

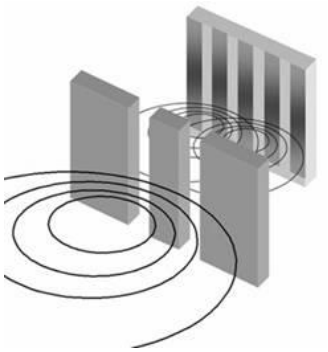

Figure 10. The double slit experiment.
http://idealab.ucdavis.edu/IST/ISTF08/lectures/F08Lecture17vhtml_files/image002.jpg, Courtesy of Evan Fletcher.

Max Planck isolated discrete quanta (quantities) of energy showing that light travelled in discrete packages, later named photon particles.[174] When one such photon at a time was sent through a double slit apparatus, the traces of characteristic wave interference pattern were still observed. This duality of the particle and wave was the beginning of quantum theory. The European Organization for Nuclear Research (CERN) runs the Large Hadron Collider in Geneva, a 27 meter circular tunnel of electromagnets that accelerate particles, colliding them to reveal the properties of quantum particles.[175]

Entanglement revolves around the communication between these smallest building blocks of the universe, quantum particles. Properties of these particles such as polarisation of photons of light, only settle on the polarised direction when the particle is observed and until they are measured, they are indeterminant. This means that the properties are essentially all the possibilities and it is only when measured that the particle assumes one value. This is often interpreted as the particle being 'blurry' until measured and this will be discussed later in this section with respect to particular artists' practice of quantum physics. Pairs of entangled particles have properties that are interrelated, so that if the property of one particle is determined, then at the exact same time, the state of the other particle is instantly known.[176] This can happen across great distances, the particles can be at opposite sides of the universe,

[174] W. F. Bynum, *A Little History of Science* (New Haven : Yale University Press, [2012], 2012),

[175] The LHC is undergoing major upgrades, which will increase the number of collisions per second to enable 10 times more data to be collected between 2026 – 2036.
'The Large Hadron Collider | CERN', accessed 4 August 2018, https://home.cern/science/accelerators/large-hadron-collider.

[176] George Musser, 'FAQ How Are Entangled Particles Created? [Video]', Spooky Action at a Distance, 2016, http://spookyactionbook.com/2016/02/21/faq-how-are-entangled-particles-created-video/.

yet entangled particles will still seemingly communicate. This is what Einstein called "spooky action at a distance", because it would imply communication is happening faster than the speed of light, though, as Einstein established, it is an impossibility.[177] How this communication occurs remains inconclusively explained, however, when it is, I attest that our understanding of our reality will be significantly shifted.

Scientists have shown that entanglement is all around us. For example, radioactive sodium gives off entangled gamma rays (electromagnetic radiation), mercury can emit entangled photons (light), and even fluorescent lights emit entangled particles.[178] Leonard Susskind, director of the Stanford Institute for Theoretical Physics, considers that entanglement could be what "sews space together"[179]. Buniy and Hsu, American university scientists have used mathematical and scientific models to show that the cosmology of the big bang implies a high degree of entanglement in the universe.[180] Entangled particles and atoms can now be made, measured and used, however, *how* they manage to communicate is still unresolved.

Because Einstein has ruled out entangled pairs communicating at a speed faster than light, other methods need to be considered. If there are higher dimensions curled up within our spatial dimensions, it could be possible for two particles to appear to be very far apart in our three-dimensional world, yet next to each other, or even with no separation at all, but in another dimension.[181] While there is currently not much support for this theory, higher spatial dimensions are in line with other modern theories; string theory proposes eleven dimensions and M-theory fourteen dimensions. At this stage the theory of wormholes connecting entangled particles has more support; this theory suggests that one of the pair of particles may go down a wormhole and stay connected to the other. [182] [183] The possibility of wormholes is

[177] Yin et al., 'Bounding the Speed of `spooky Action at a Distance'', *ArXiv:1303.0614 [Quant-Ph]*, 4 March 2013.

[178] Musser, 'FAQ How Are Entangled Particles Created?'.

[179] K Cole **quoted in**, 'Wormhole Entanglement and the Firewall Paradox', *Quanta Magazine*, 24 April 2015, https://www.quantamagazine.org/wormhole-entanglement-and-the-firewall-paradox-20150424/.

[180] Roman V. Buniy and Stephen D. H. Hsu, 'Everything Is Entangled', *Physics Letters B* 718, no. 2 (5 December 2012): 233–36, https://doi.org/10.1016/j.physletb.2012.09.047.

[181] Bradford Skow, *Objective Becoming* (Oxford, 2015), https://www.bookdepository.com/Objective-Becoming-Bradford-Skow/9780198713272.

[182] Cole, 'Wormhole Entanglement and the Firewall Paradox'.

visualised and manifests in sequences within the *Entangled* VR animation, while chapter 2 will detail how higher dimensions are referenced in my work.

Military and corporate funding provide controversial political interference in the direction of entanglement development[184], however they have given rise to two important uses: quantum computing and encryption. Quantum computing will substantially increase the computing speed and allow the computation of solutions that are unable to be tackled on current computers. Instead of a bit being either 0 or 1, a quantum bit (qubit) can exist in both states until determined. This means that all possible solutions can be checked at the same time. However, this state collapses easily and it is entanglement that can prolong it. Researchers in Japan have entangled over one million systems towards the development of quantum computing and they were only limited by data storage space.[185] Entanglement is beginning to be used in a vital role in national security encryption, because the interference of one entangled particle will determine the property of the other pair and so create an alert. The Chinese government has recently generated entangled photons on a satellite, using the vacuum of space to enable the particle to be sent to earth.

In the past few years entanglement has been a subject scrutinised by artists. In different genres, artists have imagined and reimagined ways to represent and explain through their work ways sub-atomic particles exist and impact on lived experience. The interest in entanglement lends itself to the question of how we represent reality in and through art.

Science Fiction, Fantasy, Myth, Spirituality

Science fiction (sci-fi) holds a prominent place in cinema, novels, illustrations and painting, borrowing liberally from science. While I do not align my work conceptually with sci-fi, I acknowledge the pervasiveness of the visual genres within it. My work may have formal aesthetic correlations with sci-fi but I would argue that the intent of the work does not adhere

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[183] Katia Moskvitch, 'A Link Between Wormholes and Quantum Entanglement', Science | AAAS, 2 December 2013, http://www.sciencemag.org/news/2013/12/link-between-wormholes-and-quantum-entanglement.

[184] Trevor Pinch, 'Review Essay: Karen Barad, Quantum Mechanics, and the Paradox of Mutual Exclusivity', *Social Studies of Science* 41, no. 3 (June 2011): 431–41, https://doi.org/10.1177/0306312711400657, 435.

[185] American Institute of Physics, 'Quantum Computing Advances with Control of Entanglement', Quantum Physics, 27 September 2016, https://phys.org/news/2016-09-quantum-advances-entanglement.html.

to existing definitions of the sci-fi genre. To demonstrate this, I offer a comparison with Csicsery-Ronay's seven beauties of science fiction, which addresses the many sub-sets of sci-fi.

Csicsery-Ronay states that people experiencing science fiction will expect: "fictive neology, fictive novums, future history, imaginary science, the science-fictional sublime, the science-fictional grotesque, and the technologiade."[186] Fictive neologies are *new* terms or other signs such as visual effects that are suggested will occur in the future, an element I am not using in my work.[187] Neither the Klein nor the spacetime curve are new words or objects and while I may use them in different ways to establish metaphorical readings, this does not make them fictive neologies. Csicsery-Ronay considers that fictional novums are the defining feature of science fiction. I interpret this as an aspect that is within the limits of possibility but is fictional. My work *Entangled,* is based on quantum entanglement and cognitive dissonance,[188] which are proven phenomenon, not fictional.

Imaginary science is where I position the greatest distance of my work from science fiction. Csicsery-Ronay explains that science fiction takes metaphors of social life to create imaginary science, whereas I am creating visual, immersive metaphors to evoke the scientific and mathematical complexities of entanglement. Csicsery-Ronay presents the characteristic technologicade as "the transformation of human societies as a result of innovations attending technoscientific projects."[189] There is a proposed implication of the transformation of our understanding of reality as a result of scientific entanglement, however, my work is not a fantasy of how this will change society and so falls short of the technologiade component that Csicsery-Ronay presents.

Additional areas that I do not wish to position my work in relation to are, religion, spirituality, myth and fantasy. I have found many works that overlay these with aspects of scientific entanglement. For example Gregg Braden is an international author in the field of spirituality and science. His book, *Entanglement (A Tales of Everyday Magic)* and the on-line movie based

[186] Csicsery-Ronay, I. (2008). The Seven Beauties of Science Fiction. Middletown, Conn: Wesleyan, 5.

[187] Csicsery-Ronay, I. (2008). The Seven Beauties.

[188] Cognitive dissonance is a widely used psychology term to describe two conflicting ideas. This is covered in the following section 1.7.

[189] Csicsery-Ronay, I. *The Seven Beauties* 7.

on this, applies quantum entanglement to a psychic connection between twins.[190] Braden takes scientific theories and attempts to prove his own spiritual beliefs, which include not believing in evolution. Robert Segal describes in his book, *Myth: A Very Short Introduction* (2004) creationist science as that "which appropriates scientific evidence of any kind both to bolster its own claims and to refute those of secular rivals like evolution."[191]

Segal defines myths as stories that may or may not be true, stating that, "One form of the modern challenge to myth has been to the scientific credibility of myth."[192] He does not believe that we have to abandon myth for science, and I acknowledge the wealth of influences that myth and mythologies have brought to art. However, in my work unfounded stories could confuse the complex quantum theories that I am addressing.

Richard Mathews, USA English professor and author defines fantasy as "a fiction that elicits wonder through elements of the supernatural or impossible. It consciously breaks free from mundane reality."[193] While I use the capability of virtual reality technology to create expansive experiential visual and spatial metaphors, I am not conceptually presenting the supernatural.

I aim to create an awareness of scientific entanglement, but I have fought against using the imperative of art to predominantly 'instruct' about science because as Ken Arnold states in *Strange and Charmed*, it risks "the science becomes diluted and the art serves only to illustrate."[194] In my initial investigations of animations onto glass I attempted to illustrate a number of scientific theories; of chaos theory, holographic theory, uncertainty principle as well as entanglement. Not only was the range too large, the illustrative images such as the Hadron Collider made it didactic and too directive in its visual language. Feedback that I received from the PhD confirmation process was that the viewer was so busy trying to work out what they were trying to learn, that they were not feeling or experiencing anything. This began my focus into the specific area of entanglement and the experiential encounter.

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[190] 'Does Evolution Answer This One BIG Question?', Gregg Braden, 18 May 2017, https://www.greggbraden.com/blog/evolution-answer-one-big-question/.

[191] Robert A. Segal, *Myth : A Very Short Introduction*, Very Short Introductions: 111 (Oxford : Oxford University Press, 2003, 2003),

[192] Robert A. Segal, *Myth : A Very Short Introduction,* 6, 11.

[193] Richard Mathews, *Fantasy : The Liberation of Imagination*, Genres in Context (New York : Routledge, 2011, 2011),

[194] Siân Ede, *Strange and Charmed : Science and the Contemporary Visual Arts* (London : Calouste Gulbenkian Foundation, c2000, 2000), chapter 4.

Examining existing artworks addressing entanglement

To demonstrate how contemporary works have addressed entanglement and the differences to my research, I will present an overview of a number of recent artworks. *Spooky Action at a Distance, Visualized* (2016)[195] is an installation by new media artists, The Principals, a design studio in Brooklyn NY. One of the stated intentions of this artwork by Drew Seskunas, a co-founder of The Principals, is that the immersive aspect implied that entanglement is happening all around us.[196] The use of 'visualization' in the title confirms the focus on representation; the lights are shone at angles so the rays are internally reflected through rotating prisms, creating colours and interactions between the lights that directly addresses the waveforms. They state that "light transmission was a perceptible approximation of the forces of interaction that Quantum Entanglement references", which appears to be an artistic representation of splitting photons into entangled particles. While my work also provides an experiential reference to quantum wave duality (with the spacetime curves which is discussed later) and the implication that entanglement is everywhere, my approach is not as literal as this work and *Entangled* extends the use of coloured lights and immersive properties through the capabilities of VR to offer many further references to entanglement and to address the thought processes required to understand it.

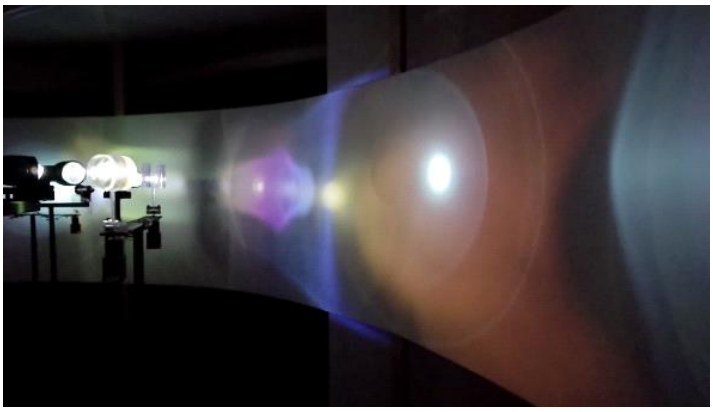


Figure 11. The Principals, USA, *Spooky Action at a Distance, Visualized,* 2016. https://www.fastcodesign.com/3055080/spooky-action-at-a-distance-visualized.

By blurring the boundaries between real objects and projected images, artists Valérie Collart, Naomie Kremer and Russian artists, Electroboutique, have addressed the entanglement of light and the indeterminant, (blurry) nature of particles before they are measured. Two video

[195] Diana Budds, 'Spooky Action At A Distance, Visualized', Co.Design, 6 January 2016, https://www.fastcodesign.com/3055080/spooky-action-at-a-distance-visualized.

[196] Diana Budds, 'Spooky Action At A Distance, Visualized'

works by Collart in an Australian exhibition, *Spooky Action at a Distance* (2016), use blurring of physical and digital boundaries, which fluctuate amongst the spatial, the image surface and the mechanisms of illusion.[197] Kremer's exhibition, *Age of Entanglement* (2015), combines paintings overlaid with video projections to blur the virtual with the real[198] and in *Chance Operations* (2015), Kremer projects a video of herself making the painting back on top of the painted surface. Kremer not only blurs the virtual and real, she disconnects the temporality, separating the two parts of the work and emphasising that the particles of light were entangled in the past but still influence each other later. Kremer's works show properties of entanglement, however, they also address personal matters such as family history, sexuality and mortality. In *Dictionary,* a multimedia sculpture, she connects previous activities of her father with the present by overlaying videos onto a dictionary.

Visual Uncertainty (2014) by Electroboutique focuses on the properties of particles only being determined when observed, by developing a secret technique where the wall is blank unless viewed through a large lens.[199] The scale of the lens provides a contrast to the minute nature of quantum, and the abstract patterns that are formed on the wall may be a representation of the patterns of entanglement, however, this interpretation is not clear. A strength of this work was the interaction which allowed the viewer to discover the patterns, however, their presence did not influence the patterns that were then displayed as is used in *Entangled.*

Some contemporary works diffuse the topic of quantum with other concerns, risking the dilution of the entanglement theme as discussed above by Arnold. *Gone phishing* (David Stjernholm), exhibited in the Bus Project *Spooky Action at a Distance* (2016) can be interpreted as linking to the fragile state in quantum when a particle has neither one property or the other. However, the overriding reading is of fraudulent internet use and the vulnerability of data in the intermediary state between sender and receiver.[200] Canadian Dance Company under Lesley Telford performed *Spooky Action at a Distance* (2016), where they used

[197] 'Kopenhagen Art Institute: Spooky Action at a Distance @ Bus Projects', Kopenhagen Magasin, 25 January 2016, http://kopenhagen.dk/magasin/magazine-single/article/spooky-action-at-a-distance-bus-projects/.

[198] Joe Ferguson, 'REVIEW: Naomie Kremer Tackles Quantum Entanglement at the San Jose Institute of Contemporary Art', *SCIART MAGAZINE*, 8 November 2015, http://www.sciartmagazine.com/3/post/2015/08/review-naomie-kremer-tackles-quantum-entanglement-at-the-san-jose-institute-of-contemporary-art.html.

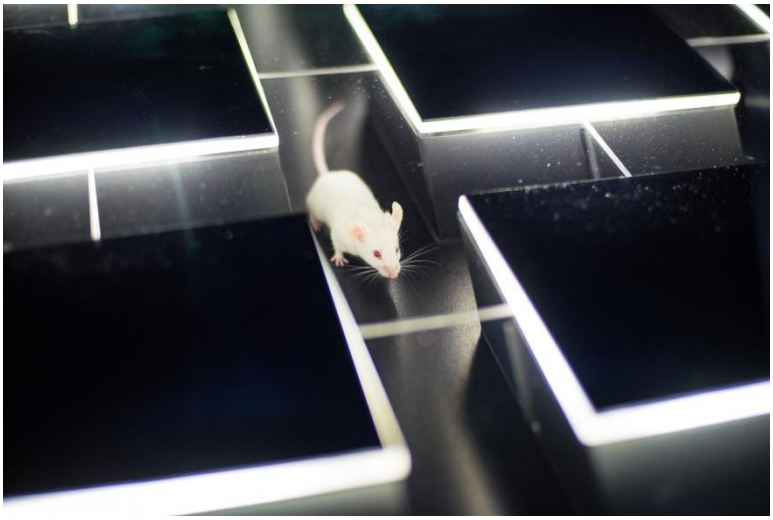
[199] 'Electroboutique: Visual Uncertainty', FutureEverything, 20 October 2014, http://futureeverything.org/artworks/electroboutique-visual-uncertainty/.

[200] 'Kopenhagen Art Institute'.

interactive lighting as well as dance and sound to present interconnectivity and personal relationships.[201]

While exploration of these themes have built meaningful works, my decision has been to focus on quantum entanglement and the importance of its possible implications, rather than risking diffusing it with another topic.

An art installation that I believe successfully focuses on quantum theory and entanglement is *1, 4…19* (2014) by the Russian collective, Where Dogs Run.[202] A live mouse runs through the real maze while a virtual maze is projected onto the wall above. Depending on the direction the real mouse takes, virtual mice join the projection, showing unrealised options as in the range of states in quantum. If the mouse is on target to collide with a virtual mouse, the real mouse has the options reduced with the addition of new walls. A focus of this work is temporal, with current options for the future determining the present. Referencing quantum, the path chosen is a probability and undetermined until the mouse goes down an option. Entanglement happens between the real and virtual, the results determining each other. This work is very intriguing; and yet the experiential encounter is predominantly geared towards the mouse.



[201] Vancouver Arts Review, 'Lesley Telford & Inverso's "Spooky Action Phase One"', *The Vancouver Arts Review* (blog), 8 December 2017, http://www.thevancouverartsreview.com/2017/12/lesley-telford-inversos-spooky-action-phase-one/.

[202] 'Where Dogs Run | 1,4... 19 (2014) | Artsy', accessed 15 February 2018, https://www.artsy.net/artwork/where-dogs-run-14-dot-dot-dot-19.

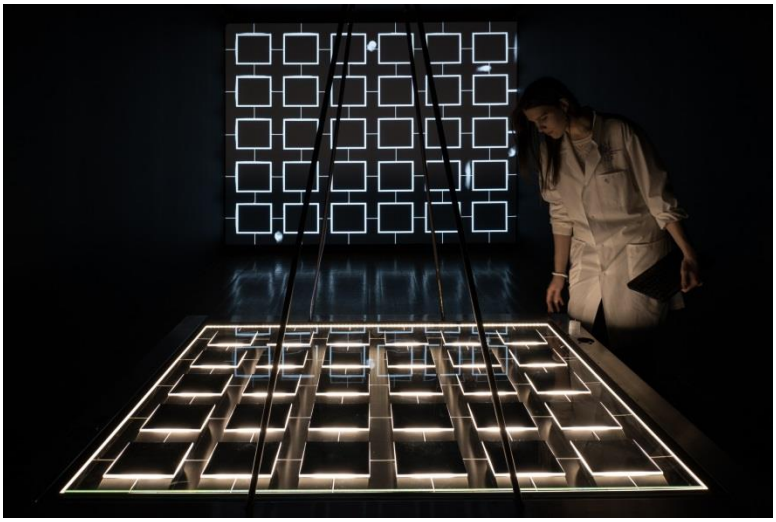


Figure 12. Where Dogs Run, Russia, *1, 4, 19,* 2014. (Two images above.)
Generative installation: mouse, robotic maze, camera, projection.
Quantum Entanglement exhibition, Laboratoria Art&Science Space, Moscow, 2014.
Photos: Yuri Palmin

Jonathan A. Rehwoldt's Master's thesis, *Spooky Action At A Distance* (2017) is a valuable body of work for positioning my investigations with respect to entanglement within current academic and artistic practice.[203] Rehwoldt approaches entanglement through his interpretation of Karen Barad's 'agential realism'. He summarises this as, "phenomena producing systems as an entangled constellation of material discursive apparatus working through one another."[204] [205] From this he proposes the interrelations of the physical studio space, digital space and the subconscious as a way to produce the materialism of the artistic phenomenon, which he uses to answer the question, "Can I experience remote human intimacy[?]"

Karen Barad is Professor of Feminist Studies, Philosophy, and History of Consciousness at the University of California and she has a PhD in theoretical particle physics and quantum theory. There is substantial depth in Barad's writings, covering the humanities, feminism, science and

[203] Jonathan Rehwoldt, 'Spooky Action At A Distance' (Master of Fine Arts, Virginia Commonwealth University, 2017), https://scholarscompass.vcu.edu/etd/4827.

[204] Jonathan Rehwoldt, 'Spooky Action At A Distance'.

[205] Bohr calls a phenomenon the inseparability of the object and the measuring arrangement, which includes the apparatus. Barad builds on the concept of phenomena, proposing that phenomena are the building blocks of existence. C. Calvert-Minor, 'Epistemological Misgivings of Karen Barad's "Posthumanism"', *Human Studies* 37, no. 1 (01 2014): 123–37, https://doi.org/10.1007/s10746-013-9285-x.

philosophy with many of her theories extrapolating from quantum science. With such a wide range of scope within Barad's work, I have chosen to focus on the aspects of entanglement that Rehwoldt interprets in his practical art to show how both Rehwoldt and Barad differ from my research in this specific area.

By generalising Niels Bohr's physics and philosophy, Barad uses quantum theory of particle properties to build her own philosophy of agential realism. [206] Agential realism is based on intra-actions, two terms she has defined. Intra-actions happen when things come together, which Barad likens to the superposition of waves forming new patterns, so as Hollin et. al. state, for Barad, intra-actions form a new 'everything'.[207] [208] Whenever this happens, an 'agential cut' is made in the world; this is where possibilities are determined and other possibilities are excluded.[209] It is based on quantum theory, relating to indeterminacy of a particle until a property is measured.[210]

Barad states that quantum theory is, "the correct theory of nature that applies to all scales"[211]. She takes agential realism into the macro realm in such diverse areas as pregnancy, sea creatures and factories.[212] Barad situates her theories in a democratic field of humans, animals, objects, conscious and the subconscious, all having agency as they intra-act with each other.[213] [214] From this, Rehwoldt's work focuses on everything being entangled at the macro

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[206] Karen Michelle Barad, *Meeting the Universe Halfway : Quantum Physics and the Entanglement of Matter and Meaning* (Durham : Duke University Press, 2006, 2007).

[207] Karen Michelle Barad, *Meeting the Universe Halfway.*

[208] G. (1) Hollin et al., '(Dis)Entangling Barad: Materialisms and Ethics', *Social Studies of Science* 47, no. 6 (01 2017): 918–41, https://doi.org/10.1177/0306312717728344.

[209] There are strong ethics issues of exclusion, however this is not relevant to my work.

[210] Graham Harman, 'Agential and Speculative Realism: Remarks on Barad's Ontology', *Rhizomes: Cultural Studies in Emerging Knowledge*, no. 30 (July 2016): 126.

[211] Karen Michelle Barad, *Meeting the Universe Halfway, 85.*

[212] G. (1) Hollin et al., '(Dis)Entangling Barad: Materialisms and Ethics', *Social Studies of Science* 47, no. 6 (01 2017): 918–41, https://doi.org/10.1177/0306312717728344.

[213] C. Calvert-Minor, 'Epistemological Misgivings of Karen Barad's "Posthumanism"', *Human Studies* 37, no. 1 (01 2014): 123–37, https://doi.org/10.1007/s10746-013-9285-x.

[214] The brief definition of agency that I am working with is, "the experience of causing actions and events in the world Stephen C. Pritchard et al., 'Non-Hierarchical Influence of Visual Form, Touch, and Position Cues on Embodiment, Agency, and Presence in Virtual Reality', *Frontiers in Psychology* 7 (25 October 2016).

scale. It is in terms of scale that my research significantly differs from both Barad and Rehwoldt.

My position is that entanglement only occurs at the quantum level. While it has been proven to operate extensively around us and can be built together to form systems such as quantum computers, it is not larger objects that are being entangled. This is in line with a number of papers reviewing Barad.[215] UK researchers Hollin et. al. point out that in Barad's theories, "the capacity to jump scales" is problematic and contentious.[216] US philosopher Graham Harman states that Barad is, "conflating two entirely different senses of the word "atomism," leading to difficult consequences for her philosophy."[217] Hollin et al. suggest that, "further attention needs to be paid to the politics of scale, and question whether insights from quantum mechanics should be smoothly related to phenomena that occur at the macro-scales that are more often of concern to social and cultural theorists."[218]

Barad insists that she is not using quantum theory as a metaphor, and that she is contributing to both social and scientific knowledge.[219] It will be discussed in chapter 2 how I employ larger objects in a metaphorical sense to enable the viewer to experience this bodily. The scaling in size of the apparatus results in its cracking, intended to reference the apparatus's role in quantum while also providing a warning of taking entanglement to macro levels.

[215] Pinch (2011) Morton(2012) Harman, Hollin et al, Woolgar and Lezaun, for example: Trevor Pinch, 'Review Essay: Karen Barad, Quantum Mechanics, and the Paradox of Mutual Exclusivity', *Social Studies of Science* 41, no. 3 (June 2011): 431–41, https://doi.org/10.1177/0306312711400657, G. (1) Hollin et al., '(Dis)Entangling Barad: Materialisms and Ethics', *Social Studies of Science* 47, no. 6 (01 2017): 918–41, https://doi.org/10.1177/0306312717728344, Graham Harman, 'Agential and Speculative Realism: Remarks on Barad's Ontology', *Rhizomes: Cultural Studies in Emerging Knowledge*, no. 30 (July 2016): 126, Steve Woolgar and Javier Lezaun, 'The Wrong Bin Bag: A Turn to Ontology in Science and Technology Studies?', *Social Studies of Science* 43, no. 3 (June 2013): 321–40, https://doi.org/10.1177/0306312713488820.

[216] G. Hollin et al., '(Dis)Entangling Barad: Materialisms and Ethics', *Social Studies of Science* 47, no. 6 (01 2017): 918–41, https://doi.org/10.1177/0306312717728344, 259.

[217] Graham Harman, (Quote in Abstract) 'Agential and Speculative Realism: Remarks on Barad's Ontology', *Rhizomes: Cultural Studies in Emerging Knowledge*, no. 30 (July 2016): 126.

[218] G. Hollin et al., "(Dis)Entangling Barad," 922.

[219] G. Hollin et al., '(Dis)Entangling Barad', 921.

Section 1.6 Simulacra, Dissonance and the Technological Sublime

This section offers links amongst aspects of simulacra, dissonance and the technological sublime that are relevant to providing simulated realities. In particular, a platform is developed to provide experiences of thought processes similar to those required to understand quantum entanglement.

Simulacra

Simulacrum is a term defined by French philosopher Jean Baudrillard as an unreal or fake reality that is indistinguishable from reality.[220] He separated simulacra into three orders: first as natural where we can step between the real and the simulacrum, "founded on the image, on imitation" [221]; second as productive, materialised by machine; and third as simulation that blurs with the reality. Baudrillard considered the third order of simulacra as the degradation of the real, by repetitive simulation that gradually replaces the real. French philosopher Gilles Deleuze shifts simulacra from more negative connotations by describing simulacra as containing "a positive power which negates both the original and copy".[222] Media theorist, Seth Giddings considers this to be because they are built upon dissimilarities from the original and can provide additional functionality. My research investigates specific positive functionalities that are gained with simulacra.

Baudrillard names the new third order simulacrum as, 'hyperreal', which is where the original reality has been replaced. In his book, *Simulacra and Simulation,* Baudrillard considers that we are actually living in 'hyperreality', where we see television and film as more real than our lives.[223] He positions the consumer reality of the USA as consuming the meaningless and

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[220] 'Jean Baudrillard. What Is a Simulacrum?', *The Next Simulacrum* (blog), 17 March 2013, https://nextsimulacrum.wordpress.com/2013/03/17/jean-baudrillard-what-is-simulacrum/.

[221] Jean Baudrillard, *Simulacra and Simulation*, The Body in Theory (Ann Arbor : University of Michigan Press, c1994, 1994), 121.

[222] Seth Giddings, 'Dionysiac Machines: Videogames and the Triumph of the Simulacra', *Convergence: The Journal of Research into New Media Technologies* 13, no. 4 (November 2007): 417.

[223] Jean Baudrillard, *Simulacra and Simulation.*

becoming a state of ignorance.[224] This consumer reality can now be considered real and arguably the original no longer exists.

The science fiction movie, *The Matrix,* presents a take that has been attributed as connecting with simulacra. The matrix is an elaborate system that no one realises is not reality; it is not a copy of reality, it is a simulacrum which is more enticing than reality.[225] A character in the Matrix is given the opportunity to move between the constructed matrix and the real. Although *The Matrix* overtly references Baudrillard's simulacra, with a copy of his book even appearing, Baudrillard decried *The Matrix* as misrepresenting simulacra because there were two separate realities that did not merge with each other.[226] Being able to leave a simulacrum and return is different from Baudrillard's third order simulacrum that blurs the edges between it and reality and does not allow transference between them.[227] Erandaru points out that *The Matrix* showed first order simulacra because the two were not intermingled, but separate worlds.[228]

Erandaru also positions Plato's *Allegory of the Cave* as a first order simulacrum because of this separation between the original and the simulation. The *Allegory of the Cave* (approx. 380BC) questions the understanding of reality and the importance of education and justice among other political themes.[229] Plato postulated that a person who had only ever seen shadows, would consider them more real than the objects that formed them. Plato talks about the pain of the realisation in the prisoner who escapes, and the slow process of understanding reality.[230] In the allegory, the original and the simulation of puppets providing the shadows are

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[224] E Erandaru, 'Augmented Reality Applications in Hand-Held Devices in the Light of Baudrillard's "Simulacra and Simulation"', accessed 13 July 2018 https://core.ac.uk/display/26436773

[225] 'SparkNotes: The Matrix Trilogy: Philosophical Influences', accessed 20 September 2018, https://www.sparknotes.com/film/matrix/section1/.

[226] Erandaru, 'Augmented Reality Applications In Hand-Held Devices'.

[227] 'Jean Baudrillard. What Is a Simulacrum?'

[228] Erandaru, 'Augmented Reality Applications In Hand-Held Devices', 22.

[229] Plato was a Greek philosopher at a time when philosophy, science and mathematics were one discipline. https://www.sparknotes.com/philosophy/republic/context/, accessed February 2019.

[230] Plato and Benjamin Jowett, *The Republic. [Electronic Resource]* (Waiheke Island : Floating Press, ©2009, 2009), http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=cat00245a&AN=massey.b3630220&site=eds-live&scope=site.

both accessible at the same time, and therefore as Erandaru suggests can be considered a first order simulacrum.

In a similar way that Baudrillard positions simulacra, I suggest that the practical uses of quantum entanglement, such as quantum computing are, and will change our world. However, the point of this research is not to investigate the social, political and ethical issues that are changed, but to offer an effective opportunity for audiences to gain insights into aspects of our current reality that we do not currently perceive.

In this way, I identify that my view corresponds with Paul Virilio's concept of 'virtuality'. He describes this as a new way of perceiving the reality due to the automation, particularly with computers, which generate the virtual reality automatically from the coding.[231] The 'vision machine' is this automation of perception, which involves a machinic perception, where our control is lost and our perceived sensory information is replaced with processed data. [232] The perceptual ability to differentiate between 'real' and virtual decreases, however, our physical reality is not changed. While this describes simulacra as a change in perception without changing reality, his is a negative demonising view of technology mainly influenced by military and war.[233] The focus of my research is in a differing element in the terms of the use of VR technologies, with creative intent and specific purpose in relation to scientific communication.

In a similar manner to *The Matrix* and the *Allegory of the Cave,* VR technology is a simulacrum where the viewer can traverse between the virtual world and the real. Emelin states that VR forms temporary simulacra; spaces that are not real yet can seem more real than our physical space.[234] The viewer stays in the physical world while a range of sensory inputs override the physical world creating a new and different reality. These can be more arresting than our reality as we can move through surfaces, experiencing a simulacrum that allows us beyond the limitations provided in our physical world. This is an aspect of VR that will be mined in more detail later in the analysis of *Entangled.*

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[231] Paul Virilio, *The Vision Machine*, Perspectives (Bloomington : Indiana University Press ; London : British Film Institute, 1994, 1994).

[232] Simon Bolz, 'Paul Virilio and the Concept of Virtuality', *Simbio* (blog), 10 March 2009, https://simbio.wordpress.com/about/paul-virilio-and-the-concept-of-virtuality/.

[233] Douglas Kellner, 'Virilio, War and Technology: Some Critical Reflections', *Theory, Culture & Society* 16, no. 5–6 (1 December 1999): 103–25, https://doi.org/10.1177/02632769922050890.

[234] Vadim A. Emelin, 'Simulacra and virtualization technologies in information society', *Nacional'nyj Psihologičeskij Žurnal, Vol 3, Iss 23, Pp 86-97 (2016)*, no. 23 (2016): 86, https://doi.org/10.11621/npj.2016.0312.

I contend that there are occasions when we can experience virtual reality merging with the physical reality, briefly providing a time when they are overlaid. When viewers reach out to touch something that they know is not real, but for a moment thought it could be, the two worlds have merged. The first order simulacrum is briefly a third order, and it is this transition that I will explore.

Cognitive Dissonance

The intermingling of the two realities discussed above can create a dissonance for the viewer. Cognitive dissonance occurs when a person attempts to understand two relevant thoughts, beliefs, opinions, knowledge or perceptions that oppose each other. [235]Festinger defines cognition as "any knowledge, opinion, or belief about the environment, about oneself, or one's behaviour."[236] The dissonance between the opposing understandings produces an uncomfortable feeling that creates pressure on the person to reduce the dissonance. This can be done by rationalisation, avoiding the situation, or changing an opinion or action.

When the person in the VR headset tries to assimilate the vision in front of them with what they know to be outside, they can experience cognitive dissonance. This most likely will only be momentarily, where they are suspended in the third order simulacra before the feeling of dissonance creates the pressure to rationalise the situation and separate the two realities. Within my VR work I have *purposefully* added disruptions to provide opportunities for this to happen. Passages that can provide this include the sound of breaking glass, no sound where the outside ambient sounds invade the visual space, sudden changes in scale and objects moving towards the viewer. These events can break the feeling of being in the VR and cognitively merge the two spaces.

I argue that dissonance provides the opportunity for the viewer to experience the change in thought processes that are required to understand quantum theory. In this moment of dissonance, common sense has been overridden and a third order simulacrum is produced, which is neither everyday reality nor just virtual reality but a new one that is both. This offers a moment to experience two conflicting realities, in a similar manner to how we need to accept the conflicting realities of classical Newtonian physics and quantum theories.

Experiencing cognitive dissonance in my VR installation provides an opportunity for the viewer to experience an entanglement. Related to scientific entanglement, the person simultaneously

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[235] Leon Festinger, *A Theory of Cognitive Dissonance* (London : Tavistock, 1957, 1957).

[236] Leon Festinger, *A Theory of Cognitive Dissonance,* 3.

holds two different positions, as do two quantum particles. There is pressure for the viewer to resolve this dissonance and so they are most likely to acknowledge that both exist; that they are inside a VR headset and also inside a gallery space. They are communicating cognitively between these spatial contexts, enacting an internal simulation of quantum communication. They then choose which space to stay in and this determines the role of the other space, in a similar way to determining the properties of the other entangled particle.

The Technological Sublime

Within the simulacra, at the moment of cognitive dissonance, I propose that my work is evoking elements of the technological sublime. Immanuel Kant (1724-1804) places the emphasis in his articulation of the sublime, on the cognitive act of reason; "sublime because the mind has been incited to abandon sensibility and employ itself upon ideas involving higher finality."[237] The sublime for Kant is a disharmony that exceeds our current understanding and imagination, and as the mind becomes aware of its inadequacy, reasoning takes over. [238] [239] [240] This is initially a discomforting and unpleasant experience which is replaced by a torrent of pleasurable emotions as the ability of reason enables the person to exceed sensory boundaries.

I suggest that the discomfort of cognitive dissonance, where conflicting events are being experienced at once is similar to the feelings of discomfort that Kant describes when the imagination cannot process what is happening. Christine Battersby states, and backs up her claim with references to French philosopher Jean-Francois Lyotard, as the pleasure of the sublime, "is generated by discord, through conflict and dissonance, as man's senses, imagination and emotions function disharmoniously—trying to grasp an infinity or a power that is too great for comprehension.[241] The sublime is referencing our own limits and it is our

[237] Immanuel Kant, *Kant's Critique of Judgement*, 2nd ed. revised (London: McMillan, 1914) §23.

[238] Eugénie Shinkle, 'Video Games and the Technological Sublime', Tate Papers, no. 14 (September 2010): 11.

[239] Jos De Mul, 'The (Bio) Technological Sublime', *Diogenes* 59, no. 1–2 (1 January 2013): 32–40.

[240] Jos de Mul, 'The Technological Sublime', Next Nature Network, 17 July 2011, https://www.nextnature.net/2011/07/the-technological-sublime/.

[241] Christine Battersby, 'Terror, Terrorism and the Sublime: Rethinking the Sublime after 1789 and 2001', *Postcolonial Studies (London, United Kingdom)* 6, no. 1 (4 April 2003): 77.

own cognitive conflicts that I am suggesting need to be confronted in order to better understand quantum theories.

Kant's dynamic sublime is evoked from forces of nature (echoing the divine), creating the feeling of awe which turns into fear because of the realisation that we might be in danger.[242] The mathematical sublime is derived from immense size in nature which evokes the feeling of insignificance because of the failure of the imagination to grasp the idea of infinity.[243] I do not aim to evoke the strength of emotions that Kant describes, however, responses to *Entangled* evidence that people, especially those new to virtual reality technology, did recount feelings of anxiety from passages that gave the illusion of heights and precipices, describing feelings of insignificance and lack of control. However, they also reported feelings of pleasure and exhilaration because of the realisation it was a VR experience. [244] Eugénie Shinkle argues that the unpleasant experience is due to the inadequacy of our imagination because of a lack of human agency; an uncomfortable feeling of being overpowered and having lost control.[245] I consider that this is an element of the discomfort and I purposefully provided opportunities for viewers in *Entangled* to feel that control was taken away from them. When the apparatus was scaled up in size and when their view was locked when travelling through the VR, viewers reported lack of control. This was contrasted with passages where viewers felt in control as they navigated the scene themselves.

Quantum entanglement, itself is a mathematically sublime concept, as it deals with the infinitely small, an idea that Kant touched on with technology of microscopes of his time. [246] Entanglement can be understood as sublime from Lyotard's postmodern definition of sublime as representing the unpresentable.[247] Quantum physics is at such a minute scale that it is invisible. To present the unpresentable, Lyotard states that "Allusion … is perhaps a form of expression indispensable to the works which belong to an aesthetic of the sublime."[248] In

[242] Jos de Mul, 'The Technological Sublime'.

[243] Jos de Mul, 'The (Bio) Technological Sublime'.

[244] Focus group feedback.

[245] Eugénie Shinkle, 'Video Games and the Technological Sublime'.

[246] Konstantinos Vassiliou, 'Sublime and Anti-Sublime: Reconsidering the Relation of the Sublime to Technology', *Contemporary Aesthetics* 15 (January 2017): 1–1

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[247] Jean-François Lyotard, 'Presenting the Unpresentable: The Sublime', *Artforum* xx, no. 8 (1982).

[248] Jean-François Lyotard, *The Postmodern Condition : A Report on Knowledge*, Theory and History of Literature: V.10 (Manchester : Manchester University Press, c1984, 1984), 45.

Entangled, I allude to quantum entanglement by creating entwined spaces between the simulacrum and the physical space to offer the experience of metaphoric entanglement. Many examples of this are detailed in chapter 2, particularly in the section on interplays and relationships.

Russian media theorist Ksenia Fedorova uses the term 'ubiquitous' to describe the technological sublime. [249] This has been a productive term to apply when developing this creative practice research because of the prolific nature of entanglement and the ubiquitous properties of light, projection and VR. I use the standard definition of ubiquitous, defined as being, "present, appearing, or found everywhere"[250] and omnipresent as "present in all places at all times,"[251] often with religious connotations.[252] Taking aside the religious aspects, these two terms are much the same. Whereas the sublime used to be considered as omnipresent, I suggest that the ubiquitous experience *Entangled* provides visually and aurally, aligns with Fedorova's definition of the technological sublime.[253]

I position my VR work within the modern definitions of the technological sublime. David Nye, in his book, *The American Technological Sublime* (1994), has attempted to contemporise Kant's ideas of the sublime with relation to the technological age.[254] Nye positions the technological sublime as technology taking the place of nature with buildings, bridges and machines overpowering and disorientating the viewer. [255] Writers such as Eugénie Shinkle, Robert Hassan, Julian Tomas and Fedorova include computers and VR technology into the technological sublime arena. Shinkle states that it is what the computer, the "ontological machine", can be used to create, that has the potential to stimulate the sublime, to present

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[249] Ksenia Fedorova, 'New Media Art and the Technological Sublime', *NAUJASIS MEDIJŲ MENAS IR TECHNOLOGINIS DIDINGUMAS.*, no. 67 (December 2012): 33.

[250] Definition of ' Ubiquity', accessed 3 April 2018, https://www.merriam-webster.com/dictionary/ubiquity.

[251] 'Definition of OMNIPRESENT', accessed 4 June 2018, https://www.merriam-webster.com/dictionary/omnipresent.

[252] 'What Does It Mean That God Is Omnipresent?', GotQuestions.org, accessed 23 February 2018, https://www.gotquestions.org/God-omnipresent.html.

[253] Fedorova, 'New Media Art and the Technological Sublime'.

[254] David E. Nye, *American Technological Sublime* (Cambridge, Mass. : MIT Press, c1994, 1994).

[255] Kirk Jeffrey, review of *Review of American Technological Sublime*, by David E. Nye, *Environmental History Review* 19, no. 2 (1995): 85–87, https://doi.org/10.2307/3984833.

the unpresentable, to disrupt perception and stimulate an emotional state characterised by duration, instability and transformation".[256]

Kant stated that the sublime is "unbounded, excessive, or chaotic in character,"[257] which links to Lyotard's description that it must be disruptive and unsettling because it expresses the unpresentable.[258] Fedorova proposes that new media can access the characteristic effects of the sublime with "sudden shifts in perspective, ecstasy, dismay and perplexity". These capabilities of new media to create the technological sublime are the same qualities that I am exploring to unsettle the viewer's understanding of reality. When I create a sudden shift in scale of size or play discordant sounds, I suggest that this disruption offers the opportunity to elicit emotional responses, which while not necessarily of awe and fear, can provide a trigger for the viewer to experience contrasting emotions, similar to the technological sublime.

1.7 Virtual Reality (VR)

The aim of my use of VR technology is to intertwine physical and virtual spaces to provide an immersive metaphoric encounter with quantum entanglement, while also questioning the potential implications of entanglement on our understanding of our world. Considerations of installation art have recognised that the activation of the space can be more significant than the objects in it.[259] This position, articulated by Bonnie Mitchell, acknowledges the importance of the whole sensory experience and relationships within the space.

The aim of inviting this level of experiential encounter through a dynamic VR environment is to fully explore the way our bodies and minds approach a synthesis of understanding, where visual, aural and haptic information get brought together to enable a heightened experience,

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[256] Shinkle, 'Video Games and the Technological Sublime', paragraph 9.

[257] Immanuel Kant, Kritik der Urteilskraft. Vol. X, Theorie-Werkausgabe. Frankfurt: Suhrkamp 1968: B74, **quoted in** Jos de Mul, 'The (Bio)Technological Sublime', *Diogenes* 59, no. 1-2 [233-234] (2012 2012): 32–40.

[258] Ashley Woodward, 'Lyotard, Jean-François | Internet Encyclopedia of Philosophy', 27 May 2017, http://www.iep.utm.edu/lyotard/.

[259] Bonnie Mitchell, 'The Immersive Artistic Experience and the Exploitation of Space', Bowling Green State University, 2010, 10.

one where processes of imagining are also involved, rather than a focus on recognition of an already known or imaged entity.

Earlier installations on glass screens and projected animations onto the water screen in Wellington Harbour offered some immersive and experiential qualities for the viewer (and can be seen in section 2.2 and Appendix 1). However, these installations could not provide the level of immersion and embodiment that I was striving for, or create the changes in scale or the capability of playing with an interweaving of real and virtual spaces that VR technology offered.

VR technology immediately questions our understanding of reality.[260] Garfield Benjamin takes a view directly relevant to my research, when he states that the conflict in the term 'VR' comes from the word 'real' rather than the word 'virtual'.[261] This provides a basis for questioning our understanding of reality and a platform for the entanglement that will be tested.

A brief discussion on the accessibility to VR and its genesis in relation to funding structures and priorities of industries such as the US military, health and education is included in Appendix 3 to provide insight into the evolution of the technology. More recently products such as Oculus, HTC Vive and PlayStation VR have become available at a general consumer level and VR is now widely used in gaming and is becoming more common as an art medium.

Technical discussion of my use of VR is also covered in more depth in appendices 1 and 3. This provides further insights into the choice of this platform and decision-making with regard to the technology.

Current Practice in VR

I have extensively surveyed practice in New Zealand, Australia, North America, Europe, and Asia and have concluded that there are few artists who use VR in the same manner that I do, with the same intent. Amongst VR artworks that have very little relationship to this research are those that use applications such as Tilt Brush to paint in 3-D as a direct extension of 2-D painting. Many VR artists are investigating different topics to mine such as Marshmallow Laser

[260] Chris Chesher, 'Colonizing Virtual Reality', 1984-1992, 27, http://www.casa.ucl.ac.uk/cyberspace/Colonizing_Virtual_Reality.pdf.

[261] Garfield Benjamin, *The Cyborg Subject : Reality, Consciousness, Parallax* (New York : Palgrave Macmillan, July 2016 ; Secaucus : Springer [distributor], 2016).

Feast's links with nature[262]; BeAnotherLab exploring issues of culture, violence and political topics[263]; artificial intelligence in works by Ian Cheng[264] and Maurice Benayoun[265]; documentaries by Aaron Koblin[266] or Nonny de la Peña[267]; space travel by Synapteos[268]; emotions and fear in *Giant* by Milica Zec and Winslow Turner[269]; relationships with the body by Jeffery Shaw and movement investigations by Nicola Plant; memories in works by artists such as Sarah Rothberg[270]; dreams in Simon Robertson's work[271], myths by Tamiko Thiel[272]; and realistic representations such as Janicza Bravo's 360 degree narrative films or Daniel Steegmann with ScanLAB Projects.[273]

An artist whose work is relevant to this research is pioneer VR artist Rachel Rossin who investigates transitions between virtual and physical spaces. In her New York exhibition *Lossy* in 2015 she inserts her paintings and combines this with photogrammetry and motion capture

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[262] Robin McNicholas and Ersin Han Ersin, 'How Technology Can Repair Our Broken Connection with Nature', CNN Style, 15 June 2018, https://www.cnn.com/style/article/marshmallow-laser-feast/index.html.

[263] 'The Machine to Be Another', The Machine to be Another, accessed 29 October 2017, http://www.themachinetobeanother.org.

[264] Jason Farago, 'Virtual Reality Has Arrived in the Art World. Now What?', *The New York Times*, 20 January 2018, sec. Arts, https://www.nytimes.com/2017/02/03/arts/design/virtual-reality-has-arrived-in-the-art-world-now-what.html.

[265] Benayoun.

[266] 'Http://Www.Aaronkoblin.Com/', accessed 3 December 2017, http://www.aaronkoblin.com/.

[267] 'Home', Emblematic, accessed 8 February 2019, http://emblematicgroup.com/.

[268] Brian Michael Smith and Hwaryoung Seo Jinsil, 'Synapteos: Exploring Virtual Cosmos with Embodied Motion Controls |', accessed 8 February 2019, http://www.idmaajournal.org/2016/02/synapteos-exploring-virtual-cosmos-with-embodied-motion-controls/.

[269] Milica Zec and Winslow Turner, *Giant*, Accessed 17 June 2018, https://www.with.in/watch/giant.

[270] 'Sarah Rothberg – WEIRD REALITY: Head-Mounted Art && Code', accessed 29 March 2018, http://artandcode.com/weirdreality/sarah-rothberg/.

[271] John Chiaverina, 'Virtual-Reality Art Gets Real', *ARTnews* (blog), 17 December 2014, http://www.artnews.com/2014/12/17/virtual-reality-art-gets-real/.

[272] '"Treasures of Seh Rem" Augmented Reality Public Art Installation, Tamiko Thiel, 2017. Salem Maritime National Historic Site. Boston Cyberarts Commission', accessed 17 July 2017, http://tamikothiel.com/tosr/index.html.

[273] 'Daniel Steegmann', accessed 3 September 2018, http://danielsteegmann.info/works/41/index.html.

software on real-life objects to build them into virtual scenes.[274] She manipulates these virtual 3-D objects by changing settings such as the gravity to fragment the images which she then repaints from screen shots. While she is iteratively translating these between the virtual and physical, she is not using 'presence' as a cognitive experience as I am, with in-depth interrogation of the cognitive interplay between the virtual and physical spaces.

Figure 13. Rachel Rossin, USA, *GTA V,* 2015.
https://killscreen.com/articles/after-gta-v-and-the-inevitable-deterioration-of-data/ This image is used with permission. It remains copyright property of Rachel Rossin. All rights reserved, not for copying or further distribution.

Jacquelyn Ford Morie has been working in VR for over 25 years and is an artist, educator and founder of her own VR company. Much of her work has aimed to provide experiences that elicit emotions and enrich people's lives in therapeutic areas such as healing, stress relief, rehabilitation and overcoming feelings of isolation. Using psychology as one of her main platforms she takes the viewer out of their ordinary world by creating a strong feeling of 'presence'. She has developed haptic and olfactory sensory feedback devices to intensify emotional experiences. [275]

Even though her aims in VR are different from mine, because her work is strongly based in psychology, at times her insights overlap with and reinforce my approach. For example, she describes VR as being a paradigm shift in experiential possibilities, and that this experience

[274] Photogrammetry is a system of using multiple photographs which dedicated software makes into 3-D models.

[275] Christina Berry, 'Dr. Jacquelyn Ford Morie', 30 August 2016, https://gigaom.com/change/speakers/dr-jacquelyn-ford-morie/.

allows the viewer to "possess knowledge of two simultaneous bodies."[276] However, Morie uses this in helping people with rehabilitation by focusing on emotions which is very different to my use as a means of scientific communication and exploring experiences of knowledge systems.

As part of my research, I met Iain Nicholls, a UK-based VR artist, who I have maintained communication with as we have both developed new VR works. Nicholls collaborated with programmer Tom Szirtes on a mixed media work *Veil*, exhibited in London in 2015, involving a physical box, modelled as a house, which came to life with imaged stories within the VR headset.[277] While this work interrogated the relationship between the physical and virtual, it is more as a forerunner of augmented reality than a crossing between the mental states within each space as in *Entangled*.

Two current artists who have been practicing in digital art and VR since the 1990s, Canadian Char Davies and US Rebecca Allen, are investigated in more depth in this section because they have produced significant artworks that I perceive overlap with areas of my research. This section will identify areas of similarity between their work and mine, and indicate areas of divergence.

Char Davies

Char Davies broke new ground in art and VR over 20 years ago that still holds its place today, even with rapidly developing technologies. Davies is primarily interested in shifting the viewer's consciousness and providing a 'fresh' way of perceiving the world and ourselves.[278] She aims to change the way people look and behave in the world with immersive experiences based on nature. Davies calls the viewer an 'immersant' to emphasise the importance of immersion in achieving these aims.

Her significant works, *Osmose* (1995) and *Ephémère* (1998) were developed by a team including a programmer, a graphic designer and sound designers. Her programmer, John Harrison, described them as complex projects using development libraries, parallel processing

[276] Morie, Jacquelyn Ford, 'Performing in (Virtual) Spaces: Embodiment and Being in Virtual Environments', *International Journal of Performance Art and Digital Media*, no. 23 (2007): 123, http://ict.usc.edu/pubs/Performing%20in%20(virtual)%20spaces%20-%20embodiment%20and%20being%20in%20virtual%20environments.pdf.

[277] https://www.herrickgallery.com/ludic-veil-2.

[278] François Penz, Gregory Radick, and Robert Howell, *Space: In Science, Art and Society* (Cambridge University Press, 2004).

and dedicated coding.[279] Davis co-designed the relatively unobtrusive vest that measures breathing by expansion and records the immersant's angular position, which was specifically engineered for these works. The immersant can travel through the virtual environment by breathing in and out to move up/down, or by leaning to turn or to travel forwards/backwards. Davies uses the breathing apparatus and the headset as the interface, the interface being a key element in the perception of the work, giving it an embodied feeling of presence.[280]

Osmose relates to the biological process of osmosis, movement through a semi-permeable surface.[281] Davies' osmosis not only refers to the scenes moving through each other and through the immersant, but also the permeation of dichotomies such as self/world, interior/exterior, and subject/object.[282] By blurring these dichotomies she is challenging privileged dualisms such as mind over body and objectification through male over female.[283] Davies describes Osmose as "a space for exploring the perceptual interplay between self and world, i.e. a place for facilitating awareness of one's own consciousness embodied in enveloping space." I discuss my use of interplays within my work in chapter 2 with respect to relationships (within narrative sequencing, aesthetic composition, and between virtual and 'real' contexts of space), however it will be shown that I do this with different aims.

The main power of VR for Davies is the confusion of perception, where the imaginary and immaterial are confused with the real.[284] She achieves this, not by aiming at an aesthetic of realism, but by using layers of transparency, blurred images and abstraction. Whereas multi-media artists such as James Turrell have experimented with distorting perception using either deprivation or overload, Davies is careful to provide gentle stimulation with 'clearings' in her work for the immersant to rest. The controlled breathing in her VR work is reminiscent of

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[279] C. (1 Davies 2) and J. (1 Harrison 2), 'Osmose: Towards Broadening the Aesthetics of Virtual Reality', *Computer Graphics (ACM)* 30, no. 4 (01 1996): 25–28, https://doi.org/10.1145/240806.240808.

[280] Grau, Oliver. *Virtual Art : From Illusion to Immersion*, The MIT Press, 2003.

[281] https://www.merriam-webster.com/dictionary/osmosis.

[282] Laurie McRobert, *Char Davies's Immersive Virtual Art and the Essence of Spatiality*, 1 edition (Toronto: University of Toronto Press, Scholarly Publishing Division, 2007).

[283] Char Davies, 'Rethinking VR: Key Concepts and Concerns.', 2003, http://www.immersence.com/publications/char/2003-CD-VSSM.html.

[284] 'Immersence, Char Davies', accessed 5 May 2018, http://www.immersence.com/.

many forms of meditation which is shown as an appropriate device to enhance the distortion of perception.[285]

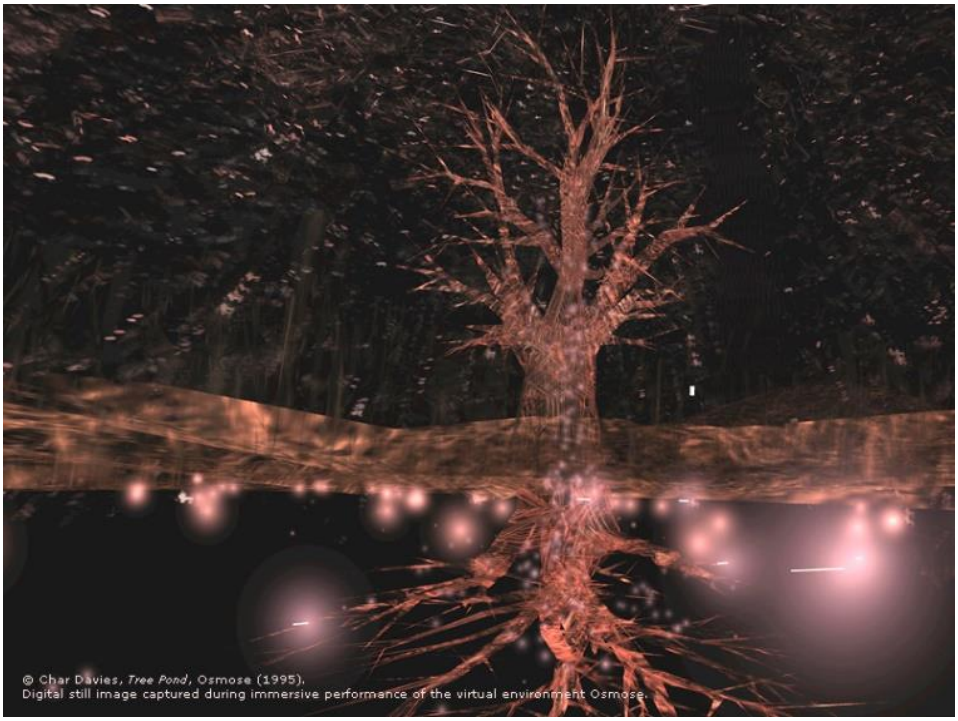

Figure 14. Char Davies, Canada, *Tree Pond*, from *Osmose,* 1995.
Digital frame captured in real-time through head-mounted display during live performance. http://www.immersence.com Then go to Osmose section) This image is used with permission. It remains copyright property of Char Davies. All rights reserved, not for copying or further distribution.

[285] Ravinder Jerath et al., 'Physiology of Long Pranayamic Breathing: Neural Respiratory Elements May Provide a Mechanism That Explains How Slow Deep Breathing Shifts the Autonomic Nervous System', *Medical Hypotheses* 67, no. 3 (1 January 2006): 566–71, https://www.sciencedirect.com/science/article/abs/pii/S0306987706001666?via%3Dihub.

"Pranayamic breathing, defined as a manipulation of breath movement, has been shown to contribute to a physiologic response characterized by the presence of decreased oxygen consumption, decreased heart rate, and decreased blood pressure, as well as increased theta wave amplitude in EEG recordings, increased parasympathetic activity accompanied by the experience of alertness and reinvigoration. The mechanism of how pranayamic breathing interacts with the nervous system affecting metabolism and autonomic functions remains to be clearly understood. It is our hypothesis that voluntary slow deep breathing functionally resets the autonomic nervous system through stretch-induced inhibitory signals and hyperpolarization currents propagated through both neural and non-neural tissue which synchronizes neural elements in the heart, lungs, limbic system and cortex."

Figure 15. Char Davies, Canada, *Forest grid*, from *Osmose,* 1995.
Digital frame captured in real-time through head-mounted display during live performance. http://www.immersence.com (then go to Osmose section) This image is used with permission. It remains copyright property of Char Davies. All rights reserved, not for copying or further distribution.

Nature is not only used as literal imagery but also metaphorically in both *Osmose* and *Ephémère*. For example, an oak tree is a dominant feature of *Osmose,* which can be read metaphorically in many contexts; the tree of life, of breath, or as Laurie McRobert describes it, the "archetypal aliveness".[286] *Ephémère* extends the metaphors to body organs, blood vessels and bones, linking the interior of the land to the interior of the body. She associates the branches of trees to subterranean roots to veins in the body; three realms linked metaphorically, spatially and also temporally as the immersant travels vertically. There are strong references to mortality, the passage of our lives and the finitude of life.

Mathematical Cartesian coordinates at the beginning of *Osmose*, provide a precedent for my diagrammatical construct of spacetime curves in *Entangled*, which is discussed in chapter 2. The 3-D coordinates in *Osmose* dissolve as the viewer moves in space, indicating that the new space is not governed by Cartesian mathematics. Davies also includes writing and coding within her work, which she aims to provide embodiment of abstract constructs.[287] Media

[286] Laurie McRobert, *Char Davies's Immersive Virtual Art and the Essence of Spatiality*, 5 May 2007.17.

[287] Char Davies, 'OSMOSE: Notes on Being in Immersive Virtual Space', *Digital Creativity* 9, no. 2 (1 January 1998): 65–74, https://doi.org/10.1080/14626269808567111.

theoretician, Oliver Grau, states that this disrupts the highly immersive experience,[288] however, the intention does not appear to be the same as my purposeful disruption of immersion.

Davies' virtual environments could be considered as an example of science communication and they have been exhibited in both science and art institutions, however, that has not been her intention and I would argue that her views take her outside of this domain. For example, she describes her works as a step towards what she quotes from Henri Lefebvre as a 'counter space', requiring the subversion of the usual forms of VR as an alternative against, "the homogenizing effect of the absolute space of Western metaphysics and science".[289] Davies also quotes Verena Andermatt Conley as saying, "the world cannot be reduced to a scientific object, that it escapes total mastery."[290]

Rebecca Allen

Rebecca Allen, Head of Design at UCLA, has used technology in innovative installations for over 30 years to provoke questioning of the mind through the immersive properties of technology. With a strong interest in human movement throughout her career, and a focus on emotions and feelings, Frank Popper states that she "humanizes" the technology,[291] as she explores multiple interfaces, such as breathing, muscle responses and brain patterns to make links between the human and the technology.

Liminality, a strong interest of Allen's, has a synergy with my interest in quantum theory and dissonance. I take the definition of liminal from Allen as, "that which occupies both sides of a boundary or threshold"[292] which she describes as being an, "in between state where you are neither here nor there or both here or there". [293] While she is not talking about quantum

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[288] Grau, Oliver. *Virtual Art : From Illusion to Immersion*.

[289] Davies, Char 'Rethinking VR: Key Concepts and Concerns,' 2003.
Lefebvre, H. 1991. *The Production of Space*. Oxford: Blackwell, **quoted in** Davies, Char 'Rethinking VR
Verena Andermatt Conley, *Rethinking Technologies* (Minneapolis : University of Minnesota Press, c1993, 1993). , **quoted in** Davies, Char 'Rethinking VR.

[290] Conley, *Rethinking Technologies*. , **quoted in** Davies, Char 'Rethinking VR.

[291] 'Allen, Rebecca - ADA | Archive of Digital Art', 2014, https://www.digitalartarchive.at/database/artists/general/artist/allen.html.

[292] Mark Borden, '31. Rebecca Allen', Fast Company, 22 May 2010, Video 00:21. https://www.fastcompany.com/3018745/31-rebecca-allen,).

[293] Mark Borden, '31. Rebecca Allen'.

theory, this has strong links to the property of a particle before it is measured, as being in neither one state nor another but in both. Allen is considering liminal in terms of humans' increasing experience of simultaneous realities and human identity. She provides a current example of liminal as the cell-phone, where the human body is present in the physical world, but the mind is focussed on the internet. Allen has explored the liminal though what she describes as intimate physical interfaces such as breathing apparatus or EEG to record electrical brain activity, each one communicating between the person and the manufactured physical responses such as force feedback or computer responses to create spaces that are in between each other.

The Brain Stripped Bare (2002), uses 360 degree surround screens of performers with the live nude performers within the same space; the virtual and the physical at the same time suggesting multiple realities.[294] At times the performer comes very close to an audience member, confronting their personal space, and 'audio spots' of very localised sound that only that audience member standing in that particular position can hear, with whispered comments such as, "I know what you're thinking", to represent telepathic communication.[295]

Telepathic communication is not scientific communication and nor are the bush souls in 'The Emergence Project' *The Bush Souls* (1997-2001), where Allen creates representations of avatar souls in a world of artificial life which is overlaid with human presence. The souls react with different characteristics such as shyness and dislike and force feedback is used to create vibrations on the controller in areas of high psychological 'energy'. Her interest here is on consciousness in an unreal world, not that of communicating science.[296]

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[294] 'The Brain Stripped Bare - Rebecca Allen', accessed 9 February 2019, http://www.rebeccaallen.com/projects/the-brain-stripped-bare.

[295] Mark Borden, '31. Rebecca Allen', video 00:18:31.

[296] Rebecca Allen, 'Emergence: The Bush Soul', accessed 9 February 2019, http://emergence.design.ucla.edu/papers/bushpaper.htm.

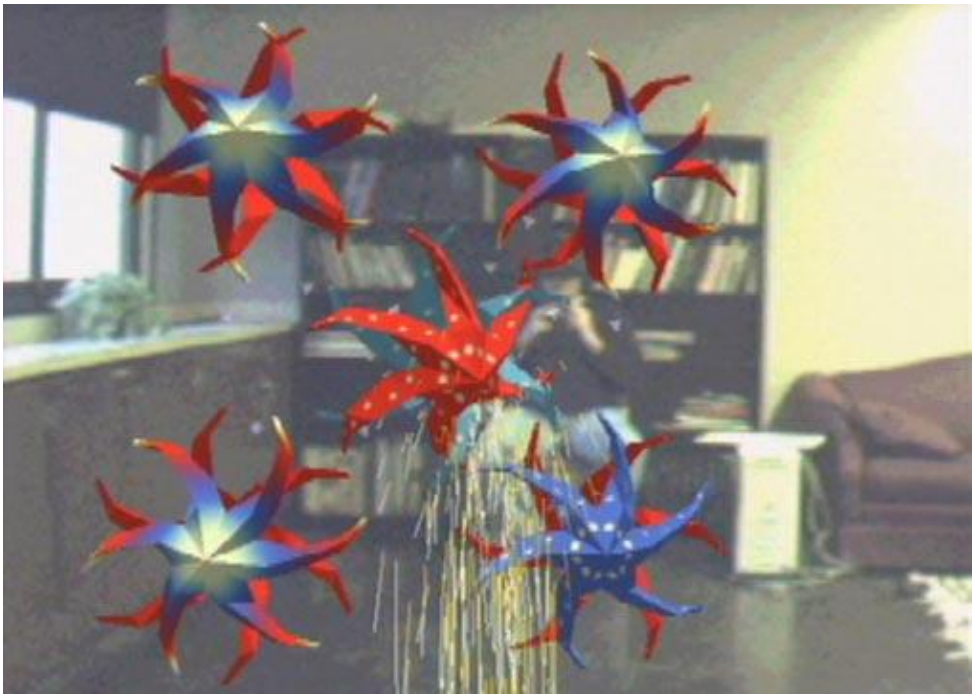

Figure 16. Rebecca Allen, USA, Coexistence, 2001. Augmented Reality Art Installation http://www.rebeccaallen.com/projects/coexistence This image is used with permission. It remains copyright property of Rebecca Allen. All rights reserved, not for copying or further distribution.

VR automatically puts the viewer in a liminal space, as defined by Allen, because the body is in the physical space and the information to the brain is from the visual VR. Allen takes liminality further by exploring augmented reality, as defined earlier, where virtual objects are overlaid on the physical space. Allen's VR work *Coexistence,* 2001, integrates perceptual feedback from breathing sensors creating force-feedback to the viewer and the combination of a camera and computer generated images to provide an augmented reality. Allen is keeping the viewer in a state of neither one reality nor the other, and, as she has pointed out, this is a state that we are commonly in on the cellphone. As argued in the above section, even with current technology, blending the virtual graphics with the camera can make the virtual seem less real. My aim is not to solely create a liminal state such as this, but to provide repeated opportunities of the strong feelings of dissonance between two spaces.

Allen's work and mine share a strong interest in perception, cognition and liminal experiences, however, her focus is predominantly on the links between the brain, the mind and consciousness which shows a difference in our conceptual aims. Her incorporation of multiple devices and feedback of data in her installations provides a different experience to my more

pared-back approach. Much of her work involves areas outside of scientific investigations resulting in a large divide between our works.

1.8 Presence

Presence within VR systems is defined as the sense of being there, the technology creating the illusion of feeling 'real' or the sense of being 'in' a place.[297] [298] [299] Presence is critical to understanding the intent of *Entangled* for two main reasons. Firstly, I aimed to create an experiential encounter where the viewer could feel part of the scientific apparatus, explore the interior and exterior and could seemingly 'become' the fluid or particles within the glass conduits. Secondly, I required the establishment of a sense of presence to enable me to create disruptions that rupture the feeling of presence, in order to stimulate an experience of dissonance.

Manipulating the available technology of VR was always a curiosity in my research to 'activate' entanglement. Key aspects of this design and research process are explained below.

Grau, whose writings within *Virtual Art*, seems to consider the environments more than the technology, traces 'illusion spaces' back to 60BC, with paintings that surrounded the viewer aiming to immerse the viewer by dissolving the boundaries between them and the image space.[300] Grau traces the evolution of this genre through panorama to VR situating modern technology as part of a longstanding aspiration within art to immerse the viewer.

[297] E. (1) Keogh et al., 'A Cross-Media Presence Questionnaire: The ITC-Sense of Presence Inventory', *Presence: Teleoperators and Virtual Environments* 10, no. 3 (June 2001): 282–97, https://doi.org/10.1162/105474601300343612.

[298] Maria V. Sanchez-Vives and Mel Slater, 'From Presence to Consciousness through Virtual Reality', *Nature Reviews Neuroscience* 6, no. 4 (April 2005): 332–39, https://doi.org/10.1038/nrn1651.

[299] Katy Tcha-Tokey et al., 'Proposition and Validation of a Questionnaire to Measure the User Experience in Immersive Virtual Environments', *International Journal of Virtual Reality* 16, no. 1 (January 2016): 33.

[300] Grau, Oliver. *Virtual Art : From Illusion to Immersion*.

Slater separates presence in VR as having two main elements: place illusion and plausibility illusion.[301] Place illusion refers to the feeling of 'being there' in the location, while plausibility illusion is "the illusion that what is apparently happening is really happening." Slater takes place illusion to be directly caused by the physics of the set-up. Plausibility illusion involves an event that you did not cause, but is directed at you. An example that Slater gives is a virtual person smiling at you, which can cause the participant to respond physiologically. Nilsson et al. state that Slater's place and plausibility are similar to Lombard and Ditton's realism.[302]

VR takes over the entire visual field creating a high level of presence.[303] The stereoscopic vision creates the 3-dimensional illusion. As Slater (2017) points out, it is a perceptual illusion as cognitively we know that we are not there. The body may automatically react physiologically before the cognitive system has had a chance to catch up. "'But I know that this isn't real'. But by then it is too late, the reactions have already occurred."[304] Autonomic responses such as heart rate, breathing levels and skin conductance have been shown to be elevated in VR where there has been a high correlation to viewers reporting the 'feeling of being there'.[305] This strength has resulted in the use of VR as a tool for desensitisation of anxiety disorders and post-traumatic stress disorder as well as an effective pain distraction.[306] [307] I have observed the power of presence in my iteration, (mentioned in the section on VR) where the rotating steel constructions created a response of ducking as well as participants using their arms to protect

[301] Slater, Mel. 'Place Illusion and Plausibility Can Lead to Realistic Behaviour in Immersive Virtual Environments'. *Philosophical Transactions of the Royal Society B: Biological Sciences* 364, no. 1535 (12 December 2009): 3549–57. https://doi.org/10.1098/rstb.2009.0138.

[302] Niels Christian Nilsson, Rolf Nordahl, and Stefania Serafin, 'Immersion Revisited: A Review of Existing Definitions of Immersion and Their Relation to Different Theories of Presence', *Human Technology: An Interdisciplinary Journal on Humans in ICT Environments, Vol 12, Iss 2, Pp 108-134 (2016)*, no. 2 (2016): 108.

[303] Matthew Lombard and Theresa Ditton, 'At the Heart of It All: The Concept of Presence', *Journal of Computer-Mediated Communication* 3, no. 2 (September 1997).

[304] Mel Slater, 'Immersion and the Illusion of Presence in Virtual Reality', *British Journal of Psychology* 109, no. 3 (August 2018): 431–33, https://doi.org/10.1111/bjop.12305.

[305] Mel Slater, 'Immersion and the Illusion of Presence in Virtual Reality', 431–33.

[306] Sanchez-Vives and Slater, 'From Presence to Consciousness through Virtual Reality', April 2005.

[307] The capabilities of VR in establishing presence have been shown to be successful in treating anxiety and measurements of affect of perception established.

Julia Diemer et al., 'The Impact of Perception and Presence on Emotional Reactions: A Review of Research in Virtual Reality', *FRONTIERS IN PSYCHOLOGY* 6 (30 January 2015), https://doi.org/10.3389/fpsyg.2015.00026.

parts of their body. I decided to reduce this single event 'threat' to focus more on subtle disruptions that psychologically unsettle rather than provoke a physical defence action.

Sanchez-Vives & Slater highlight that reactions within VR are elevated even though the participant's "absolute knowledge that the VE (Virtual Environment) is fake".[308] I have collated findings from: Heeter (1992); Biocca & Levy (1995); Slater& Wilbur (1997);Lombard & Ditton (1997); Schubert, Friedmann & Regenbrecht (2001); Sanchez-Vives & Slater (2005); Slater (2009); Nilsson et al (2016); Sheridan (2016); Tcha-Tokey, Cristmann, Loup-Escande & Richir (2016); K. M. Lee (2004); Nilsson et al (2016). [309] [310] [311] [312] [313] [314] [315] [316] [317] [318] [319] [320] A summary chart that I formulated can be found in Appendix 5. From this analysis I considered the

[308] Sanchez-Vives and Slater, 'From Presence to Consciousness through Virtual Reality', April 2005, 18.

[309] Carrie Heeter, 'Being There: The Subjective Experience of Presence', *Presence: Teleoperators and Virtual Environments, MIT Press* Fall (1992), https://www.researchgate.net/publication/200772979_Being_There_The_Subjective_Experience_of_Presence.

[310] Frank Biocca and Mark R. Levy, eds., *Communication in the Age of Virtual Reality* (Hillsdale, N.J: L. Erlbaum Associates, 1995).

[311] Mel Slater and Sylvia Wilbur, 'A Framework for Immersive Virtual Environments (FIVE)...', *Presence: Teleoperators & Virtual Environments* 6, no. 6 (December 1997): 603.

[312] Matthew Lombard and Theresa Ditton, 'At the Heart of It All: The Concept of Presence', *Journal of Computer-Mediated Communication* 3, no. 2 (September 1997).

[313] Thomas Schubert, Frank Friedmann, and Holger Regenbrecht, 'The Experience of Presence: Factor Analytic Insights', *Presence: Teleoperators & Virtual Environments* 10, no. 3 (June 2001): 266–81, https://doi.org/10.1162/105474601300343603.

[314] Sanchez-Vives and Slater, 'From Presence to Consciousness through Virtual Reality', April 2005.

[315] Mel Slater, 'Place Illusion and Plausibility Can Lead to Realistic Behaviour in Immersive Virtual Environments', *Philosophical Transactions of the Royal Society B: Biological Sciences* 364, no. 1535 (12 December 2009): 3549–57, https://doi.org/10.1098/rstb.2009.0138.

[316] Niels Christian Nilsson, Rolf Nordahl, and Stefania Serafin, 'Immersion Revisited'.

[317] Thomas B. Sheridan, 'Recollections on Presence Beginnings, and Some Challenges for Augmented and Virtual Reality', *Presence: Teleoperators & Virtual Environments* 25, no. 1 (Winter 2016): 75–77, https://doi.org/10.1162/PRES_e_00247.

[318] Tcha-Tokey et al., 'Proposition and Validation of a Questionnaire to Measure the User Experience in Immersive Virtual Environments'.

[319] Kwan Min Lee, 'Presence, Explicated', *Communication Theory* 14, no. 1 (1 February 2004): 27–50, https://doi.org/10.1111/j.1468-2885.2004.tb00302.x.

[320] Niels Christian Nilsson, Rolf Nordahl, and Stefania Serafin, 'Immersion Revisited'.

elements that I could not change, practical factors I could focus on and the areas that I did not want to include in my work, because the increase in presence was at the expense of other factors.

Properties of the VR system that create presence include sensory outputs such as visual display resolution and sound quality which are largely set by the manufacturers. The priorities in the manufacturer decision-making involve cost, political, educational, medical use and features required by the largest market of home users, the gaming industry. I chose the Vive because it was the latest on the market and at the time was at the forefront in allowing the viewer mobility around the space, a feature that increases presence. The frame rate of 90 Hz gives a smooth visual transition and the wide field of view of approximately 110 degrees, have both been shown to increase presence even if realism is low.[321]

There are elements using the software that I have been able to manipulate to create transparent, reflective and refractive attributes of glass to increase the properties of presence and in doing so engage the viewer. This has been achieved by using a refractive index of 1.9, slightly higher than real glass, and setting a high transparency that still has enough opacity to replicate aspects of impure material in the physical world. Strategic positioning of lights enhanced the qualities of reflection and refraction and this resulted in colourful scenes; colour having been shown to increase presence.[322] I was able to set post-processing volumes to change brightness and sharpness within the work which also increases presence in VR. [323]

I chose not to use any 360 degree camera work in my VR as the limitations of this technology were apparent to me through viewing the VR installations at Somerset House (UK) in 2016. This was a top-billed VR show in London using Oculus and Vive technologies. Icelandic singer, Bjork, had been filmed with 360 degree cameras and at no stage did I feel that she was really there or that I was immersed in her dancing. The reviewer for the UK Guardian stated that the lack of resolution and some out of focus graphics made it “hard to let yourself go

[321] Sanchez-Vives and Slater, ‘From Presence to Consciousness through Virtual Reality’, April 2005.

[322] Lombard and Ditton, ‘At the Heart of It All’, September 1997.

[323] Lombard and Ditton.

completely".[324] However, directional sound has been shown to create presence within VR,[325] and in this exhibition it guided you where to look when she moved around the VR space.

In collaboration with sound specialist, Isaac Lundy, we have created passages within my work that use directional sound both subtly, so as to build up atmospheric qualities, and more obviously to create disruptions. For example, the sound in the passage of the enlarged Klein comes from different speakers to enhance the spatial reading and the sense of presence. Sudden directional sound of breaking glass alerts the viewer to a specific direction. In early trials it was observed that the viewer turned their body in the direction of the sound, indicating presence. These tests resulted in the volume being increased so the turning of the body was still observed, however presence was disrupted because of the inclusion of a very realistic, recognisable sound amongst the more abstracted electronic tracks.

Although other sensory input techniques have been shown to increase presence, my investigations have indicated complications that led to my decision to not include these.[326] They can run the risk of being gimmicky, as in vibrating chairs and sprays of water in amusement park experiences, or in a recent exhibition in Wellington, *Future Playgrounds* (2018), where an attendant sprayed smoked wood scent to coincide with the visualisation of trees burning in a VR scene. My experiments with the Vive equipment using force feedback were not convincing as the vibration that was set up in the controller did not correlate strongly enough with the desired stimulus. New technology in this area is increasing rapidly (as discussed in the section on virtual reality), and when these are available at a consumer level, with judicious use, they have the potential to increase the experience of presence in the VR experience.

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[324] Joe Muggs, 'Björk Digital Review – to Virtual Reality and Beyond', *The Guardian*, 1 September 2016, sec. Music, https://www.theguardian.com/music/2016/sep/01/bjork-digital-review-somerset-house-vulnicura-virtual-reality-vr.

[325] Lombard and Ditton, 'At the Heart of It All', September 1997., Huong Q. Dinh et al., 'Evaluating the Importance of Multi-Sensory Input on Memory and the Sense of Presence in Virtual Environments', in *Proceedings of the IEEE Virtual Reality*, VR '99 (Washington, DC, USA: IEEE Computer Society, 1999), 222–, http://dl.acm.org/citation.cfm?id=554230.835733., Stefania Serafin and Giovanni Serafin, 'Sound Design to Enhance Presence in Photorealistic Virtual Reality', in *ICAD 04-Tenth Meeting of the International Conference on Auditory Display, Sydney, Australia* (Conference of Auditory Display, Sydney, Australia, 2004), https://www.academia.edu/5320339/Sound_Design_to_Enhance_Presence_in_Photorealistic_Virtual_Reality., Maria V. Sanchez-Vives and Mel Slater, 'From Presence to Consciousness through Virtual Reality', *Nature Reviews Neuroscience* 6, no. 4 (April 2005): 332–39, https://doi.org/10.1038/nrn1651.

[326] Sanchez-Vives & Slater, (2005) have shown haptic feedback to increase presence.
Dinh et al., 1999 have shown that olfactory effects increased the sense of presence.

One area of consideration that has repeatedly caught my attention has been the use of wind. An iteration that was trialled in my glass works included fans to rotate the hanging disks of glass to enable the images to travel around the walls. Moon & Kim, (2004) designed a wind apparatus for virtual reality, however they were not able to show that it conclusively increased the properties of presence and they proposed that a design that was not realistic could in fact lower presence.[327] Their set-up appeared complicated with wires and fans suspended around the participant, detracting from a pared back and engaging installation that I am aiming for.

Interactivity, the extent that the viewer can modify the VR in real time, has been acknowledged as one of the major factors in obtaining presence in VR.[328] Even with unrealistic subject matter or design features and low resolution, interactivity has been shown to increase presence.[329] Gaming uses high reaction speed interactivity creating strong levels of presence. This does not fit with my aim of a contemplative experiential encounter.

A number of interactive methods were trialled in earlier iterations of my VR artwork. I provided the viewer with a controller, which acted as a torch, conceptually linking in the idea that if only we could see things better, in the sense of higher dimensions and quantum measurements, we could have a deeper understanding of our reality. User feedback was that they found it repetitive having to shine the torch to see and that when the lighting was such that they did not need it, they found it annoying to have to carry the torch. While they agreed that initially the torch added interest and made them feel part of the environment, it soon had the opposite effect detracting from the feeling of presence. I then programmed the torch to trigger events. For example, I had a video of Einstein that played at the bottom or top of the spacetime curves when the torch was shone in that direction. The video stopped as soon as the torch was pointed away, making it clear that this was the trigger. The result was that the viewer became so intent on seeing what they could trigger that they were distracted from the main emphasis of the work.

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[327] Taeyong Moon and Gerard J. Kim, 'Design and Evaluation of a Wind Display for Virtual Reality', in *Proceedings of the ACM Symposium on Virtual Reality Software and Technology*, VRST '04 (New York, NY, USA: ACM, 2004), 122–128, https://doi.org/10.1145/1077534.1077558.

[328] Biocca and Levy, *Communication in the Age of Virtual Reality, 1995*.

[329] Interactivity has been shown to be a key reason for experiencing presence by:
Slater and Wilbur, 'A Framework for Immersive Virtual Environments (FIVE)...', December 1997, Lombard and Ditton, 'At the Heart of It All', September 1997., Lee, 'Presence, Explicated'., Thomas B Sheridan, 'Constraint, Intelligence, and Control Hierarchy in Virtual Environments', *Intelligent Motion and Interaction Within Virtual Environments*, 2007. Wender et al., (2009)

I created a scene where the viewer could use the controller to interact with the spacetime curve; an idea bordering on gaming without the complexity of good gaming programs. Even a simplified version of a game complicates the experience, as in *Virtual Playgrounds*, where one exhibit was in the form of a game and an attendant coached each person through it. This was reported as a cumbersome and distracting experience.[330]

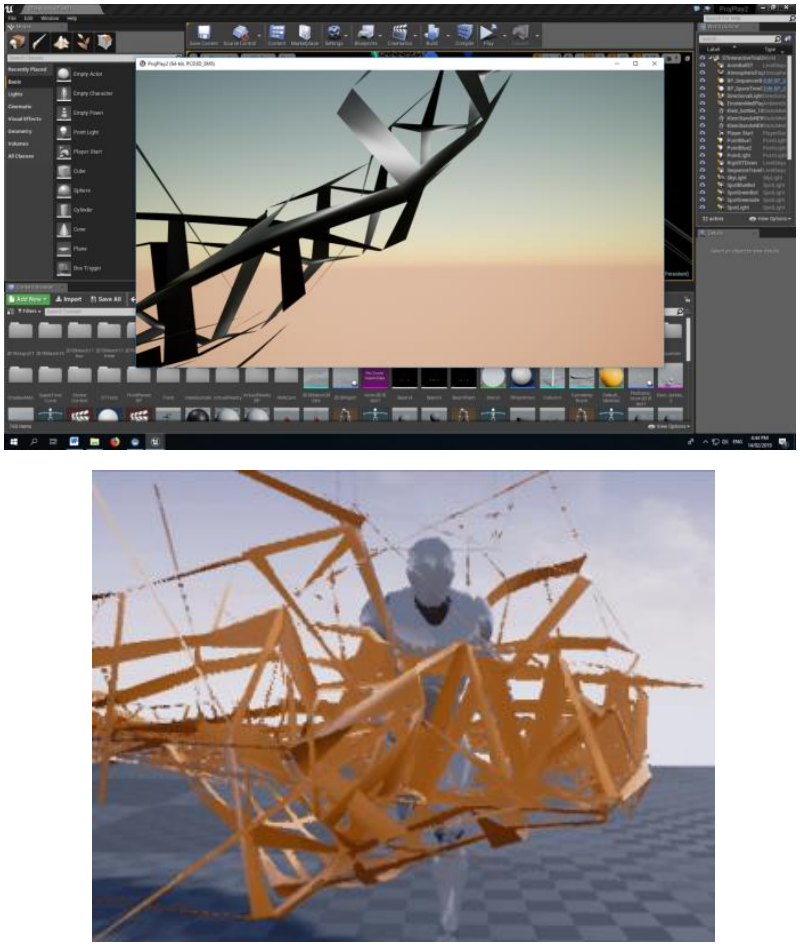

Figure 17. Claire Hughes, Screenshots of development and trials with interactive spacetime curve.

All the above scenarios I trialled required the torch to be visible in the VR. Without a hand, the torch was floating by itself and with a hand, it needed an arm. Trials of this provided a conflicted aesthetic with hands and arms that obviously did not belong to the viewer.

My final testing of interactivity was aimed at giving the viewer some sense of control. I used virtual boxes, that when the viewer walked into them, would trigger a response. These were

[330] *Future Playgrounds* is a touring new media show featuring digital artists from the United States, Turkey and Canada. I experienced all the VR exhibits in when it toured New Zealand.

situated in a specific area or within an object. In testing mode, observing people in the scene made it evident that they were often unaware that they had triggered an action, and at other times they thought they had, when no trigger was present. The final version of *Entangled* includes only a few triggers to provide a level of presence and also a degree of ambiguity as to how much control the viewer has.

The main element of interaction that enhances the feeling of presence in *Entangled* is the capability to move around the scene. This allows the viewer to make the decisions where they position themselves and what they see. One focus group discussion mentioned that each person creates a different experience both visually and aurally depending where they positioned themselves, which made them feel more engaged with the experience.

1.9 Embodiment and Postphenomenology

"…it seemed like the rubber hand belonged to me."
"…it seemed like the rubber hand was part of my body."
"…it seemed like my hand was in the location where the rubber hand was."
"…it seemed like the rubber hand was in the location where my hand was."
"…it seemed like I was in control of the rubber hand."
"…it seemed like my hand was out of my control."[331]

When it comes to understanding the affects of an immersive VR environment on human subjects I have equipped myself with a body of knowledge regarding embodiment and the philosophical ideas postphenomenology. Where embodied explains and encapsulates sensory perception, postphenomenology positions the importance of the role of technological 'mediation' in everyday experience. This framework is later substantiated through analysis of my work by drawing from qualitative and quantitative research data obtained from visitors to my work at Toi Pōneke.

A definition of embodiment is derived by a psychometric study by Longo et al. [332] They use the rubber hand illusion, which they describe as, "one of the few means of manipulating

[331] Matthew R. Longo et al., 'What Is Embodiment? A Psychometric Approach', *Cognition* 107 (1 June 2008): 978–98, https://doi.org/10.1016/j.cognition.2007.12.004.

[332] Matthew R. Longo et al., 'What Is Embodiment?

embodiment", to determine the characteristics of embodiment. [333] [334] Their research concluded that ownership, location and agency form the structure of embodiment. Ownership related to the person considering something as a part of their body and the questions asked by Longo et. al. were of the form, did it seem like it belonged to me? Location involved the person knowing where their body, or something they were interpreting as their body, was positioned in the environment. This related to questions of the type, 'it seemed like it was in the location of …' Agency, which they defined as, "the experience of causing actions and events in the world"[335] was probed by questions such as, "it seemed like I was in control of …"

Experiments have shown that VR can affect the viewer's perception of their body size. A virtual hand can be elongated to three times its length and still have reported ownership.[336] In a further example, perceived male belly size was shown to be changed to a larger size through VR.[337] One VR experience in *Björk Digital, Mouthmantra VR,* took the viewer into the singer Björk's mouth, where you could peer out from behind her tonsils and teeth. This gave me the feeling of being a small person inside a large mouth, reminding me of *Fantastic Voyage*, the 1966 film where people were miniaturised and taken into a person's body.[338] Analysis of the responses to *Entangled* detailed in chapter 2, show that when the scale changed, some viewers reported that they felt scaled as well.

Mel Slater, who has spent many years researching presence in VR, explains that the response to VR actions, even when we know they are not real, is what he calls 'plausibility illusion'.[339]

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[333] Matthew R. Longo et al., 'What Is Embodiment?

[334] Dalila Burin et al., 'That's My Hand! Therefore, That's My Willed Action: How Body Ownership Acts upon Conscious Awareness of Willed Actions', *COGNITION* 166 (September 2017): 164–73, https://doi.org/10.1016/j.cognition.2017.05.035.

[335] Pritchard et al., 'Non-Hierarchical Influence of Visual Form, Touch, and Position Cues on Embodiment, Agency, and Presence in Virtual Reality', 2016 18.

[336] Michael Schaefer et al., 'Morphing the Body: Illusory Feeling of an Elongated Arm Affects Somatosensory Homunculus', *NeuroImage* 36, no. 3 (1 July 2007): 700–705, https://doi.org/10.1016/j.neuroimage.2007.03.046.

[337] Jean-Marie Normand et al., 'Multisensory Stimulation Can Induce an Illusion of Larger Belly Size in Immersive Virtual Reality', *PLOS ONE* 6, no. 1 (19 January 2011): e16128, https://doi.org/10.1371/journal.pone.0016128.

[338] de la Pena et al., 'Immersive Journalism: Immersive Virtual Reality for the First Person Experience of News', *Presence: Teleoperators & Virtual Environments* 19, no. 4 (August 2010): 291–301.

[339] Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments.

Proprioceptive cues, which are the internal bodily abilities to sense stimuli regarding our position, motion, and orientation, can be fooled by VR. Changes of view responding to the movement of the viewer in the headset establish a presence that makes it plausible for the other actions to be real. Julieta Aguilera argues that real time connections to the body, made to natural experiences, are brought into the VR to allow the viewer to redefine their body within this new experience. [340] Psychology experiments, such as the rubber hand experiment, where perception of where the participant's hand is located, have shown that proprioceptive shift can occur. As presented later in chapter 2, responses from viewers in *Entangled* range from not knowing where their body was at all, to feeling like they were falling down the vortex and feeling like they were part of the apparatus.

It is the dissonance between what our body is doing and what we are seeing in the VR that I use as an experiential entanglement. Popat's review of Gibson/Martelli's *White Island* (2014) described the experience of being in VR without seeing our body as putting more emphasis on the internal senses, the proprioceptors, while still experiencing the visual VR world. He states, "In that moment my embodied self knew that my arms were raised in front of my face, but my empirical perspective on the world presented visual evidence that my arms were not there. Two different ways of knowing the world collided."[341] When the collision occurs they are briefly one, at other times they are separate yet intertwined; an experience of entanglement.

Works such as *Osmose* have contributed towards a move from realistic imagining to abstraction focusing on sensory bodily factors. Her work creates an embodiment, by immersing the viewer's body within the VR. However, Davies also states that, "feelings of disembodiment can coexist with those of embodiment"[342], by the use of the breathing interface to create feelings of floating and falling.

Mel Slater, 'Place Illusion and Plausibility Can Lead to Realistic Behaviour in Immersive Virtual Environments', *Philosophical Transactions of the Royal Society B: Biological Sciences* 364, no. 1535 (12 December 2009): 3549–57, https://doi.org/10.1098/rstb.2009.0138.

[340] Julieta Aguilera, 'Mindful Embodiment in Synthetic Environments', *Metaverse Creativity* 4, no. 1 (June 2014): 5–14, https://doi.org/10.1386/mvcr.4.1.5_1, 6.

[341] Sita Popat, 'Missing in Action: Embodied Experience and Virtual Reality', *Theatre Journal* 68, no. 3 (September 2016): 357–78.

[342] Char Davies, 'Changing Space: Virtual Reality as an Arena of Embodied Being.', 1998, http://www.immersence.com/publications/char/1998-CD-Virtual_Dimension.html, paragraph 11.

Other aspects of embodiment are discussed elsewhere in this research. Control has been introduced in the above work on presence with interaction and is analysed with respect to *Entangled* in chapter 2. Embodiment occurs in more ways within *Entangled*, such as images projected on the body, the audience viewing others within the VR, the use of the webcam and the creation of shadows. These are also discussed more fully in chapter 2.

Postphenomenology

With the use of VR in this work it is salient to consider postphenomenology which underscores relationships with technology as a way of understanding the human interaction with the world through technology. North-American philosopher of science and technology, Don Ihde, developed postphenomenology releasing his book *Technics and Praxis: A Philosophy of Technology* in 1979. It is relevant to my work that Ihde specifically considers scientific apparatus and provides a theory of how technology can shape our experience of the world and our understandings of our physical reality.[343]

Ihde states that he developed his approach to technology through his phenomenological study of scientists' bodily engagement of the world through instruments. He acknowledges Thomas Kuhn and Bruno Latour's recognition of the role of scientific instruments along with Edmund Husserl's 'intentionality' and, Maurice Merleau-Ponty and Martin Heidegger's 'being in the world' as influences on his development of postphenomenology.[344]

Philosophers of technology, Robert Rosenberger (US) and Peter-Paul Verbeek (Netherlands) position Ihde's development of postphenomenology from the phenomenological tradition and American pragmatist philosophy. [345] Postphenomenology starts with descriptions of human experience, however it steers away from linguistic and consciousness emphases. Instead it uses a pragmatic stance with investigations of empirical technological developments that are shown in lived experience. Ihde takes into consideration both human and non-human artefacts creating a material-orientated philosophy. He does this from a first person perspective, relevant to my emphasis on using VR to provide an experiential environment.

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[343] Don Ihde, *Technics and Praxis: A Philosophy of Technology* (Springer Science & Business Media, 2012).

[344] Don Ihde, preface to *Postphenomenology and the Philosophy of Technology*, Editor-in-Chief Robert Rosenberger, Georgia Institute of Technology, accessed 2 February 2019.

[345] Introduction to Robert Rosenberger and Peter-Paul Verbeek, eds., *Postphenomenological Investigations: Essays on Human-Technology Relations*, Postphenomenology and the Philosophy of Technology (Lanham: Lexington Books, 2015).

Rosenberger and Verbeek state that postphenomenology refutes descriptions, such as Merleau-Ponty's, that science analyses from a distance, providing a reduced reality. They position science and technology as being able to have a closer engagement with the world by shaping relationships. Rather than science and technology reducing the human-world relationships, it expands them by viewing technology as a mediator between humans and the world. Human-technology-world is the schematic way Ihde represented it.[346]

Postphenomenology positions the importance of the role of technological 'mediation' in everyday experience. Mediation is defined by Verbeek as how technological artefacts influence the relationship between people and the world. Verbeek states that, "Artefacts are not neutral intermediaries, but actively co-shape people's being in the world: their perceptions and actions, experience and existence."[347] Postphenomenology does not position technology as merely functional instruments, but as having the capability to shape the human experience by magnification and reduction. For example a telescope provides us with increased capabilities which shape our experience with the object being observed. However, technology produces trade-offs such as in VR where our capabilities are expanded as we gain the ability to see 3-D visual spaces, but the trade-off is that we cannot see our spatial location in the physical world.

Husserl's phenomenology served to replace the modernist separation between subject and object with relationships between them that are intentional.[348] This intentionality involves the human subject as having a directed mental state that creates a joint existence between them and the object. Postphenomenology takes this further by consideration of the human and non-human intentionality. An object is non-neutral; it has intentionality built into it. For example glasses have an intentionality of magnifying, however, they also have an intentionality of positioning on the face. Ihde's notion of 'multistability' replaces previous phenomenological ideas of an 'essence' of an object as it considers the stability of many intentionalities. He uses qualitative methodologies to determine stable intentionalities that provide information about variations in the phenomena. With *Entangled* the intentionality of creating presence varies with the disruptions which have intentionality of decreasing presence.

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[346] Ihde, Don. *Technology and the Lifeworld : From Garden to Earth,* Indiana University Press, 1990.

[347] Peter-Paul Verbeek, *What Things Do: Philosophical Reflections on Technology, Agency, and Design* (Penn State Press, 2010), 4.

[348] Robert Rosenberger and Peter-Paul Verbeek, eds., *Postphenomenological Investigations: Essays on Human-Technology Relations*, Postphenomenology and the Philosophy of Technology (Lanham: Lexington Books, 2015), chapter 1.

One particular example of multistability that Ihde investigates is the ambiguity of perception in examples such as the Necker cube, which is described as a Gestalt switch. Kuhn describes a Gestalt switch as when “it must occur all at once (though not necessarily in an instant) or not at all" [349]The Necker cube is an ambiguous optical illusion which can be perceived in two discrete and different ways.[350]

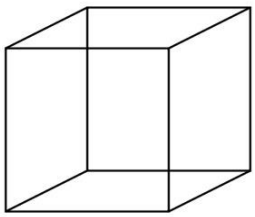

Figure 18. The Necker cube which can be seen as two different spatial configurations.

These two ways of seeing the cube cannot be combined; the viewer sees it as one or the other.

Paradigm shifts, which I have discussed in terms of the change of knowledge systems from Newtonian physics to quantum theory, are described by Kuhn as being like a gestalt switch. [351] However, I argue that with VR the feeling of presence is a continuum rather than a sudden shift. By using disruptions I am trying to get viewers to move along this continuum. The mediating technology is forming different stabilities, but not always sudden shifts. This is exemplified by viewers who reach out to touch a virtual object while at the same time knowing that it really is not physically there. Such a feature is more in line with dissonance than a Gestalt shift.

Intentionality is positioned by Ihde as the creator of the subjectivity of the human and the objectivity of the world. As Rosenberger and Verbeek sum up, “Postphenomenology is the practical study of the relations between humans and technologies, from which human

[349] Thomas S. Kuhn, *The Structure of Scientific Revolutions: 50th Anniversary Edition* (University of Chicago Press, 2012,), 149.

[350] Schwartz Jean-Luc et al., ‘Multistability in Perception: Binding Sensory Modalities, an Overview’, *Philosophical Transactions of the Royal Society B: Biological Sciences* 367, no. 1591 (5 April 2012): 896–905, https://doi.org/10.1098/rstb.2011.0254.

[351] Thomas S. Kuhn, *The Structure of Scientific Revolutions*.

subjectivities emerge, as well as meaningful worlds."[352] I interpret this with VR technology to mean the intentionality is to create other 'worlds' in the virtual space by the mediating technology. When the new world's relationship with the viewer questions their reality, this is creating a new subjective experience for the viewer.

Ihde asserts that mediation between the human and the world is the primary role of technology. He classifies four main relations: embodiment relations; hermeneutic relations ; alterity relations and background relations. [353] I will introduce these and extend them to VR technology and the virtual worlds.

Taking Merleau-Ponty and Heidegger's focus of how technologies alter our 'being in the world', Ihde incorporates embodiment relations into his postphenomenological philosophy. Here embodiment involves technologies that transform and reshape a user's experience. This occurs because the device forms a type of symbiosis with the person so that the technologies "'withdraw' and are barely noticed if at all" and become part of the person's bodily perceptual awareness.[354] The focus is taken away from the technological devices and is placed on the object. Ihde gives the example of a person wearing glasses that mediate between the person and the world. The glasses become part of the person's bodily awareness because as the person looks through the glasses they cease being a separate object and become part of the person. This example could be extended to the VR headset because the viewer looks through it to see the VR world. The degree to which the person 'sees through' the VR technology will be related to the feeling of presence, which has been previously discussed.

Hermeneutic relations involve interpreting from the technology, so that rather than looking at the actual technology the person is reading or interpreting the information. Ihde uses the reading of a thermometer as a hermeneutic relationship, where it is the interpretation of the reading that creates the knowledge of hot or cold.[355] To consider this in VR, video games researcher, Espen Aarseth sums up the hermeneutic relations when he says, "virtual worlds technology is not about creating alternatives to reality, but about interpreting and

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[352] Robert Rosenberger and Peter-Paul Verbeek, eds., *Postphenomenological Investigations: Essays on Human-Technology Relations*, Postphenomenology and the Philosophy of Technology (Lanham: Lexington Books, 2015) 12.

[353] Preface by Don Ihde. *Postphenomenology and the Philosophy of Technology*, Editor-in-Chief Robert Rosenberger, Georgia Institute of Technology 2015.

[354]Don Ihde, *Technology and the Lifeworld : From Garden to Earth,* 73.

[355]Don Ihde, *Technology and the Lifeworld : From Garden to Earth,* 20.

understanding our own reality. Until now, narrative has been the privileged object of hermeneutics, but now we should see virtuality as a strong contender for the attention of the hermeneuts."[356] The hermeneutic relationship in my work involves interpreting our physical reality through the mediated technology of VR.

Alterity relations are how we relate to technology in similar ways to relating to humans, as a 'quasi-other'. An example is Siri on the iPhone, where the interaction with her is as an 'other' person. Ihde considered that computer games are alterity relations when there is a competition between the player and the technology. Ihde states that, "In competition there is a kind of dialogue or exchange. It is the quasi animation, the quasi-otherness of the technology that fascinates and challenges. I must beat the machine or it will beat me."[357] This is not so relevant in my work as I do not create competition or provide an avatar or other 'quasi-other'.

Background relations are from the technological aspects that are operating without the attention of the user, such as refrigerators and air conditioners. With VR there are many background technologies, such as the computer, coding and motion tracking that are achieved by background relationships that the viewer is unaware of, however, they are still relating to them.

By digging deeper into the relationships formed by the technology, in terms of a mediating role, postphenomenology provides insight into how we obtain knowledge through our embodied experience. Communication has been investigated in this chapter through art, science and technology. The following chapter provides an analysis of how this is evidenced in this body of creative practice.

[356] Espen Aarseth, 'Virtual Worlds, Real Knowledge: Towards a Hermeneutics of Virtuality', *European Review* 9, no. 2 (May 2001): 227–32, https://www.cambridge.org/core/journals/european-review/article/virtual-worlds-real-knowledge-towards-a-hermeneutics-of-virtuality/737A133851516D320854A523059399E9.

[357] Don Ihde, *Technology and the Lifeworld : From Garden to Earth,* 100, 101.

Chapter 2: Discussion of Art Investigations

Processes involved in the development of these works are discussed throughout this document. Further information can be found in appendices 1 and 3.

2.1 Overview of Main Art Investigations

Earlier trials and two significant works produced during the course of my PhD are introduced to highlight various approaches to my concepts and designs, as is the major project Entangled at the public community gallery Toi Pōneke, Wellington.

Why Anything?

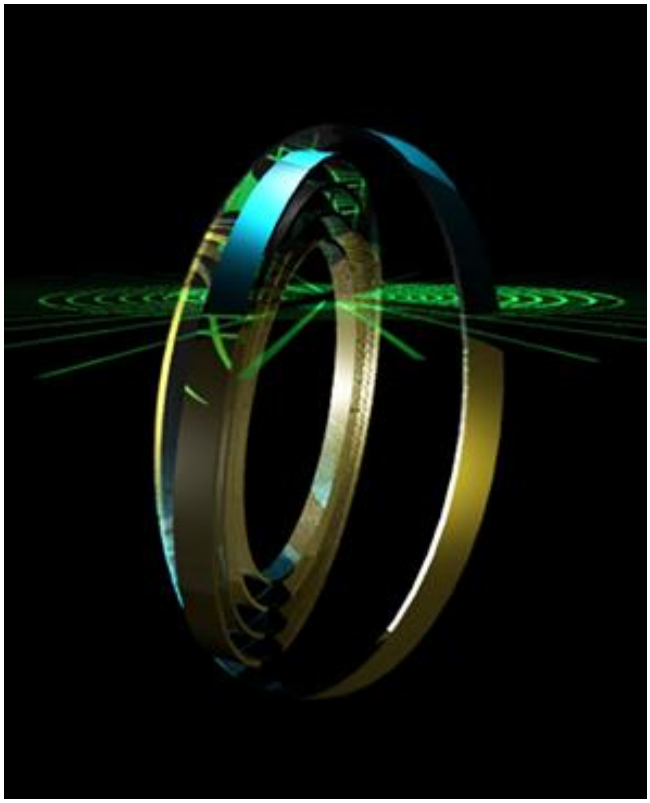


Figure 19. Claire Hughes, *Why Anything?* 2016, Screenshot.

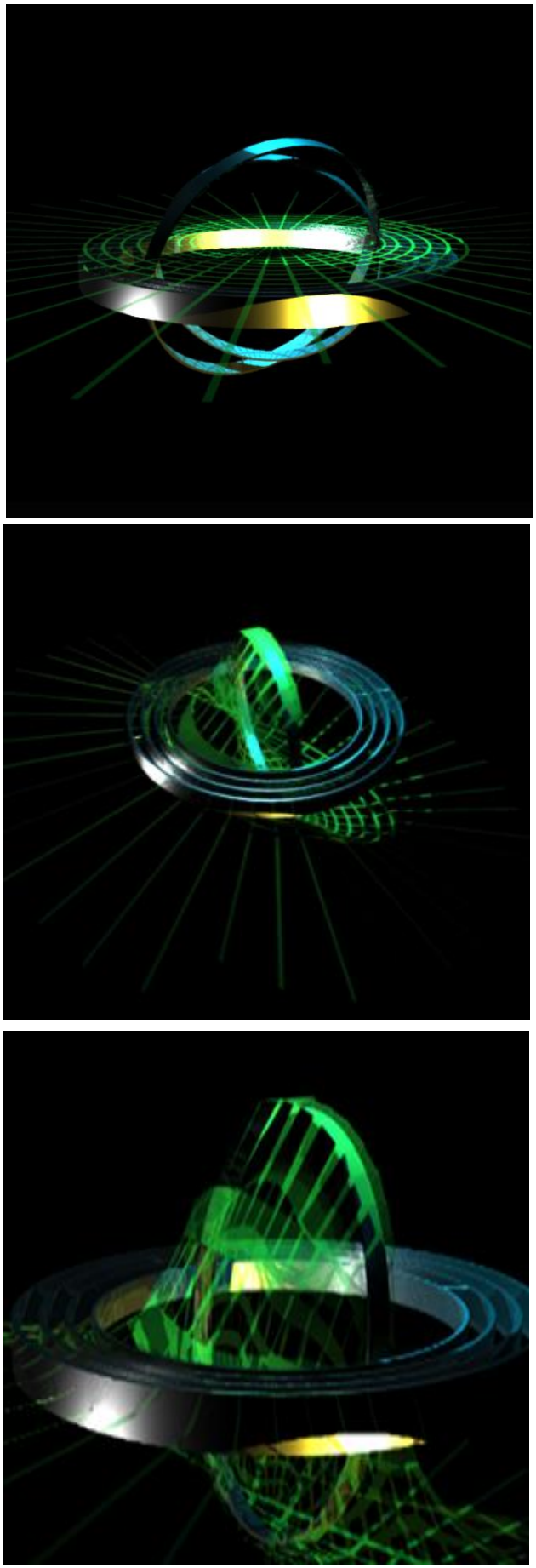


Figure 20. Claire Hughes, *Why Anything?* 2016, Screenshots.

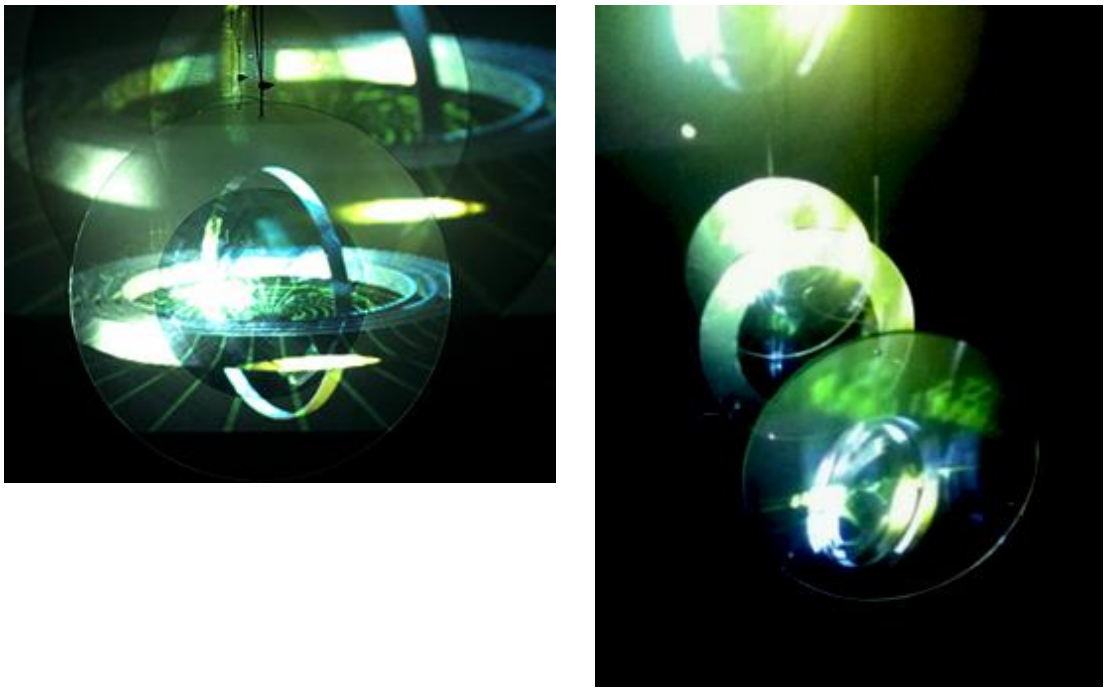


Figure 21. Claire Hughes, *Why Anything?* 2016, Photographs of installation.

Extensive investigations and testing of physical spaces, rear projection film, projection, virtual modelling and animation which were undertaken in the first year of this creative practice. Spatial trials and scaling of materials provided useful information for further installation practice. The content of the work explored multiple scientific theories as the work transitioned from illustrative science towards a tighter focus and more targeted investigations of scientific communication and experiential encounters in later work. More detailed information on these trials is provided in Appendix 1.

The culmination of explorations resulted in an installation called *Why Anything?* This consisted of an animation projected onto three glass disks with rear projection film adhered to allow the images to pass through each one. The movement of the disks and the immersive qualities were instrumental in leading to more immersive environments. The animation focused on the implications of scientific theories by animating a gimbal to destroy a 3-D model of the diagrammatic spacetime curve.[358] The flat representation of space and time from Newtonian physics was transformed to the curved representation of gravitational pull by the rotating

[358] A gimbal consists of rings suspended at right angles.
https://en.oxforddictionaries.com/definition/gimbal
The spacetime curve is explained in more detail in section 2.31

gimbal. Finally it was totally mangled to represent further possible changes to the understanding of space and time. This animation informed further works with the spacetime curve featured in the projections and VR.

Matter Matters

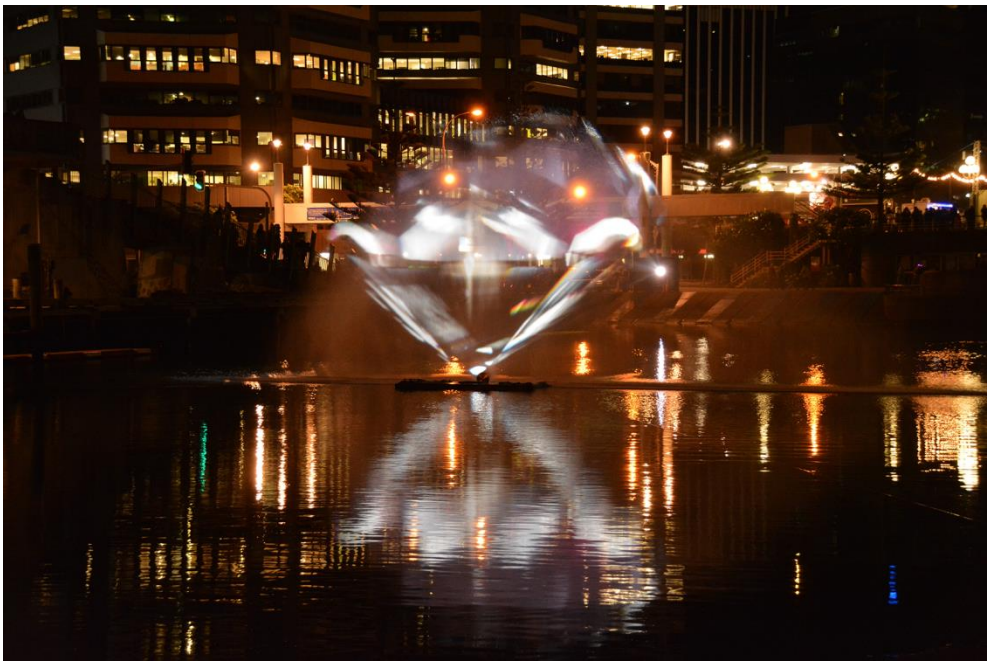


Figure 22. Claire Hughes, *Matter Matters,* 2016, Lux Festival, Wellington, Photographs courtesy of Denise Gandy.

Matter Matters was a work developed to explore scale and immersion with a more public and larger audience. This was designed within the context of humour in science communication. Created for the Lux Light Festival in Wellington in 2017, it was shown on a 6m high water screen located in Wellington Harbour. It consisted of a projection from one side of the lagoon that was visible on the water screen from any direction. Sound was a new aspect to my investigations to provide both entertainment and atmosphere. The animation consisted of gems, exploding from a 'big bang' and forming hierarchies and entanglements with each other. This is explained in detail in Appendix 1.

Findings from this work were relevant to the development of the VR installation. The playfulness fulfilled the entertainment aspects, however, I could see that a more serious work could convey complex science ideas that I was interested in exploring. To enable this I required fuller immersion than was achieved with the water screen. I had taken aspects to absurdity, such as rubies dancing the cancan, and I decided to pull back on this and have a more subtle approach, while not abandoning the impact of scale. I decided that VR was able to provide both scale and immersion, while also allowing for an intimate experience within an installation that also provided opportunities for audience engagement.

A collaboration with two sound specialists enabled exploration of sound with the animation. The fast tempo of *Matter Matters* was tempered in VR both visually and aurally. The sound of the big bang in *Matter* Matters, with its abruptness, volume and incongruity of sound was adapted to that of crashing glass in *Entangled.* The more abstract segments of the sound track of *Matter Matters* were taken into the VR work, which is explained further in the following analysis of *Entangled.*

The animation of the spacetime curve, which was established in *Why Anything?* was resolved in *Matter Matters.* Where the gimbal had previously distorted the spacetime curve, the rubies animation created a more rhythmical and twisting effect. When the rubies were made invisible and sections reversed, the new spacetime curve animation dived into the sea in a wave-like form. This was extended in the VR installation onto the glass disk and inside the VR. In a sense this entangled my major works of this creative practice.

Entangled Virtual Reality Installation

This creative research culminated in the installation *Entangled* at Toi Pōneke, where the presentation of a VR work was intertwined with the physical space, and other non-VR components to investigate the productive union between science communication relating to quantum entanglement and changes in knowledge processes. The exhibition ran for three weeks in 2018 at Toi Pōneke Art Gallery in Wellington. The first part of the installation consisted of a 1.5m glass disk with adhered rear-projection film, suspended off-centre in the space. The projector was attached to the ceiling to project onto the glass and the wall behind. The L shape of the gallery space enabled a separation of this from the VR, yet still integrated the two areas with the projections and sound. The plinth where the headset was positioned for use was located on the far wall, and the headset cables were suspended from the ceiling to allow viewers to walk around the space. Non-slip pale grey vinyl was adhered to the floor in the centre of this space to capture a second projection from above. This defined the space for the VR and provided the audience with a real-time view of what the person was seeing in the headset. The Toi Pōneke exhibition was different to from the layout for the examination installation, and all analysis below relates to the Toi Pōneke installation.

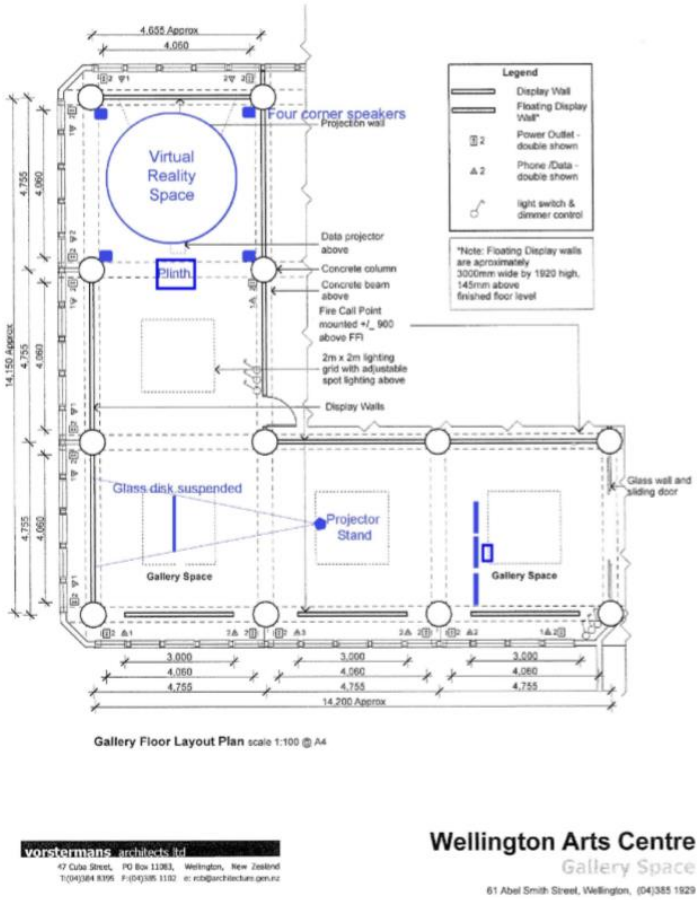


Figure 23. Claire Hughes, *Entangled,* 2018, Floor Plan from proposal for exhibition at Toi Pōneke, Wellington.

Figure 24. Claire Hughes, *Entangled,* 2018, Installation set-up Toi Pōneke, Wellington.

Figure 25. Claire Hughes, *Entangled,* 2018, Toi Pōneke, Wellington.

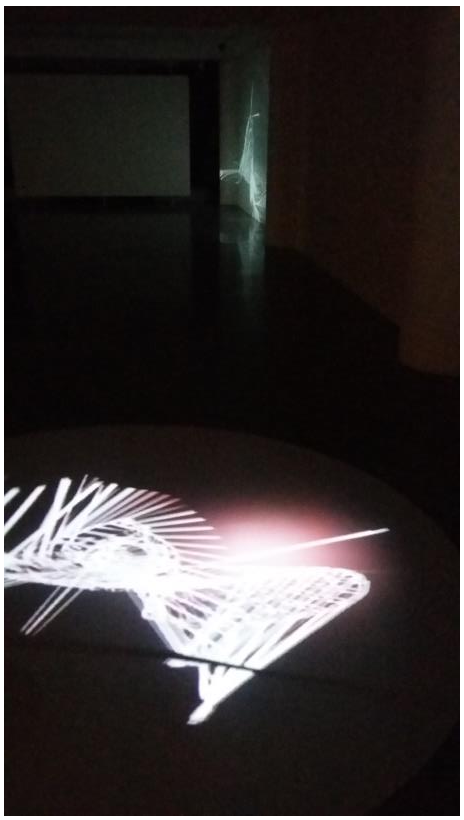


Figure 26. Claire Hughes, *Entangled,* 2018, Toi Pōneke, Wellington.

Walking into the L-shaped gallery, viewers to the exhibition encountered the suspended glass disk in front of them, with the animation playing on it and the wall behind. The reflections on the floor preceded the disk in activating the space. Viewers were able to move freely around the disk, view it from both sides and intercept the projection to the wall with their bodies. To the viewers' right at the end of the gallery, the VR technology was evident by the images projected onto the floor and the headset resting on the spot-lit plinth. The circular shapes from the disk and the vinyl on the floor, along with the use of projection, physically connected the two spaces.

Communication also occurred between the physical and virtual spaces intertwining events to provide metaphoric entanglement. By wearing the Vive headset the viewer is immediately physically embodied in the VR technology, offering immersive experiential encounters. The person in the VR headset is embodied in their own view by the projection overhead. The webcam positioned outside the virtual environment feeds into their virtual world and a reiterative entangled process occurs.

Within the VR environment there are two main components that form the virtual environment: the Klein bottle and the diagrammatic representation of the spacetime curve. The following sections define these apparatuses and describe how they are used to create the

exploratory landscape. Within the work, the apparatus morphs from very small, referring to the subatomic scale of quantum science, to very large, giving an impression of the magnitude of the cosmos.

Capabilities of the VR technology offer the feeling of presence and, in accepting the different rules within the VR, common sense is shown to be disregarded. Combined with disruptions to the feeling of presence, viewers are offered the opportunity to experience conflicting feelings of dissonance, which have been argued as an insight into new knowledge shifts required to understand quantum theories of our physical reality. My research design employed a public questionnaire and formed more specialist focus groups to come to better understand the effect and impacts of my work.

2.2 Questionnaire and Focus Group

Aims

Response collections were set up to provide information on the experience of *Entangled* to ascertain whether the creative practice has met stated aims. This research aims to sit at the intersection of art and science communication and so the most relevant analysis was deemed to be phenomenologically-based using interpretation of first person experience with an analysis of notable features. [359]

Questionnaire

The questionnaire was designed for the general public in mind, left at the gallery for anyone over 16 to fill out. The number of questions posed was limited to increase the likelihood of engagement. Questions were framed in an easy to understand manner, while aiming to gain responses on specific areas such as immersion, dissonance and the sublime. For example, 'Did you feel more part of the scene when it was black and white or when it was in colour?' captured responses on presence and embodiment as well as the influence of colour. To evoke responses about agency and control, I posed the question, 'Did you notice triggering any events or causing shadows?' The questions about the apparatus when it was large and small resulted in responses that related to the viewer's perception of ownership of their body within

[359] Low-level ethics approval for human involvement in this project was received on 1 August 2018.

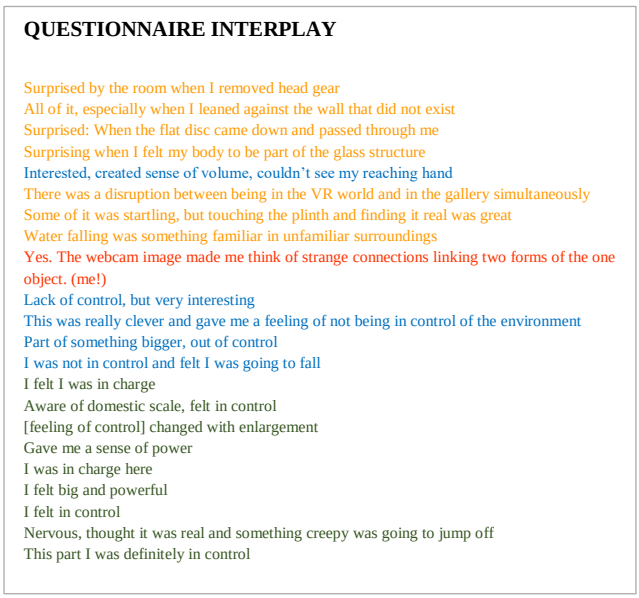
the VR. Additional information was captured beyond the target of the questions and a section was provided for general comments.

Forty-three responses were gained from the exhibition venue. These were collated into a spreadsheet and from informal analysis, topics emerged. Comments were further collated into these topic areas to provide easy accessibility to incorporate the material into the written work. The spreadsheet was sorted on the classifications of those who had used VR a number of times and those who had little or no experience to make comparisons of their responses. People who had used VR ten times or more were more likely provide analysis of the use of the VR. Those who had never used VR provided the most emotive comments.

Surprised?	Trigger events or shadow	Have you heard of entanglement	Other comments	Age range	How often play games	Used VR before?
The flash of light caught me by surprise	Shadows of people grew as I moved	I felt like I was part of a science experiment within an art work. Amazing	Suspension of disbelief made this an unforgettable experience	3	Never	No
Yes the grey bits between sections disconcerting	No	Good way to visualise the concept	I went through 3 times - very different each time	4	Never	No
When the shadow changed sizes I found it disruptive and different	The shadows got bigger as I moved about - it was disruptive	No but I was intrigued by the use of science in an art work	I don't know what I was expecting, but this blew me away	1	Never	No
Light beam passing through me	Disconcerted, slightly scared, unsure, almost wanted to break away.	No	- Really nice VR, not like a video game, nice	2	Most days	Once
Surprised by the room when I removed head gear	Yes	Yes, reminded of the curve of time theory	Lovely work. Thank you	4	Never	Once
Shadows and some noises	Not at all. The shadow part was cool though	Not at all	Really cool. Liked the start by having the black in the room	2	Most days	Once
The glass shutter, the human silhouettes	Loved the vive box shadow	No	Fantastic use of the vive	2	Once a week	Once
Constantly	Myself	No, felt a depth of infinite space and time	Well worth experiencing	4	Most days	Once
Water falling was something familiar in unfamiliar surroundings	Shadowy figures disconcerting - I wanted to take the headset off	Yes, but I don't know enough about it	An amazing multi-sensory experience	2	Never	Once

Figure 27. Part of spreadsheet from questionnaire responses, sorted on 'Used VR before?'

Analysis of responses from the 43 viewers who completed the questionnaire in the gallery showed that this work found its way to an audience new to VR. 81% had used VR technology five times or less and 43% had never used a VR headset before.


QUESTIONNAIRE INTERPLAY

Surprised by the room when I removed head gear
All of it, especially when I leaned against the wall that did not exist
Surprised: When the flat disc came down and passed through me
Surprising when I felt my body to be part of the glass structure
Interested, created sense of volume, couldn't see my reaching hand
There was a disruption between being in the VR world and in the gallery simultaneously
Some of it was startling, but touching the plinth and finding it real was great
Water falling was something familiar in unfamiliar surroundings
Yes. The webcam image made me think of strange connections linking two forms of the one object. (me!)
Lack of control, but very interesting
This was really clever and gave me a feeling of not being in control of the environment
Part of something bigger, out of control
I was not in control and felt I was going to fall
I felt I was in charge
Aware of domestic scale, felt in control
[feeling of control] changed with enlargement
Gave me a sense of power
I was in charge here
I felt big and powerful
I felt in control
Nervous, thought it was real and something creepy was going to jump off
This part I was definitely in control

Figure 28. Sample of analysis of questionnaire responses.

Focus Group

Twenty-five people were emailed with an overview of the exhibition and invited to participate in any one of the focus group meetings. People were chosen from Wellington-based PhD candidates, Masters students, Massey University staff, artists, art collectors and staff at Toi Pōneke. Of these, fourteen were able to view the exhibition and participate in the focus group. Demographics of group:

Focus Group 1

4 females and 5 males.

3 Massey lecturers, 3 PhD students, 1 MFA, 2 interested art followers with an interest in science.

Focus Group 2

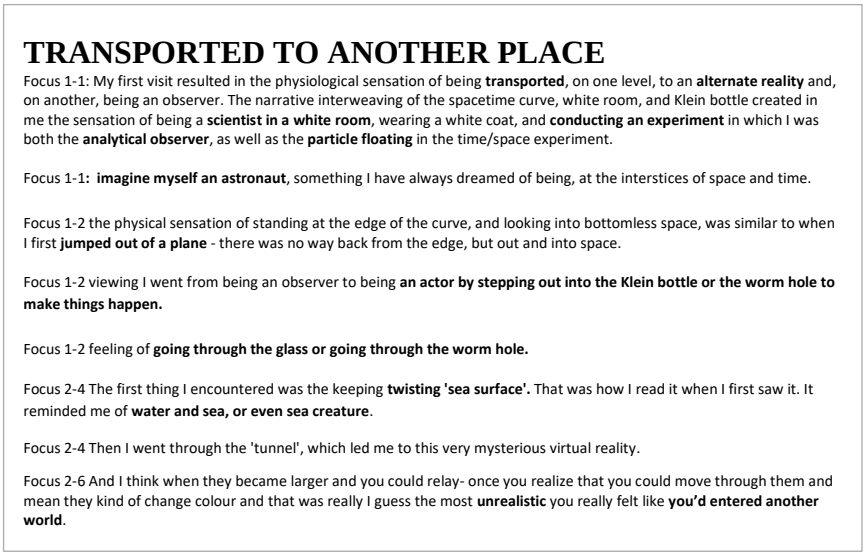
3 females and 2 males

3 PhD students, 2 previous performance- based TV practitioners.

The focus groups were initially asked to give their feedback on the exhibition and then asked to respond to the following topics: the physiological effects on their body; emotional responses; and scientific concepts. These were stranded into the sequences of the two apparatuses and the interplays between the physical and virtual spaces.

There was a noticeable difference in responses between those who had used VR before and those who had little or no experience. There was also a difference in discussions from those who had previous knowledge of quantum entanglement to those with no prior knowledge. People with a good understanding of entanglement made some very astute comments about the range of entanglement. These are provided in the discussions below.

All comments were transcribed and analysed on the basis of the focus strands. Further investigation showed similar topics emerging as the questionnaire analysis had produced.



TRANSPORTED TO ANOTHER PLACE

Focus 1-1: My first visit resulted in the physiological sensation of being **transported**, on one level, to an **alternate reality** and, on another, being an observer. The narrative interweaving of the spacetime curve, white room, and Klein bottle created in me the sensation of being a **scientist in a white room**, wearing a white coat, and **conducting an experiment** in which I was both the **analytical observer**, as well as the **particle floating** in the time/space experiment.

Focus 1-1**: imagine myself an astronaut**, something I have always dreamed of being, at the interstices of space and time.

Focus 1-2 the physical sensation of standing at the edge of the curve, and looking into bottomless space, was similar to when I first **jumped out of a plane** - there was no way back from the edge, but out and into space.

Focus 1-2 viewing I went from being an observer to being **an actor by stepping out into the Klein bottle or the worm hole to make things happen.**

Focus 1-2 feeling of **going through the glass or going through the worm hole.**

Focus 2-4 The first thing I encountered was the keeping **twisting 'sea surface'.** That was how I read it when I first saw it. It reminded me of **water and sea, or even sea creature**.

Focus 2-4 Then I went through the 'tunnel', which led me to this very mysterious virtual reality.

Focus 2-6 And I think when they became larger and you could relay- once you realize that you could move through them and mean they kind of change colour and that was really I guess the most **unrealistic** you really felt like **you'd entered another world**.

Figure 29. Sample of transcript analysis of focus group.

A decision was made to adapt the same topic headings for both sets of data and collate all the information into these headings. Key words were highlighted within comments. This provided an effective way to access and incorporate responses into the following sections.

2.3 Analysis of *Entangled*

Within the exhibition *Entangled,* there are four features I discuss in relation to audience navigation of the exhibition and VR; the conceptual and aesthetic aims of this work. These features are:

2.31 Apparatus

2.32 Spacetime curve in action

2.33 Scaling the Klein Apparatus

2.34 Interplays

2.31 Apparatus

I adapt my definition of apparatus from Giorgio Agamben as "anything that has in some way the capacity to capture, orient, determine, intercept, model, control, or secure the gestures, behaviors, opinions, or discourses of living beings."[360] I propose that the virtual reality technology and the physical gallery space can both be considered as apparatuses. The gallery space (which in this case adhered to a 'white cube' mode of presentation) has an established set of conventions of engagement between the viewer and the art work. I was aware of this contextual framing as I designed the installation. These established patterns of behaviours also informed how I structured and communicated opportunities for direct participation, and observation within the space.

Within the VR, the constructions are also apparatuses: the glass bottles, the spacetime curve construction, the room with the plinth and the cylindrical construction. The physical space forms apparatuses: the gallery space including the walls and floor; the glass disk; the vinyl on the floor and the projector and projections. These apparatus form relational systems, bringing together a bounded group of theories and providing metaphoric relationships.

Focus groups and questionnaires bear out various empathetic approaches in the design of my installation and the viewers' encounters with VR. Most (81%), of the respondents to the questionnaire had used VR five times or less, so I understood the need to design the physical layout with care. [361]

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[360] Agamben, Giorgio, *'What Is an Apparatus?' And Other Essays* (Stanford, CA: Stanford University Press, 2009), http://www.sup.org/books/title/?id=17450,14.

[361] Viewers were not immediately confronted with the VR and I provided easy instructions for the use of the headset with no additional devices required, such as controllers. I used the best available technology

People commented that they were able to feel a sense of presence as they interacted with the space. Examples include surprise when removing the headgear due to the expectation to still be able to see the objects in the VR and astonishment when leaning against a wall that did not in fact exist.[362] Additionally, while most people saw this relationship from within the VR, one person commented, "When I took the headset off I was very aware of everything that was in the room because it had an association with the VR."[363] Such interactions and phenomena are not uncommon and indicate the postphenomenological relationship between the viewer, the technology and the world. The technology is mediating the experience to such an extent that the viewers' bodily interaction with the world is at times confused. It is this confusion that is mined further within this chapter with interrogations into cognitive dissonance.

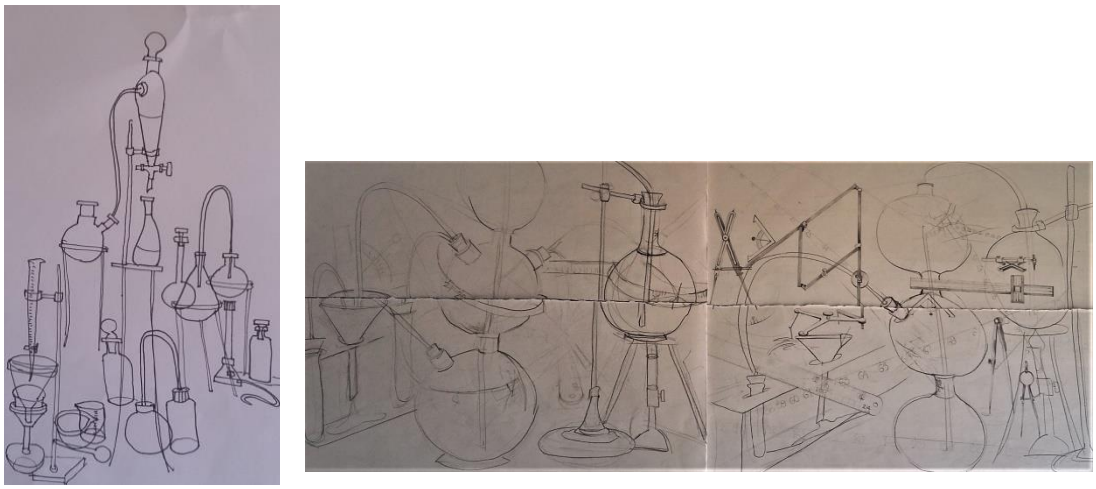

Figure 30. Claire Hughes, Preliminary drawings for apparatus.

at the time of the exhibition. The view in the headset was projected onto the floor which enabled the viewer to have a preview of what they would see.

[362] Questionnaire responses

[363] Focus group member 2-5

Figure 31. Claire Hughes, Colour studies for apparatus.

Two pieces of computer-generated scientific apparatus form the landscape of the virtual reality: the glass apparatus and the spacetime curve. For the first, I took influence from the Klein bottle. The Klein bottle is a mathematical construct, described by German mathematician Felix Klein in 1882, to illustrate the topology of a single-sided closed surface.[364] It is an extension of the Möbius strip, which also has only one surface. The viewer can experience the inside and outside of the Klein bottles within the VR, and, as it only has one surface, it is legitimate to walk through surfaces in the VR representation. Appropriating classical laboratory equipment of glass stoppers and interconnected tubes suggests possible uses; however, it can serve no practical use. Its function in this art work is from its properties as two conjoined Klein bottles. The use of glass was purposefully chosen for the aesthetic properties as well as a metaphor for the transparency required in science communication to combat anti-science views. In the gallery space, viewers were provided with an information sheet which briefly described this apparatus.

The 3-dimensional Klein bottle is non-orientable; if you move a two dimensional object around the surface, when it returns to the starting point it is a mirror image. Here it becomes relatable to entanglement, with two particles that are mirror images of each other's properties, non-separable in terms of always being linked. To amplify the sense of entanglement, I joined two Klein bottles together, forming a more obviously paired relationship. The two one-sided

[364] Stephan C. Carlson, 'Topology', Encyclopedia Britannica, accessed 25 February 2019, https://www.britannica.com/science/topology.

entangled surfaces become entangled together forming a more complex entanglement. This refers to the massive web of entanglement that provides its power, enabling developments discussed earlier, such as quantum computers and Susskind's 'sewing' of space and time.

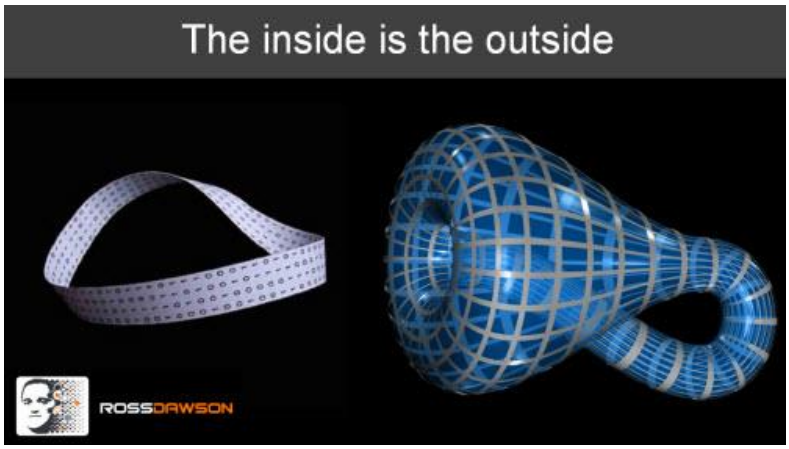

Figure 32. Möbius strip on left hand side Klein bottle on right side. Ross Dawson, USA, https://rossdawson.com/blog/the-inside-is-the-outside-the-mobius-strip-and-klein-bottle-as-metaphors-for-the-future-of-organizations/, Courtesy of Ross Dawson.

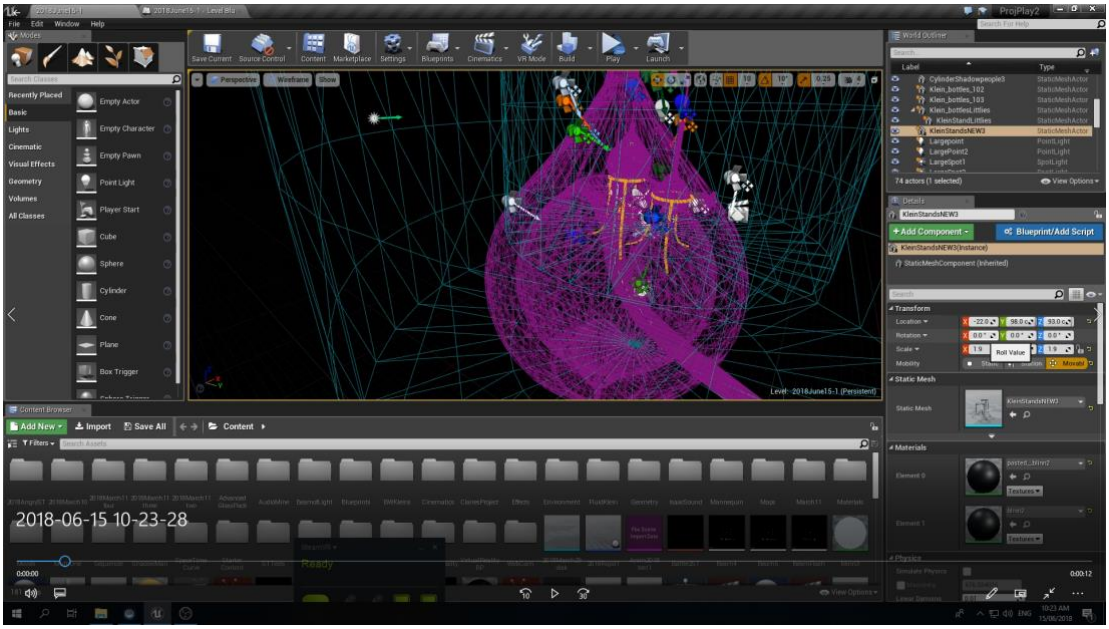

Figure 33. Claire Hughes. Modelling of Klein bottles for *Entangled*.

I incorporated shadows of the Klein bottles to provide a metaphorical sense of entanglement within 3-dimensions. The Klein bottle has a theoretical role as the representation of the shadow of an object in four spatial dimensions.[365] Higher spatial dimensions could possibly provide a solution to the mysteries of the communication between entangled particles. The Klein bottle is required to cut into itself in 3-dimensional space, whereas as in four spatial dimensions, the bottle only needs to be twisted to make it into a closed surface. The first appearance of the Klein bottles in the VR transition room is as a 2-dimensional shadow which signposts the interplay in dimensionality. Initially the 3-dimensional object is not in sight, indicating a link that cannot be seen, an entanglement that is yet to be worked out. This 2-D shadow is a shadow of a shadow because it is the shadow of the 3-D Klein bottle, which is itself a shadow of the 4-D Klein bottle. A viewer knowing the dimensionality theory of the Klein bottle could recognise this as a playful reference, however a direct question on this was not asked in the focus groups.

The second scientifically related piece of apparatus in *Entangled* is the spacetime curve, which is diagrammatical representation of the three spatial dimensions fused with time. In *Entangled* it not only provides a relational system of not only space and time, but metaphorically provides entanglement relating to paired curves forming new relationships.

This diagrammatic form was initially derived from Newton's classical mechanics which placed space and time as totally independent, implying a flat curve, independent of temporal effects such as gravity of large objects.

Mathematician Hermann Minkowski introduced the term 'spacetime' in 1908 from Einstein's special theory of relativity:

> "The views of space and time which I wish to lay before you have sprung from the soil of experimental physics, and therein lies their strength. They are radical. Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality." [366]

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[365] Andrew J. Hanson, Tamara Munzner, and George Francis, 'Interactive Methods for Visualizable Geometry', *Computer* 27, no. 7 (1994): 73–83.

[366] Hermann Minkowski at the 80th *Assembly of German Natural Scientists and Physicians* (21 September 1908)
Quoted in: Hendrik Antoon Lorentz et al., *The Principle of Relativity: A Collection of Original Memoirs on the Special and General Theory of Relativity* (Courier Corporation, 1952), 75-91.
Minkowski was a German mathematician who had been Einstein's professor.

The representation of curved spacetime came later from Einstein's general theory of relativity (1915) where it was modelled as a four-dimensional Lorentz manifold.

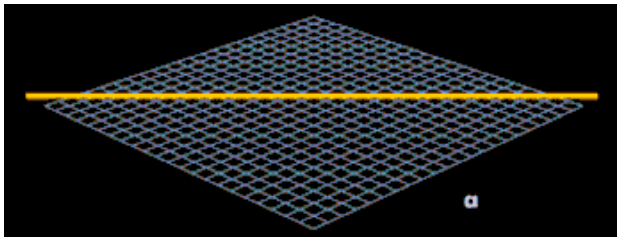

Figure 34. Classical representation of Newton's space and time.
https://i.stack.imgur.com/w4CK6.gif

Courtesy of Imgur copyright.

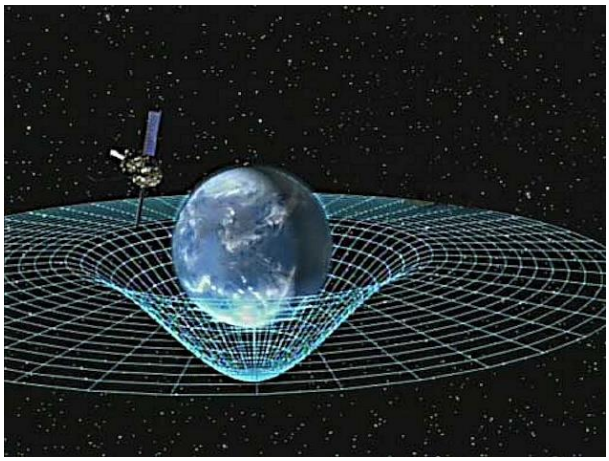

Figure 35. Image by NASA
http://www.nasa.gov/mission_pages/gpb/gpb_012.html,
Public Domain,
https://commons.wikimedia.org/w/index.php?curid=4072432

It is a representation similar to this that I use to symbolise our understanding of reality in the 20th and 21st centuries; a representation familiar from popular science books, art installations and light shows as illustrated in examples below.

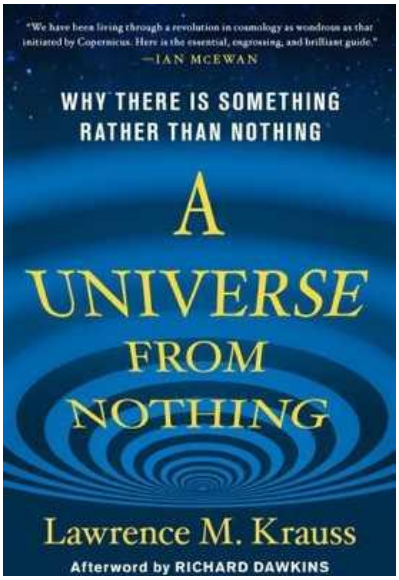

Figure 36. Book cover image sourced from: https://listverse.com/2012/07/02/10-great-popular-science-books/ This image is used with permission of Lawrence Krauss. It remains copyright property of Lawrence Krauss. All rights reserved, not for copying or further distribution.

Figure 37. Alan Watts, USA, *A Wormhole Actualization Machine (WAM),* 2014, Screen capture from video. https://www.tested.com/art/makers/461455-building-wormhole-actualization-machine/ Permission under Creative Commons Licence.

My representation of the spacetime curve is modelled in 3-D and can be experienced in the VR. The following section will show how this is brought to life as an apparatus, cognisant of the spectrum of possible applications across contemporary art and science communication.

2.32 The Spacetime Curve in Action

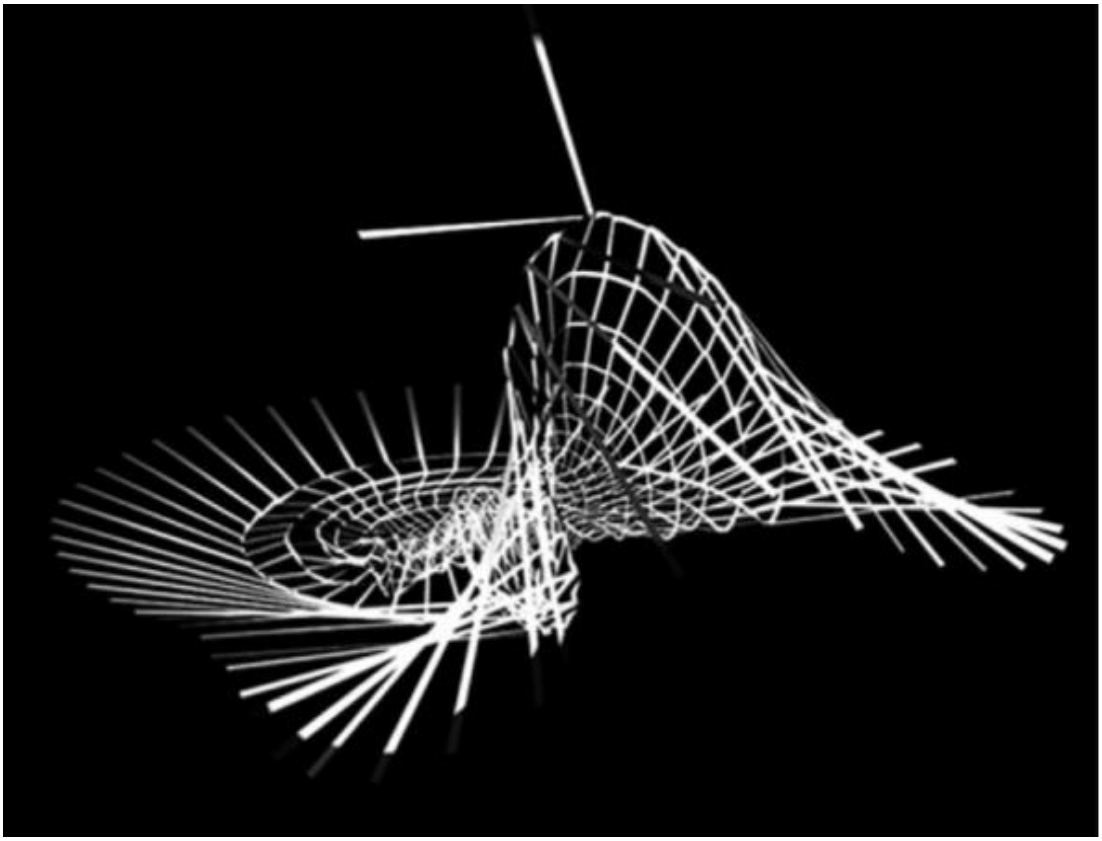

Figure 38. Claire Hughes, *Entangled,* 2018, Screenshot

This section focuses on the adaptation of the spacetime curve, (the diagrammatical representation of spatial and temporal relationships) and its metaphoric role in conveying aspects of quantum entanglement. Patterning is a particular example of imaging relationality, and its importance in entanglement as well as a stimulus for imagination will be discussed. Science communication features of awareness, enjoyment, interest, opinions and understanding will be shown to be operating through the imagery of the spacetime curves imaged within *Entangled*.

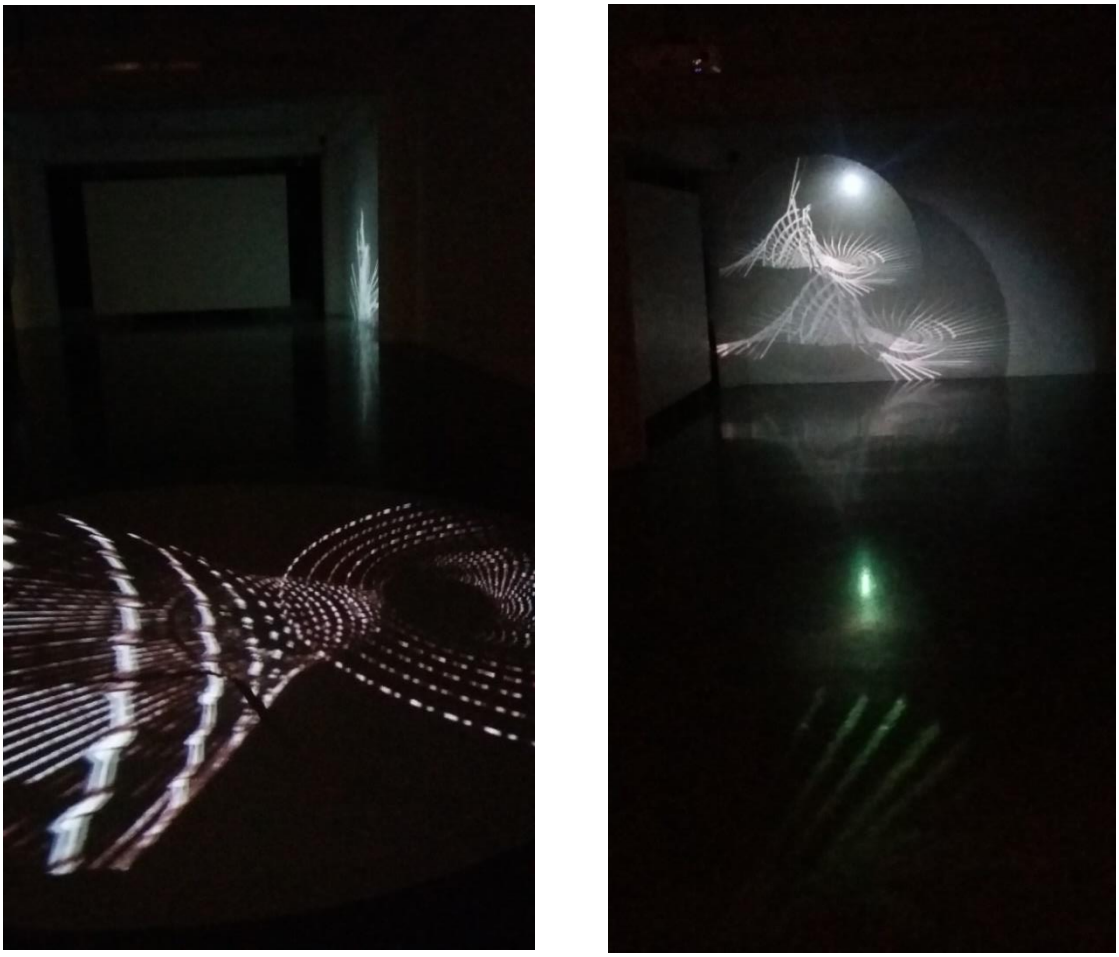

Figure 39. Claire Hughes, *Entangled,* 2018, Toi Pōneke, Wellington.

Three aspects are evident in the exhibition: an animated projection onto the large glass disks sets the scene; the black and white curves in the VR; and the rigid spacetime curve that acts a precipice and provides the illusion of physically travelling through it.

Reflection

The installation at Toi Pōneke featured two principal components: *Reflection,* a projection on a large glass disk and the VR landscape. *Reflection* is a stand-alone work with its own logic, while also offering a transition and an intertwining of the physical space and the VR. The sequence that plays on the glass disk has been modelled from a flat spacetime curve and animated to show the creation of curvature from Einstein's theories of the bending of spacetime. It is presented on projection film so that it is viewed both 'upon' a surface and travelling through

an object.[367] A detail of contortions within the animation seek to represent the struggle of transiting from the understanding of Newtonian mechanics, which we know well through the flat spacetime curve, to Einstein's curved spacetime. Through trials, I arrived at the most effective results for the rendering of the animation; this being black and white, emphasising the diagrammatical construct. In gallery-based testing people commented, it was, "archival", "a graphic experience" and "more like a documentary". These qualities provide a more serious note to highlight the graphical patterning.

A viewer likened the animation to a twisting 'sea surface'. If the viewer is positioned so that the glass and the rear image are in line, at times the two become superimposed. While this is not the same as the interference of waves, the visual building up of the two wave-like animations references this. The relational points that the spacetime curve is constructed from are now viewed as waves; reminiscent of the dual wave and particle theory in the double slit experiment that is the foundation of quantum theory (discussed in section 1.5). The quantum property of indeterminacy, which is described as blurry because all values are possible until they are measured, is referenced by the reflections that form on the floor.

There are direct relationships that are aesthetic and provide metaphoric communication of entanglement. As a focus group member said, "On entering the first gallery I spent some time in a meditative state watching the satisfying dialogue between the two elements, the pattern projected onto the Perspex [glass] and that on the wall." [368] This 'dialogue' between the screens is enabled by the photons (particles of light) travelling so fast that the animations on the two screens appear as one. Quantum entanglement occurs when two particles behave as one, and so in this way the two screens can be considered as an instance of metaphoric entanglement.

[367] Trials with a range of rear projection films enabled the balance between the images on the glass and the amount of light projected though it to enable a relationship to be formed between them but not to dominate each other.

[368] Focus group 1-3.

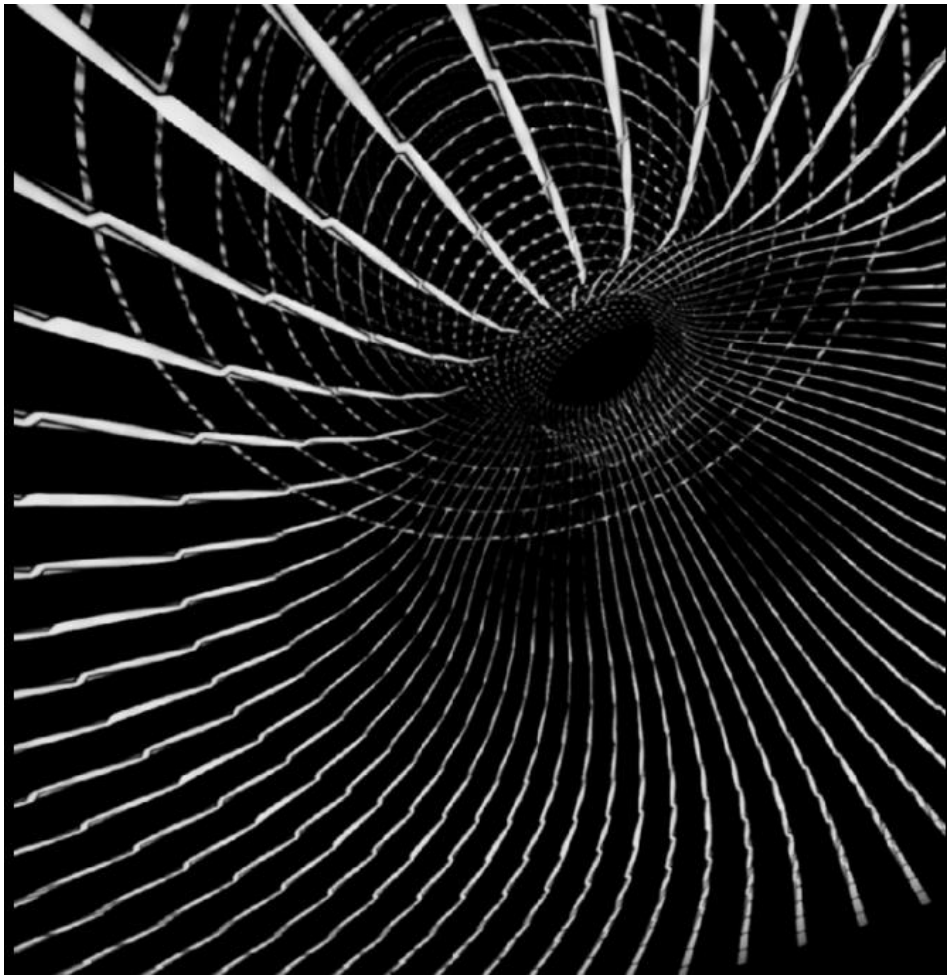

Figure 40. Claire Hughes, *Entangled,* 2018, Screenshot.

Black and white spacetime curves in VR

The black and white spacetime curves float down from the upper region of the VR environment creating patterns that appear to pass around or through the viewer. Rationalist and empiricist scientists seek patterns to form generalisations. Here, patterning is taken into the visual art realm to offer the embodied experience of relationships. The illusion of the spacetime curve travelling through the corporeal body provides an experience in 3-dimensional patterns not only around the viewer, but enveloping them. Scientific information in this experience is provided by immersive and spatial means.

Some viewers articulated that within this immersive, embodied experience, they were uncertain as to whether the curves were going up or down. One person said that, "it did shift the sense of my own body in space."[369] This can be understood as spatial ambiguity, which is an example of the 'plausibility illusion' where the VR is fooling the body's proprioceptive cues. People were observed holding their hands out for the spacetime curves to pass through them and reaching out to grab the curves. Spatial cues that operate in the physical world are tested as to whether they operate in the virtual environment. Science identifies patterns to condense knowledge into laws and theories. In this segment patterns create new rules to understand this particular spatial VR experience.

The spacetime curves are entangled with each other; as one comes down, its pair goes up, with the viewer situated within this metaphoric entanglement. The technology is operating as a postphenomenological mediator creating the subjective experience for the viewer while providing the objective intentionality of the virtual world. The viewers' subjectivity is evidenced by responses gained in the testing. People commented that this section made them intrigued, excited and curious about what was going to happen.[370] This is a key aspect of scientific communication because such affective responses indicate increase engagement in science, as previously noted in section 1.1.

Creative thinking has been cited as an element required in understanding quantum physics. There was evidence that this segment evoked creative responses. One person said they enjoyed using "poetic licence" to augment their reading of the sequence. Another observed "I went through the 'tunnel', which led me to this very mysterious virtual reality."[371] Some viewers identified the wormhole shape made by two spacetime curves, which was set up to encourage creative thinking and query the possibility of the role of wormholes in entanglement.

By retaining the aesthetic and metaphoric associations through art, first hand experiences can provide insights into scientific theories and processes that otherwise would not be possible. Art can perform a productive role in offering new perspectives and ideas in science and this work has sought to accomplish this without the dilution of the art experience, but by enriching it.

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[369] Focus group member 1-5.

[370] Questionnaire responses.

[371] Focus group member 1-4.

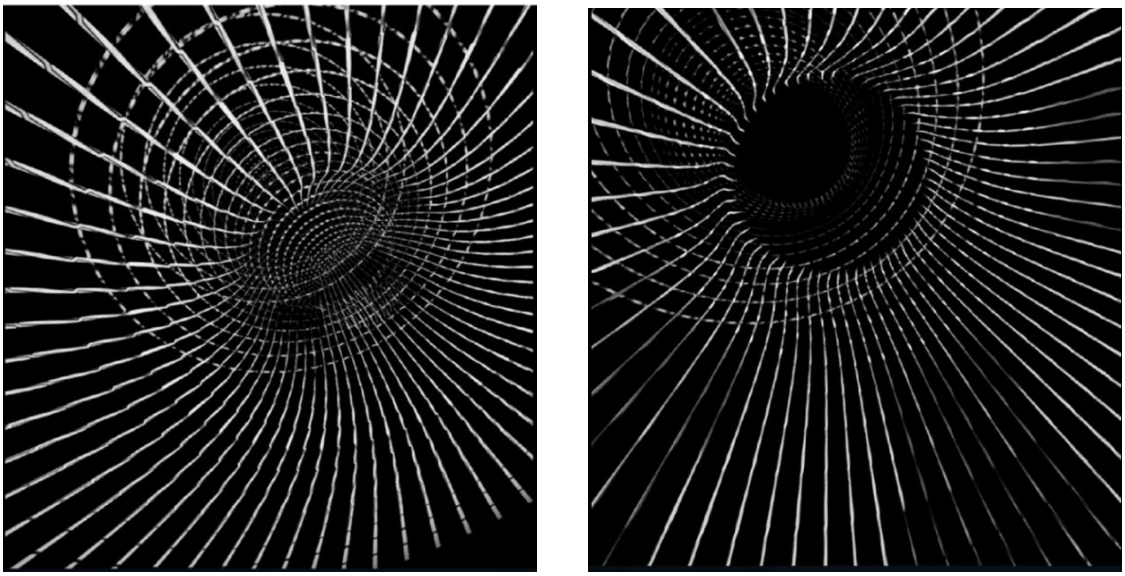


Figure 41. Claire Hughes, *Entangled,* 2018, Screenshot.

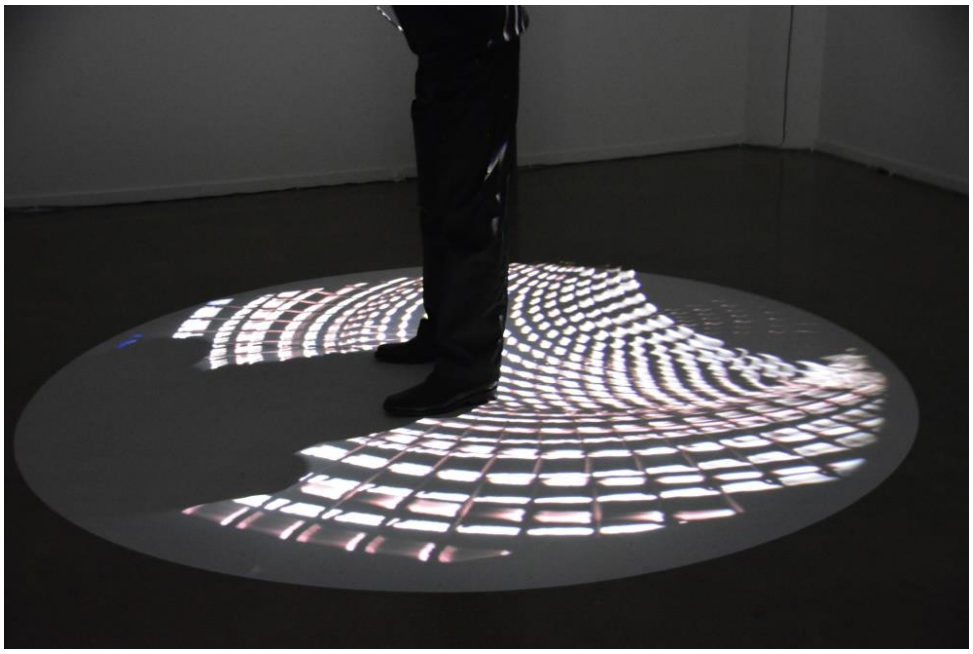


Figure 42. Claire Hughes, *Entangled,* 2018, Toi Pōneke, Wellington, Photograph courtesy of Denise Gandy.

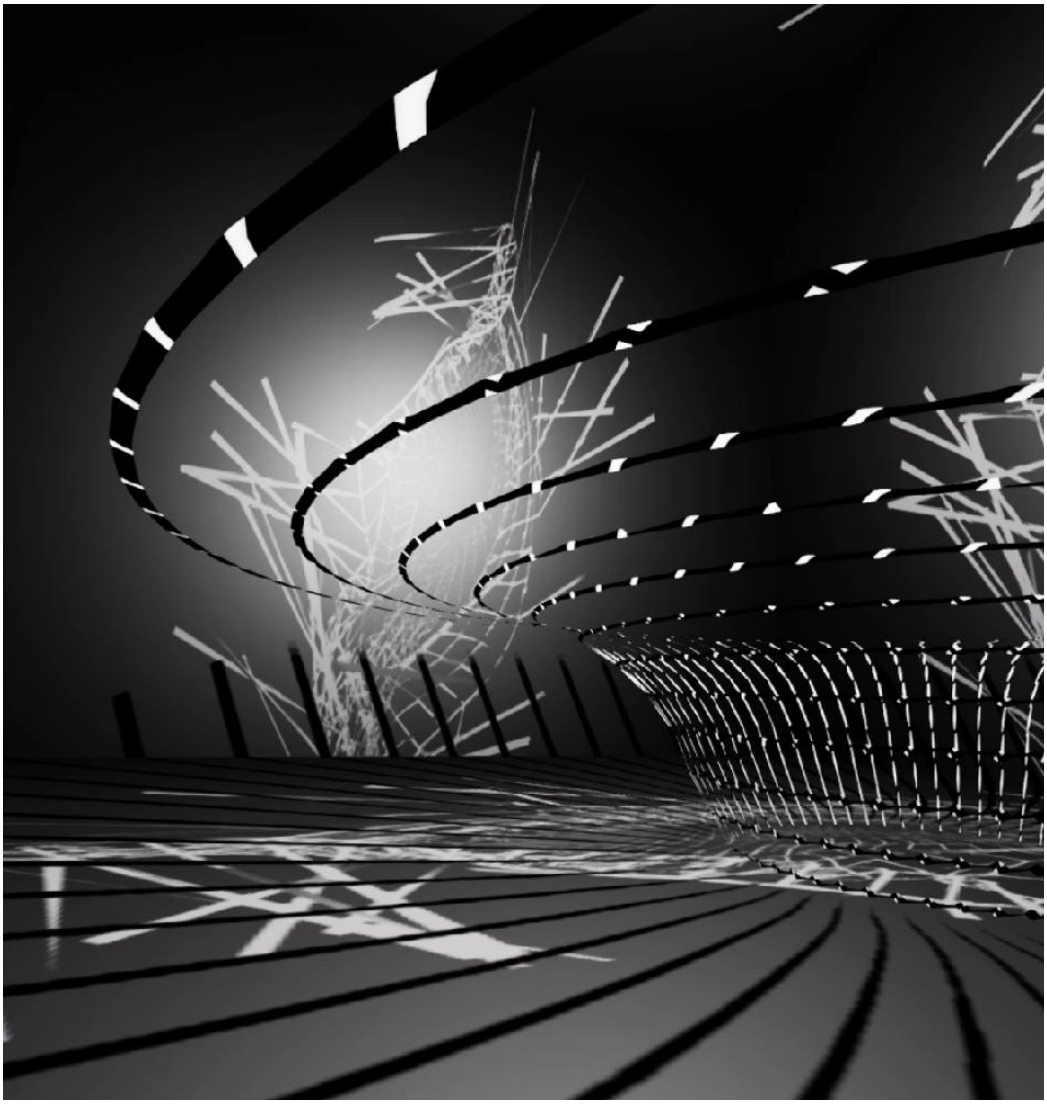


Figure 43. Claire Hughes, *Entangled,* 2018, Screenshot.

The spacetime curve as a vortex

The rigid spacetime curve appears as a stationary vortex or tunnel within the VR. At times the animations on the surfaces of the virtual room appear to interact with each other, almost teasing as they stretch across the surfaces, spatially entwined, entangled in the sense of all being the same, whatever one does the others do. Within the VR, the appearance of the rigid spacetime curve provides a clue that the video animations are actually deforming spacetime curves.

When the 3-D stationary spacetime apparatus appears in the VR scene, it is on top of the 2-D animation of the spacetime curve that is playing on the virtual floor. These intertwine together creating an inter-dimensional metaphoric entanglement.

The focus of the stationary spacetime curve is to demonstrate how the mathematical/science construct of the spacetime curve is changed into an experience that engenders increased emotions similar to the sublime by engaging the imagination. Initially the spacetime curve grounds the viewer in the 'floor' of the VR room, however, when the room is removed people indicated some strong reactions. Comments such as feeling like being on "the edge of a precipice"[372], or "the edge of a cliff and staring into an abyss of some mysterious energy in a turbulence"[373] echo Kant's description of the dynamic sublime, as do the reactions such as, "I stood in the middle of the room and shrieked."[374] Considering the part where the viewer is taken through a spacetime curve and their view is locked, some reported screaming, feeling lost, terrified, frightened, disorientated, anticipatory, and three people experienced some vertigo.[375]

Some viewers' perception of shifting ground or finding and loosing anchor points brought associations more familiar from haptic entertainment activities such as "a rollercoaster before the drop"[376], "a theme park ride"[377], "when I first jumped out of a plane"[378] . The aim of inviting this level of experiential encounter through a dynamic VR environment is to fully explore the way our bodies and minds approach a synthesis of understanding, where felt and seen information gets brought together to enable a heightened experience, one where processes of imagining are also involved, rather than solely recognition of an already known or imaged entity.

The illusion of immensity in *Entangled* references both Kant's mathematical sublime and Fedorova's property of ubiquity (being everywhere at once) in new media technological

[372] Focus group 1-3.

[373] Focus group 1-4.

[374] Focus group 2-1.

[375] Questionnaire responses.

[376] Questionnaire response.

[377] Questionnaire responses.

[378] Focus group 1-1.

sublime. The spacetime apparatus was described by some as, “infinite”[379] and a “bottomless space”[380]. This feeling of enormity and the abyss below intends to provide a visual metaphor for the precipice of the scientific knowledge of reality. Perspective operates to make the shadows appear to be receding into the distance, into an area that has uncertain boundaries, as if the spacetime curves are ubiquitous. Ironically, this impression of a large area is achieved by rendering a contained surface for the shadows to form on. This requires imagination on the part of the viewer in perceiving it this way; the mathematical and technological sublime evoked by illusionary perception.

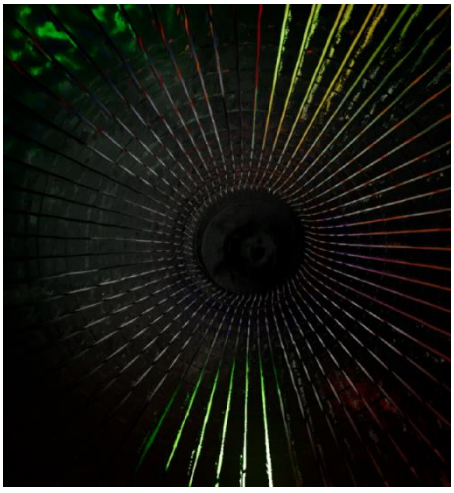
The segment where the viewer travels through the stationary spacetime curve has the scene locked to the viewer’s headset. This means that whatever direction the viewer moves their head, the spacetime curve stays positioned in front of them. Without this technique, testing showed that the illusion of travelling through the spacetime curve did not occur. Extensive testing was required in my designs to mitigate against the effects of inducing motion sickness in the viewer as locking the view is known to induce motion sickness. The speed of the travel and reduction in time that the headset was locked to the view resulted in minimal reported feelings of sickness. The aim was to provide a variation to the viewing of the VR, providing a contrast to the level of control by reducing it in this instance.

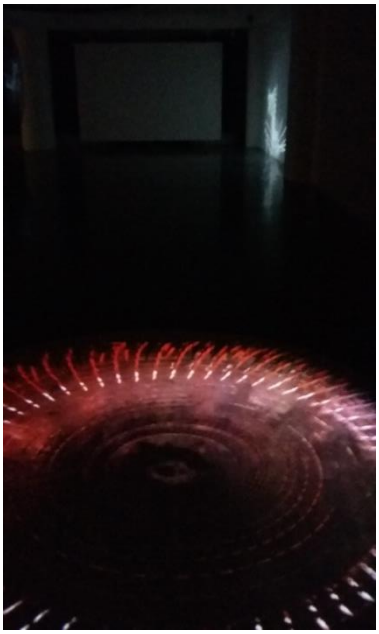
This section has outlined how the complex nature of quantum entanglement has been experienced through metaphors of entanglement. These have been shown to offer embodied, engaging encounters which have evoked reactions that have bordered on the sublime and drawn out imaginative interpretations and responses.

[379] Questionnaire response.

[380] Focus group 1-1.

Figure 44. Claire Hughes, *Entangled, 2018,* Screenshot.





Figures 45. Claire Hughes, *Entangled,* 2018, Screenshot and Photograph, Toi Pōneke.

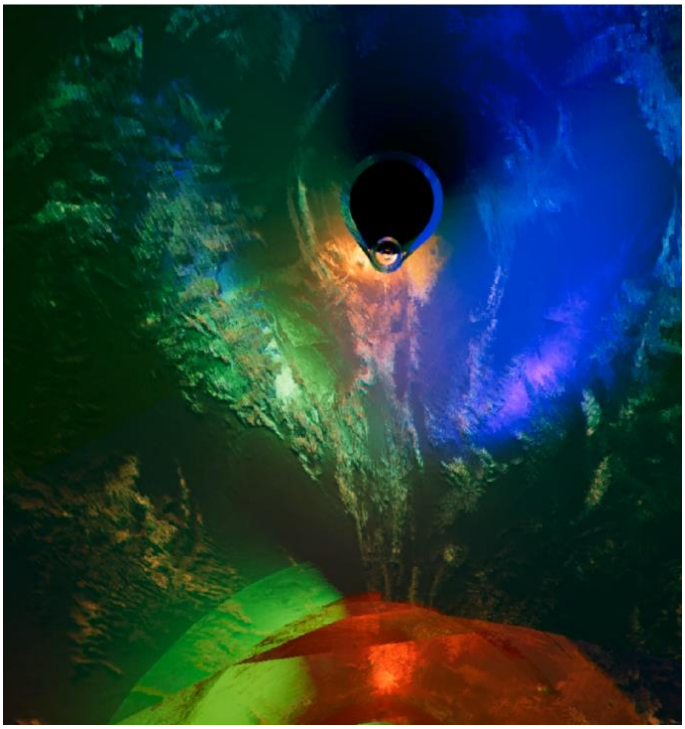


Figure 46. Claire Hughes, *Entangled,* 2018, Screenshots.

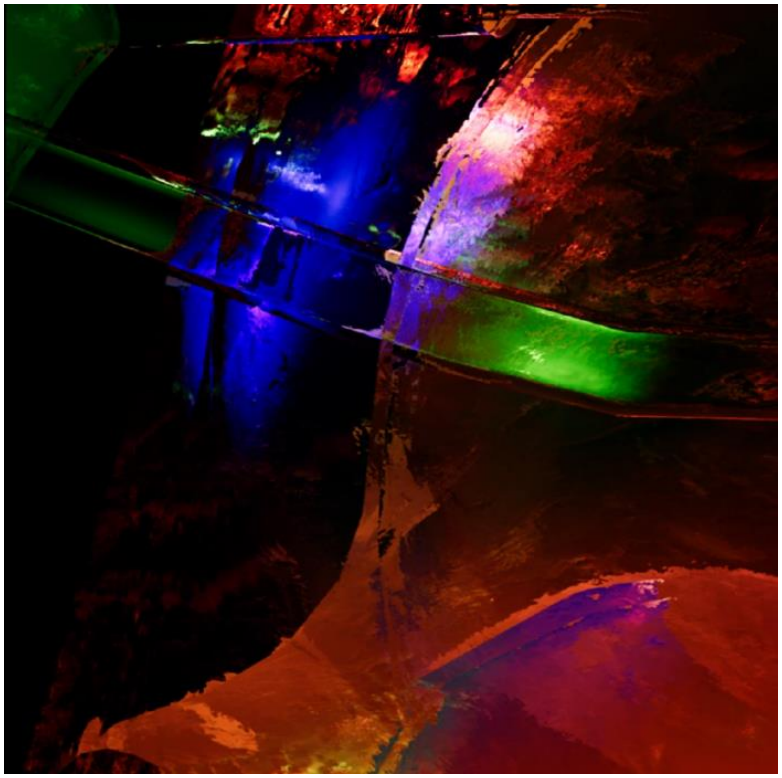


Figure 47. Claire Hughes, *Entangled,* 2018, Screenshot.

2.33 Scaling the Klein Apparatus

Experiencing spatial scaling of the Klein bottles and being able to explore each size to the extent that occurs in this work is not an opportunity that is offered in real life. This is an example of the possibilities offered through VR technology. The Klein bottle scenes provide experiences that build associations to collectively challenge understandings of physical reality on a micro and macro scale.

The viewer encounters the glass Klein bottle apparatus in three sizes. Each size represents a scale relative to understanding our universe: the smallest Klein relates to minute scales of scientific enquiry; the middle-size to our world as we know it; and the largest relates to the cosmic universe. The glass apparatus is a metaphor for scientific enquiry at each level and the viewer is invited to experience the scaling and explore the apparatus.

Figure 48. Claire Hughes, *Entangled,* 2018, Screenshots, Small, medium and large Klein bottles.

Figure 49. Claire Hughes, *Entangled,* 2018, Screenshots.

Scaling up the size of the Klein bottles establishes new rules that operate in this virtual environment. If the viewer had been bending over the small Kleins they will have become part of the expansion; an embodied experience that entwines them with the Klein bottles. The scaling segments resulted in viewers reporting changes in perception of their own size. A viewer commented that they, "felt the universe growing and expanded"[381] and a link was made by some to Alice in Wonderland.[382] One focus group member described this as feeling like they were, "diminishing or made to feel larger depending on what the objects and things were doing and I found that really fascinating… not only the sense of the objects that were impinging on the environment and moving but the way my personal sense of scale was made very strange." Other people stated they found it, "amazing, surreal, trippy, magic"[383], all reminiscent of Alice in Wonderland, however very different because this was how *they* felt, not Alice. Many questionnaire and focus group responders expressed the feelings of being embodied in the science experience and some even felt like the scientist or as the fluid or particles inside the apparatus. [384] Other embodied experiences also show the differences in laws and rules inside the VR from the physical space. Questionnaire responders described it as being like they were floating, weightless, free, passing through glass and through planes. A focus group member stated they felt, "engulfed in this amazing immersive weird flight"[385], expressing the different rules they experienced because of the mediating technology of the VR. Embodied experiences in *Entangled* were summed up by a focus group member as, "what we were seeing was making the scientific more tangible … it wasn't about intellectually understanding more of the science, [it was] to experience – allowing us to physically experience as an embodied being."

Presence is a crucial element in *Entangled* to provide this level of embodied experience. Spatial exploration and interaction have been shown to be important aspects in providing the illusion of presence. The structure of the Klein bottle, its scaling and movement provide the incentive

[381] Questionnaire response.

[382] Focus group member 2-1.

[383] Questionnaire response.

[384] Focus group respondent 1-1 described it as a, "physiological sensation of being transported, on one level, to an alternative reality and on the another, being an observer … the narrative interweaving of the spacetime curve, the white room, and Klein bottle created in me the sensation of being a scientist in a white room, wearing a white coat, and conducting an experiment."

[385] Focus group member 1-5

to explore and interact. A viewer commented, "It was more like being allowed to go in the museum and then having the Klein bottle and actually being allowed to walk inside it, and really experience something."[386] This also gives the viewer a level of control because they determine their own view within the scene; control is another element that has been shown to increase reported presence. Additionally, research shows that colour, reflection and refraction of light can enhance presence; these are properties that are strongest in the mid-sized and large Klein bottle segments of *Entangled.* It was when the Klein apparatus was at its largest that the majority of viewers reported to be the most present in the VR. They described this part as suspension of disbelief, immersed, "quite alarming to register just how complete a reality the scenes were"[387]. Twenty-six questionnaire respondents said they felt most part of the scene during the Klein apparatus segments.[388]

When the Klein bottles were small, some viewers talked about their attempts at interacting as: wanting to get closer; trying to pick it up; wanting to examine it and attempting to touch it. This indicates the plausibility illusion of presence, as it is 'fake' simulacra and the viewer is overriding their own common sense.

The tensions within *Entangled* aim to stimulate the viewers' questioning of their understanding of reality. Tensions such as the mathematical sublime can evoke the feeling of insignificance because of the enormity of size. People commented that they found the spatial dimensions vast, infinite, and that they felt dwarfed with feelings of being scared, disorientated, in awe and overwhelmed.[389] These comments contrasted with those who felt comforted and enjoyed being inside the glass apparatus.[390] The contrasts of emotions of awe through to feelings of comfort are similar to the feelings induced by the sublime. Lyotard positioned the post-modern sublime as representing the 'unpresentable', which is what

[386] Focus group member 2-1

[387] Questionnaire response

[388] Some of the responses were: "immersed, delighted"(questionnaire response), "Suspension of disbelief made this an unforgettable experience" (questionnaire response), "Quite an astonishing experience, enjoyed it, and "the moment you put that thing on, you are immersed, it's quite immediate."(Focus group member 1-7).

[389] Questionnaire responses included: "felt the depth of infinite space and time"; "like an ant"; "like a child"; " I felt like I was dwarfed by science"; "scared"; "disorientated"; "awe"; "oppressed, spooked, wanted it to go away"; "a bit eerie"; "invasive into me"; "intimidated" and "overwhelmed, bombarded with the scale I'm immersed within".

[390] For example, focus group member 2-3 said, "It was quite wombish … The nice soft pinky colour was comforting," focus group 2-5 that it was "a very interesting sensation".

quantum entanglement is. Lyotard stated that work needed to be disruptive and unsettling to express the 'unpresentable'[391] and Fedorova considered that new media can access the characteristic effects of the sublime with sudden shifts causing dismay and perplexity.

Entangled uses these capabilities to purposefully disrupt presence in VR. In the Klein segments, viewers reported their experience was disrupted by a change of scale, penetration of virtual glass, changes in sound, in pacing, shaking of the whole scene and contrasts between black and white and colour.[392] These disruptions were described by viewers as making them surprised or shocked and some expressed that they were annoyed and did not understand why the experience had been interrupted; they were perplexed. One person said "You want to stay in that world, so if you're then being made aware of another perspective or whatever, then we resent that."[393]

The disruptions of presence make the viewer aware of the virtual and physical environments at the same time; they are experiencing conflicting events which is cognitive dissonance. Piaget's constructivist theories posit that the viewer will try to balance the two conflicting experience. An example described by one of the focus group can highlight this experience with the small Klein bottles. The viewer reported, "wanting to pick up its small manifestation 'sitting' on the floor and indeed attempting to do this only to find it was thin air … Or feeling the need to walk around the bottle so as not to knock it over or damage it."[394] VR can elevate responses even though the viewer knows the environment is 'fake'. This person is explaining experiencing two things at once, trying to pick something up that is not there, and that they really know is not there. It is a complex experience where not only is common sense is overridden, but the person is experiencing two conflicting events.

VR is a first order simulacrum as the two perceived realities are separate and the viewer can enter either one, as in *The Matrix* or *Plato's Cave.* However, I suggest that there are times within the Klein segments that the viewers' actions indicate an amalgamation of thought processes for the real and the virtual. This occurs when the viewer reaches out or tries to touch the virtual objects and the simulacrum of the first order becomes an experience of the third order. For a moment, the viewer is experiencing two conflicting states happening at

[391] Woodward, 'Lyotard, Jean-François | Internet Encyclopedia of Philosophy'.

[392] Questionnaire responses

[393] Focus group member 1-7

[394] Focus group member 1-3.

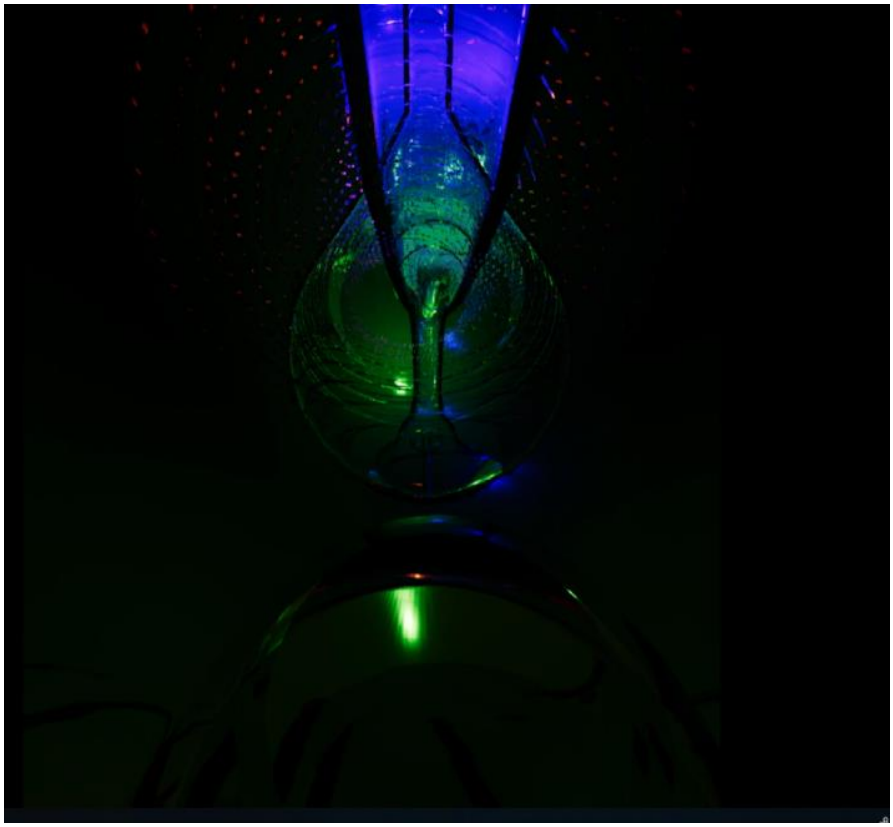
once; cognitive dissonance. An equilibrium is restored as the viewer realises the difference between the rules in VR and the physical environment. As one person put it, "when you try to touch something you are suddenly brought back to reality."[395] One person explicitly commented, "Felt as I was in 2 places at once"[396], and another that, "There was a disruption between being in the VR world and in the gallery simultaneously." [397] These people are describing a dissonance; their mind is in two conflicting places. While they may not realise why they are experiencing cognitive dissonance, all the same they have.

This is decisive of this creative practice research on thought processes required for quantum theory. It goes deeper than providing the VR technology that creates a level of presence that overrules common sense. It is more than having two experiences with different rules or even incommensurable paradigms. It is more than comparing the physical world/virtual reality dichotomy with Newtonian physics/quantum physics. In *Entanglement* cognitive dissonance provides an experience of trying to understand two things at once that do not make sense. Like understanding quantum theories of matter being a wave and a particle at the same time, or understanding that measuring one dimension accurately means the other is blurry or indeterminant. Or, like entanglement, where two particles act as if they are one, interacting without physical interaction. The viewer in *Entangled* has experienced the overriding of their common sense, they have experienced two different paradigms, but also, the hardest of all, the experience of the knowledge shift that involves trying to understand two conflicting inconsistencies that form the basis of the 'strangeness' of quantum physics.

[395] Focus group member 2-3.

[396] Questionnaire response.

[397] Questionnaire response.



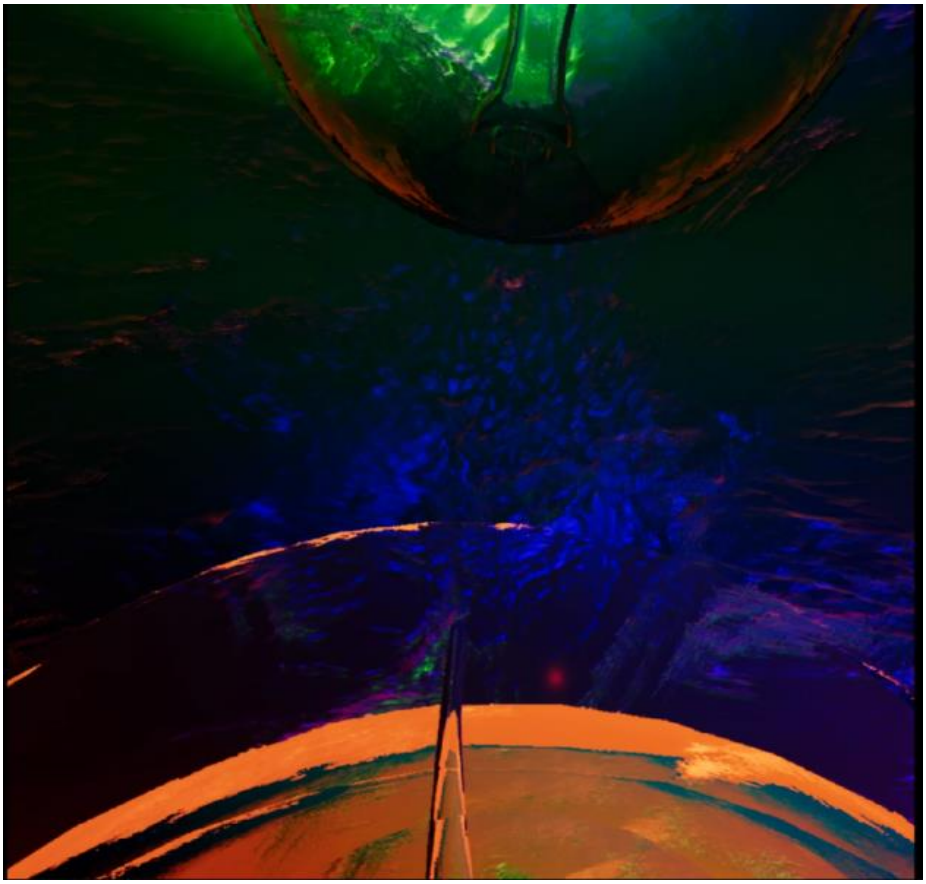


Figure 50. Claire Hughes, *Entangled,* 2018, Screenshots.

2.34 Interplays and Relationships

Interplays that occur between the physical and virtual spaces provide metaphoric entanglements. One viewer articulated this as, "we are led to an intuitive sense of how two things can be 'spookily' entangled (demonstrating precisely identical behaviour, where one responds to what is happening to the other) even though they are in completely separate locations."[398] Viewers who were familiar with quantum theory showed that they recognised layers of metaphorical scientific entanglement throughout *Entangled*.[399]

The physical glass and the modelled VR glass bottles are interconnected at a distance by their properties of transparency, reflection and dispersion.[400] These were manipulated extensively within the VR and trialled to create similar effects to the physical properties.[401] The glass disk also links to other circular shapes within the installation providing an aesthetic cohesion between the spaces and a sense of entanglement through shape.[402] The circular shapes are used within the work to represent scientific endeavour, such as telescopes, microscopes and the Large Hadron Collider, which all use circular cross-sections. [403] This was first explored in earlier works and reinforces a relationship with aspects of the material and visual cultures of science.

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[398] Focus group member 1-9.

[399] For example, focus group 1-9 commented, "Scientific notions of quantum entanglement are overlaid and made more accessible though these allusions," and Focus group 1-2 stated, "I liked the way the viewing mimicked entanglement (in the physics sense). I see something that changes as soon as I look at it." The second person is referring to the determination of the properties of one particle changing the other in quantum entanglement.

[400] Refraction is the bending of the light when it passes through an object and dispersion of light causes different colours to be bent by different amounts, for example when sunlight goes through a prism. The refractive index is a measure of how much light is bent at the edge of a particular material. Window glass is usually considered to have a refractive index of around 1.5.

Dispersion of light is the bending of the colour components because of their different wavelengths. (https://www.quora.com/What-is-Dispersion-of-light-1).

[401] The VR glass was set with a refractive index of 1.5. The transparency was trialled to achieve a similar effect to the adhered rear projection film on the glass disk; so the Klein glass was not completely transparent and the settings allowed the lights to sit on the Klein surface to give it form. The dispersion was achieved by altering the Klein bottle settings and the lights engineered to create nuanced effects that were mainly achieved through extensive trials.

[402] Circular shapes are found in VR with the Klein bottles, spacetime curves, cylinder surround and the webcam screen. In the physical space there is the glass screen, that round shadow on the wall and the vinyl on the floor.

[403] See Appendix 6 for image of Hadron Collider.

Further layers of spatial, aural, haptic and contextual relationships were registered by viewers. Haptic experiences, such as touching the real plinth in the gallery space which was located in the same physical position as the viewer perceived the plinth in the VR, created an entanglement between the physical and virtual.[404] There are various correlations of the tempo, for example, the slow movement of the webcam screen as it travels downwards relates to the spacetime curves slowly descending earlier in the work.

The sound track for the physical gallery space was determined by the VR work, and as it travels through the gallery it connects both spaces creating a ubiquitous environment. Walking into the gallery and hearing the sound was described by some as a multi-sensory experience even before using the VR.[405] After discussions about the nature of the project, Lundy used sounds he recorded in real life and mixed them with electronic sounds to provide a further entanglement between the 'real' and virtual.[406]

The sound was constructed with asynchronous alignments and tracks which were fed to any one of a combination of the five speakers to create spatial disparities within the gallery and smooth or disjointed transitions. The most obvious, recognisable sound within the soundscape was the breaking glass. This is the sole literal sound amongst an abstract soundtrack, aimed to heighten its role as a disturbance. Many responses confirmed this and some people recognised its displacement from the actual breaking of the Klein bottles in VR.[407] The sound provided a sudden disruption to create a dissonance that also feed into sublime aspects of the work. In contrast there are times when there is no sound or it is very quiet, enabling ambient noises from the gallery space to become part of the VR soundtrack. This was intentional to enable a further entanglement between the VR and the physical space and to allow spontaneous

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[404] "Being able to touch it made what I thought you wanted to express very strong… that you tried to create several layers there between the real and the virtual real." Focus group 1-4.

[405] Discussed in focus groups, particularly by focus group member 2-1.

[406] Many decisions were made with the integration of the sound. Initially Lundy and I discussed the use of beats to signify time, however, this gave too strong a musical quality which provided a comforting and familiar background instead of the aimed for disjointed and uneasy effect. People in the focus group (2-1, 2-2 and 2-4) talked of the sound being emotional and that the vibrations that the sound set up felt like another level of experience within the VR which added to the visual perception of the surfaces moving. (Focus group member2-3.)

[407] Focus group person 1-2 said that "hearing the noise of the glass breaking by people in the gallery away from the installation provided a third level of encounter."

disruptions to occur from the physical space outside to trigger the experience of cognitive dissonance.

The circular vinyl on the floor was identified by many people as a form of entanglement. The viewer in the VR has the image that they are viewing projected over their body from above, entangling their body in their own view. Most VR exhibitions that I have researched or attended either have no view visible to the audience or have it projected on the wall or through a monitor. My research has not shown any works where the viewer is entwined in their own view to create a metaphoric entanglement.

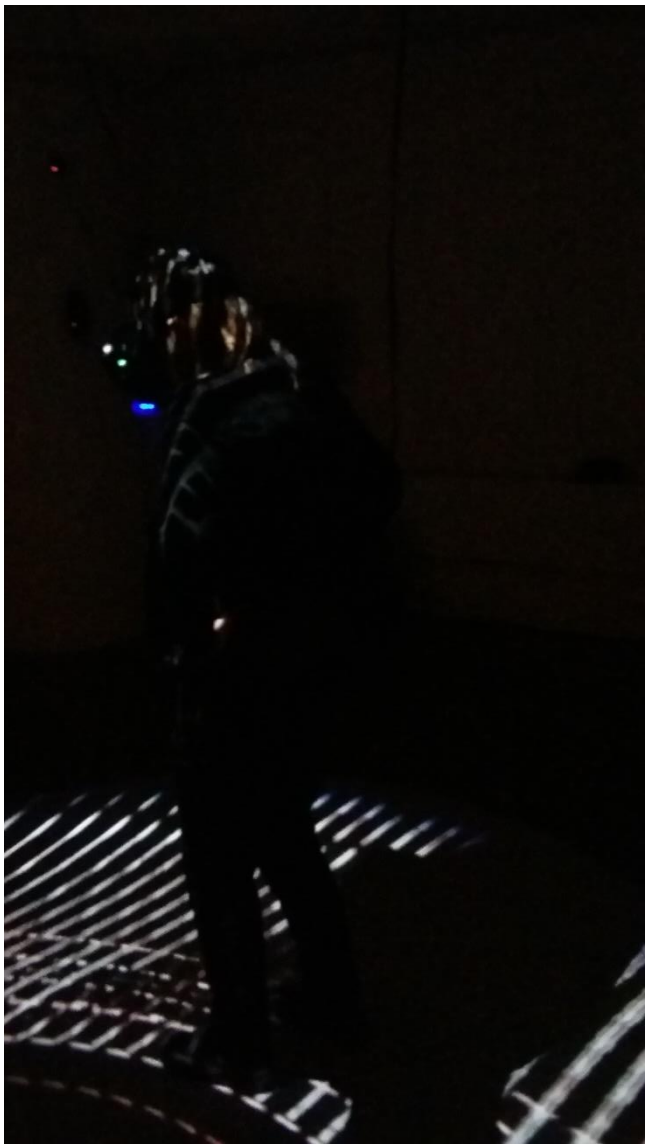

Figure 51. Claire Hughes, *Entangled,* 2018, Toi Pōneke, Wellington.

When the viewer's line of sight moves, this determines what the audience will see projected on the vinyl; a communication between the VR and the projection. I suggest this is similar to scientific entanglement, where one particle determines the properties of the other. The 2-D projection on the vinyl on the gallery floor is just as 'real' or 'unreal' as what they are seeing in 3-D virtual reality; thereby offering another opportunity to question what 'reality' may be. One focus group member summed it up as, "each version equally 'real', and yet each, only a projection of something more complex again that is mostly unseen."[408]

The 3-D headset view and the 2-D projection of what the viewer is seeing are occurring in the same physical space and time, but because of the 'barrier' of the VR technology, these views are not only entangled, they are in a sense very distant in what could be described as 'other worlds'. I propose that *Entangled* can provide an experience of how entanglement communication may be operating with two quantum particles that appear to be communicating over enormous distances, yet there may be some barrier not allowing us to see that they are actually very close, possibly in the same position.

Shadows are entwined between the virtual and physical spaces in *Entangled* to create experiences of the underlying physical reality of quantum physics. "The much simpler 2D shadows of this activity elegantly demonstrate the difference between underlying reality and the shadow of it that we can see."[409] This comment by a focus group member on *Entangled* offers an articulation that matches aspirations for using shadows in this artwork; namely that we cannot see the complexities of quantum, which are the underlying reality, we see traces of it, shadows of it. In this segment the modelled person whose shadow we see is invisible, just like the underlying reality of quantum communication that we cannot see.

[408] Focus group member 1-9

[409] Focus group member 1-9

Figure 52. Claire Hughes, *Entangled,* 2018, Toi Pōneke, Wellington. Top: Photograph courtesy of Denise Gandy, below: Screenshots.

One of the aims of the incongruent nature of the shadows is to create a further instance of dissonance, to provide the experience of conflicting thought schemas in understanding quantum theory. At the appearance of shadows, people expressed that they felt jolted, scared, overwhelmed, discomforted, disconcerted and annoyed, with eight respondents of the questionnaire reporting it as the part that most surprised them.[410] Dissonance is not a comfortable feeling and these responses indicate that a conflict and tension was built up between the largely scientific scenery that they were able to be immersed in and the appearance of shadows of people which reminded them of the outside space.

The shadows do not just update *The Allegory of the Cave* into contemporary technological idiom; I assert that they confront the viewer with scientific theories that can change the understanding of reality. An object and its shadow are inextricably linked, where one moves the other follows; two parts that are metaphorically entangled. Plato postulated that a person who had only ever seen shadows, would consider them more real than the objects that formed them. When the shadows of people appear in *Entangled*, their form is not visible and the shadows become the (virtual) reality for the viewer.

The shadows of people have been designed to appear as a mixture of silhouettes and shadows, to provide a confusion of dimensionality between them and to reference layers of reality as in Plato's cave. This simulacrum entangles and embodies the viewer by allowing the viewer's movement to alter the shadow's scale and distortion.[411] The shadows also move slowly, independently of the viewer and responses indicated that this was perceived as ghostly and uncomfortable[412], with one person stating that the shadows were "representing an extra dimension of my body"[413]. When a viewer walks towards an invisible virtual person in the *Entangled* VR*,* the shadow becomes larger and larger until they walk through and the shadow disappears. At a point before they pass through the invisible virtual person, the viewer's own body and the invisible virtual body will spatially coincide to an extent that it can appear as if it

[410] Focus group members 1-3, 1-6, 1-4 and Questionnaire responses

[411] Questionnaire responses showed 12 people referred to these as shadows and seven described them as silhouettes, figures or human forms. Focus group two did not discuss shadows, however, in focus group one, three people described them as shadows and three as figures or people. The lack of clarity of these forms relates to the indeterminant nature of quantum particles before they are measured as discussed in section 2.3 on entanglement and in 3.32 on the role of space time curves. For the remainder of this section I will refer to them all as shadows, however they could be either.

[412] Focus group member 1-6.

[413] Focus 1-2.

is the viewer's shadow that is being cast. This embodiment serves to draw out the entangled relationship that the technology is mediating, to provide a more personal experience for the viewer.

The embodiment is extended with the webcam as it entangles the viewer with their own body between the physical and virtual environments.[414] The images it captures from the physical space are relayed in real time into the virtual reality scene. The screen in the VR is a round disk that initially appears high above, like a moon descending towards the viewer. It transitions from the previous large planet-like scenes, to a more intimate linking as the viewer is able to discern that the screen contains a real-time video representation of them.[415]

Viewers reported a strange dislocation and they indicated high levels of immersion and embodiment when the webcam screen passed through their body. Reports were of surprise of the penetrating planes and the feeling that their body had become part of the glass structure.[416] [417] One person described it as, "almost synesthetic really where you actually felt the planes penetrate you… a somatic experience - embodied and so referenced other experiences that I have had, like swimming."[418] I see this reaction as being potentially reminiscent of Char Davies' work *Osmose,* where the participant used the control of their breath to increase the feeling of floating in space. The webcam screen travels from above the viewer, through them and finally the viewer can look down at themselves on the screen. These changes require the viewer to re-orientate themselves as they view their body from different perspectives.

The changes of view are captured in the webcam and relayed back into the VR; the first step in a more complex entanglement. There is a reiterative process occurring with the webcam, the

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[414] A webcam was placed in one corner above the height of the viewer.

[415] There were a lot of comments made about how the audience enjoyed watching other people as they were experiencing VR. Two focus group participants mentioned how strange it was that after watching others with the projector playing around them in a public way, when they went into the space it became private and solitary to an extent that they almost immediately forgot about those watching.[415] This indicates the immersive nature of the VR and a further way the installation operated as an artwork with opportunities for individual and collective experiences.

[416] Focus group 2.2 commented, "I remember getting quite a surprise when I appeared in it, a bit of distortion of my reality that I suddenly appeared in it." (Focus group 2.2).

[417] Focus group 1-3 described it as "quite visceral and corporeal: the descending 'ceiling' that 'touched' the top of my head and proceeded to travel as a horizontal plane downwards through my body."

[418] Focus 1-7.

projector and the headset. The first image that a person sees of themselves on the webcam screen is then projected down onto the vinyl surface in the physical environment. The next image caught by the webcam will include the image of them that is projected onto the vinyl. Each time the viewer looks at their image on the VR webcam screen, it is projected back onto the vinyl on the floor and the loop continues. This web of entanglement, although not always visually decipherable, is performing all the same. Reiterative entanglement, reminiscent of Susskind's sewing of space and time can be metaphorically experienced.

One person summed up the intentions of this experience of entanglement as, "the webcam image made me think of strange connections linking two forms of the one object. (me!)"[419].

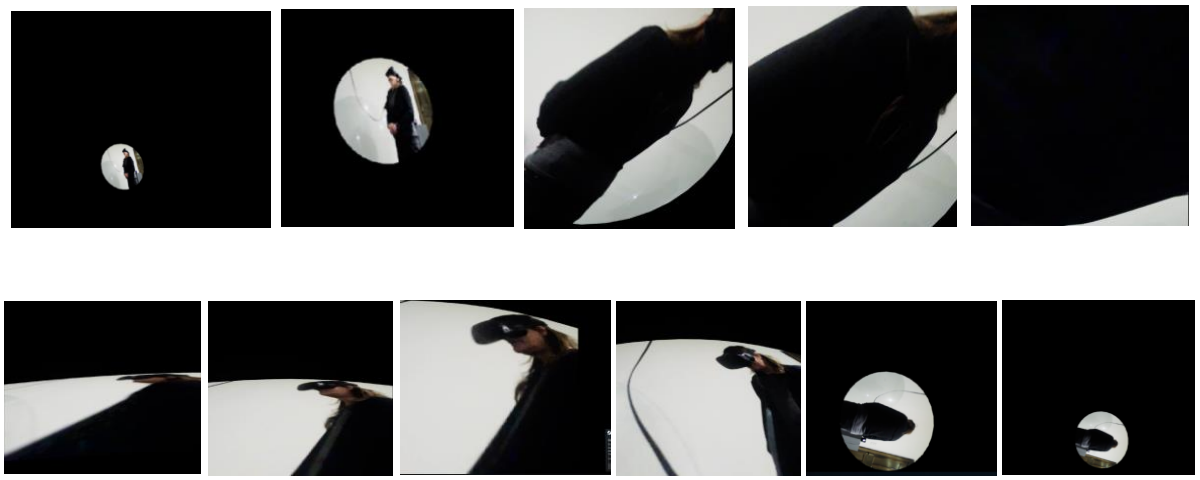

Figure 53. Claire Hughes, *Entangled,* 2018, Screenshots showing screen with webcam real-time captures passing through the viewer's body.

Figure 54. Claire Hughes, *Entangled* (2018) Photograph with webcam image displayed on vinyl in gallery.

[419] Questionnaire response.

Conclusions

The challenge in this creative practice research was to create aesthetic experiences that contravene common sense reasoning and provide insights into the type of thought processes and experiential perception that is required to deepen and expand our understanding of our physical reality in the 21st century. The implications of this research are potentially wide reaching.

To leave behind or wilfully abandon 'common sense' is presented as the key requirement to tackling quantum theories.[420] This coincides with features of creativity, of creative thought processes and methods, and in the creation of direct engagement with aesthetic experiences. This body of work sought to combine these relative elements of science and art with a technological third: the use of VR to produce an immersive artwork that addresses quantum theory and entanglement.

The aims apparent in this investigation are:

1. How can immersive art experiences provide insights into complex scientific theories, in particular quantum entanglement?
2. What is the correlation between a creative art work and science communication in generating awareness of our physical reality?
3. Can virtual reality art play a role in providing new contributions to paradigmatic shifts in knowledge?
4. If so, how might VR also be utilised to allow audiences ways to better comprehend, embrace and understand such scientific discoveries?
5. Finally, what is unique about creative art and the creative thought processes which can then provide for innovative *experiences* of these above dynamics?

This research identified that a strong and believable sense of presence was one of the main strengths of VR as a creative, experiential platform. It revealed experimental findings in psychology, medicine, training technology and gaming to investigate 'presence' in depth, however no practical body of artwork has been found to have investigated subverting 'presence' in virtual reality systems with the aim of 'presenting the unpresentable' of quantum entanglement. This sense of presence was strategically subverted in the installation to provoke

[420] Feynman, *QED*, 5.

a conflicting experience of transitioning between immersion in the VR realm and the feeling of being more fully in the physical environment. While many developers in VR aim to make the immersion as immediate and complete as possible,[421] my investigations have shown the potential to manipulate this, with regard to referencing and weaving experiences felt in the physical world and the VR constructed realm, in order to challenge current perceptions and understandings of our physical reality. The research employed findings that indicate that enhanced understandings of quantum physics require a change in conceptual thinking. Researchers have suggested that experiencing cognitive dissonance can assist in creating the critical thinking that may be needed to comprehend our reality in the future.

The use of VR within this creative practice provided experiences not possible in 'real life' in order to enable questioning of perceived reality. Shifting perspectives from properties of the physical world to the mediated virtual realm, when aspects such as gravity can be usurped by the VR, creates a dislocation in perception. Viewers were able to walk through virtual glass surfaces and explore the inside of apparatus that would normally be unavailable, experience floating through scenes and participate in the illusion of travelling through a representation of spacetime curves. Ideas were able to be conveyed by taking events based on scientific principles to heightened and extended visual and spatial renderings, such as enlarging the apparatus based on the Klein bottles, and experiencing an image of yourself, captured via a live stream webcam, passing through the your own body.

Verification of effective and engaging embodiment was reported directly by viewers, and also indirectly by responses in changes in the viewer's perceived size and corresponding feelings of domination and ambiguity in terms of control. Spatial exploration was considered to increase the level of immersion, and the collaboration with sound artist Isaac Lundy contributed to the effective spatialisation within the installation, providing a permeating effect throughout the whole gallery space.

Feedback was an essential aspect of the development of this research in terms of assessing the efficacy of the work to stimulate the identified questioning in my research hypothesis. I explored innovative uses of VR within creative practice and experimented with how to engage with scientific communication of complex physics theories, specifically focused on quantum entanglement. I believe that this research has demonstrated the value of informal and

[421] Many papers support the importance of presence. For example: "Often, an interaction designer's aim is to design for as much presence as possible" Giuseppe Riva et al., 'From Intention to Action: The Role of Presence', *New Ideas in Psychology* 29, no. 1 (1 January 2011): 24–37, https://doi.org/10.1016/j.newideapsych.2009.11.002.

structured feedback in examining the efficacy and heightened engagement in this developing field, specifically relating to the use of VR within contemporary art practice, and the possibilities of a union of the fields of contemporary art and science communication.

Research of current art practice engaged in the field of science communication has shown a gap in immersive art investigations into physics concepts, in particular quantum entanglement. The contemporary definition of science communication which aims to evoke awareness, enjoyment, interest, changes of opinions and understanding in science has been shown to operate in this work by questionnaire and focus group responses.[422] One of the aims of science communication is to draw in viewers who may not be engaged in science. The gallery exhibition was successful in involving viewers new to VR technology with analysis of respondents showing that 43% of viewers had never used it before. While exposure to new audiences is not in itself proof that scientific concepts become understood, it increases the awareness and when correlated to the data obtained through the focus groups and questionnaires, the conclusion can be reached that exposure to scientific principles through creative art works is successfully translated.

To provide effective and engaging experiential encounters with properties of quantum entanglement, the aim was to create visual and spatial metaphorical relationships in a manner that could be experienced by the viewer. The installation *Entangled* achieved the goal of providing multiple opportunities to experience metaphoric entanglement. Klein bottles were modelled as a pair, but also entangled with their own single surface. Shadows within the physical space were entangled with the objects because they were inextricably linked to each other, similar to entangled particles. The projection of the spacetime animation in the physical space appeared on the glass and the wall and floor, entwined by transparency and reflection. Within the virtual space this animation appeared on virtual walls, all moving identically, but spatially separated. The interplays between the virtual and the physical spaces were shown to be where VR technology could entangle the events as they played out in both realms. The view the person determined by wearing the headset was projected on top of them and on the circular vinyl on the floor, connecting their view inside and outside the VR, separated by scale, location and dimensionality, but moving together. Circular shapes and forms provided entanglement between the spaces. The webcam provided another opportunity for the virtual

[422] Burns, TW, DJ O'Connor and SM Stocklmayer. 'Science Communication: A Contemporary Definition'. *Public Understanding of Science* 12, no. 2 (April 2003).

and physical spaces to be entwined, this time bringing the gallery space and image of the viewer back into the VR realm.

Particles entangled at the quantum level appear to communicate at distances that are too far away for information to travel instantaneously, and currently, it appears as if there is a barrier making it impossible for us to see how this communication operates.[423] This VR artwork provides the opportunity to experience this currently intangible property of quantum entanglement, where the viewer knows that the entanglement is occurring between the virtual and physical spaces, however, there is a barrier to perceiving them at the same time. I elected to explore these transitions and interplays using VR rather than augmented reality for reasons noted in section 1.8.

I used the capability of VR to provide opportunities for the viewer to transition between the feeling of presence within the virtual space to the awareness of the outside physical space. I argued that this transition provides a moment when the viewer's mind is aware of both spaces, creating a conflict in thought processes; an *experience* of cognitive dissonance. Disruptions were provided visually, aurally and haptically to evoke the transitions.

This research has shown that viewers did experience times when they felt the transition from feeling in the virtual experience to outside of it. Responses showed that disruptions were felt with sudden scaling or flashes, jarring qualities such as the shadows and silhouettes of people, contrasts in emotions of fear to comfort, sound changes with the breaking glass, discordant tracks, opportunities for ambient noises and the webcam screen travelling through their body; one person even described this as a dissonance and others commented that it was an uncomfortable experience.

While these occasions mentally took the viewer out of the VR environment, the viewer re-engaged with the VR and no-one indicated that the disruptions caused them to stay out of the immersive experience, showing that the risk of subverting presence was not detrimental to the work. The disruptions to the feeling of presence were shown to provide the opportunity for viewers to momentarily experience a cognitive dissonance; an interface that will increasingly be required to understand a radically changed reality.

The use of VR in contemporary art is in its relative infancy, and this work indicates some of the potential it offers to create scenarios that are not possible in everyday life, with a specific purpose and efficacy. This body of research provides an opening for VR to be used in a creative

[423] This is discussed in section 2.35

context to provide communication of complex scientific theories and the thought processes required to challenge existing assumptions and accepted knowledge. While software for VR has been evolved primarily for other areas such as gaming, medicine and military, this research shows that it is possible to modify the programming and visual effects to create a targeted aesthetic experience with a different outcome in mind to the predominantly narrative-based quest, or instructional experiences noted in sections 1.1 and 1.8. New developments in VR technology and improved capabilities of augmented reality signal the potential for this line of enquiry to be further interrogated with new hardware and software developments.

The interplay between the fields of contemporary art and science communication is an increasing domain, in part because of more prominent articulation of similarities between the fields of art and science, rather than a binary position of difference.[424] Rather than using art as a tool to 'illustrate' science, this research argues that immersive experiential art has an effective future in communicating and engaging with scientific thinking. This research is positioned in the early stages of recognition that complex aspects of science and the processes of knowledge acquisition, that are often considered out of reach of non-specialists, can actually be experienced by creating a stronger interplay between contemporary art and science communication.

With science discoveries continually forging ahead, thanks to initiatives such as the Large Hadron Collider, understanding these complex theories may become more important, not just for the specialist physicist, but for the general public. This thesis argues that the strategies employed by, and the conceptual framing evidenced in the VR work *Entangled,* where we are placed in a scenario where we simultaneously experience and comprehend opposing realities, are going to be required for future generations. This is not just in games, entertainment or education but in understanding and living in our physical reality and the evolution of humans and scientific technology. The sphere of art and creativity has an important role to play in stimulating awareness about the role science and technology has in the twenty-first century. While a significant aspect of the research concerned the experience of reality, wider implications are not beyond the scope. These include the ethical, moral and social and economic concerns with regard to the evolution of humans and technology especially when scientific concepts create new paradigms. What to do with new knowledge is the ultimate test of the human race.

[424] This is discussed in section 2.1

Figure 55. Claire Hughes, *Entangled,* 2018, Screenshot.

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Appendices

Appendix 1: Initial artistic investigations expanded

Works leading up to *Why Anything?*

This overview of investigations leading up to the work *Why Anything* provides insights into the later development of my VR installation. Some of my explorations into multiple scientific theories are outlined to demonstrate the transition from illustrative science towards a tighter focus and more targeted investigations of scientific communication and experiential encounters in later work.

Initial trials involved creating 3-D models and animations in Maya software that could be projected onto transparent surfaces. The aim was to create ethereal screens of ambiguous reality. Different types of rear projection film were tested and two were chosen, a holographic clear film and a slightly frosted film which retained more of the images from the projection. A metal frame was constructed to allow spatial testing of ideas and processes. For exhibition quality, the film was adhered professionally to glass, as bubbling had been problematic. The larger size Perspex had bent so this was resolved by using safety quality glass which had been polished on the edges with holes pre-drilled.

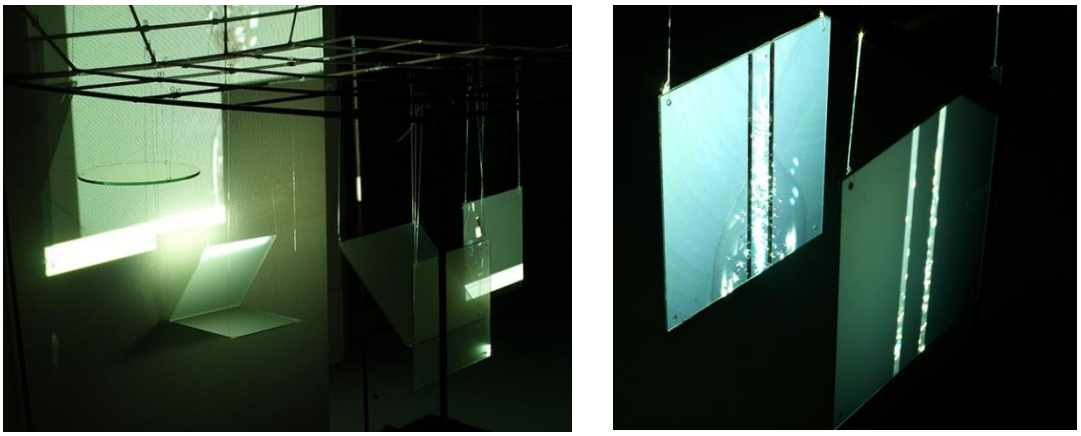


Figure 56. Claire Hughes, Photograph courtesy of Denise Gandy.
Photographs from extensive testing of animations and materials. Photos: Denise Gandy.

The famous double-slit experiment, which heralded the beginning of quantum theory, was represented by slits in the film and use of mirrored film to change the properties of the images. This was taken no further because of its literal representation. (See image above)

The first animation developed was the model of the flat spacetime grid and this was used to test the capabilities of the reflective and transparent properties of the rear projection film. These were set up as a deconstruction of Pepper's Ghost [425] creating virtual spaces in the investigation of the holographic theory of the universe. The use of this technology dating from the 1860's referenced the long-held fascination in ways in which illusory technologies can be used to create imagery that defies or challenges existing logics or perceptions of reality. In the left hand image below a phantom screen can be seen behind the top piece of glass. My interest in virtual spaces was triggered in these tests and formed part of the decision to move to VR technology.

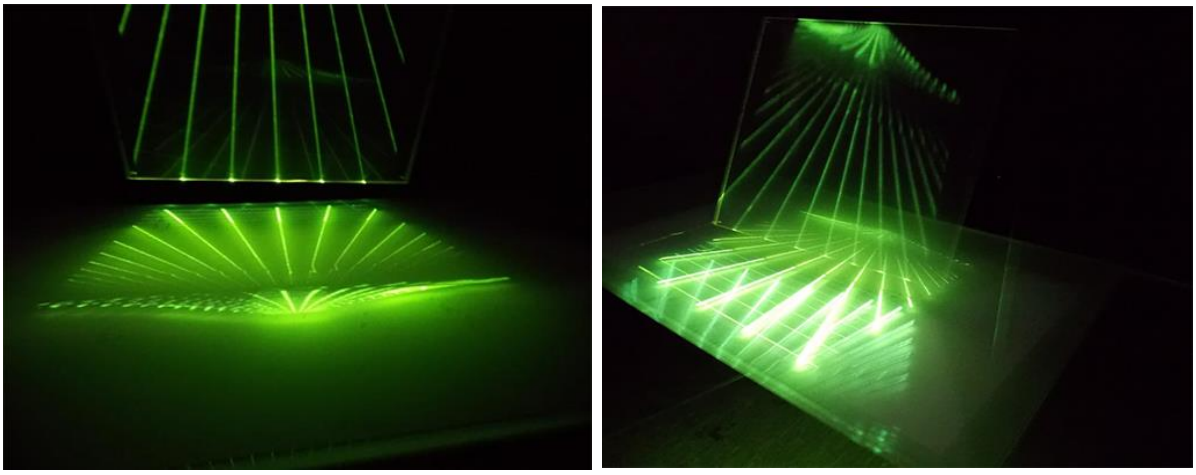


Figure 57. Claire Hughes, 2015, Trials of screens and phantom screens.

I had made a series of steel gimbals as part of my Masters of Fine Arts to investigate higher dimensions and built on this by constructing a 3-D virtual model of a gimbal and animating it so the rings of the gimbal rotated at 90 degrees to each other, referencing the 90 degree separation of dimensions. These were projected onto suspended glass to create reflections that interfered with each other. The round shape of the gimbal rings lead to trials with circular glass; this shape developed further throughout this work as a reference to scientific apparatus from microscopes to the Large Hadron Collider.[426] A larger installation of a circular disk of toughened glass 1.5m diameter and 4mm thick referenced planetary shapes and the glass also

[425]Pepper's Ghost was an illusion developed over 150 years ago where the use of mirrors and glass created a phantom image that had a ghostly appearance. https://cosmosmagazine.com/physics/the-science-behind-the-pepper-s-ghost-illusion accessed 3 October 2018.

[426] The Large Hadron Collider (LHC) is described in more detail in the appendix 6.

augmented conceptual issues of fragility and the ethereal qualities of holograms. In the first trial, this was suspended horizontally, however, a planned effect of perceived danger for the audience became a very real consideration in the suspension procedure. This was resolved by suspending it vertically, causing less stress to the glass, and this method was taken into the physical space of the final installation, *Entangled.* The ideas behind the horizontal suspension were replicated in the VR as the screen for the webcam.

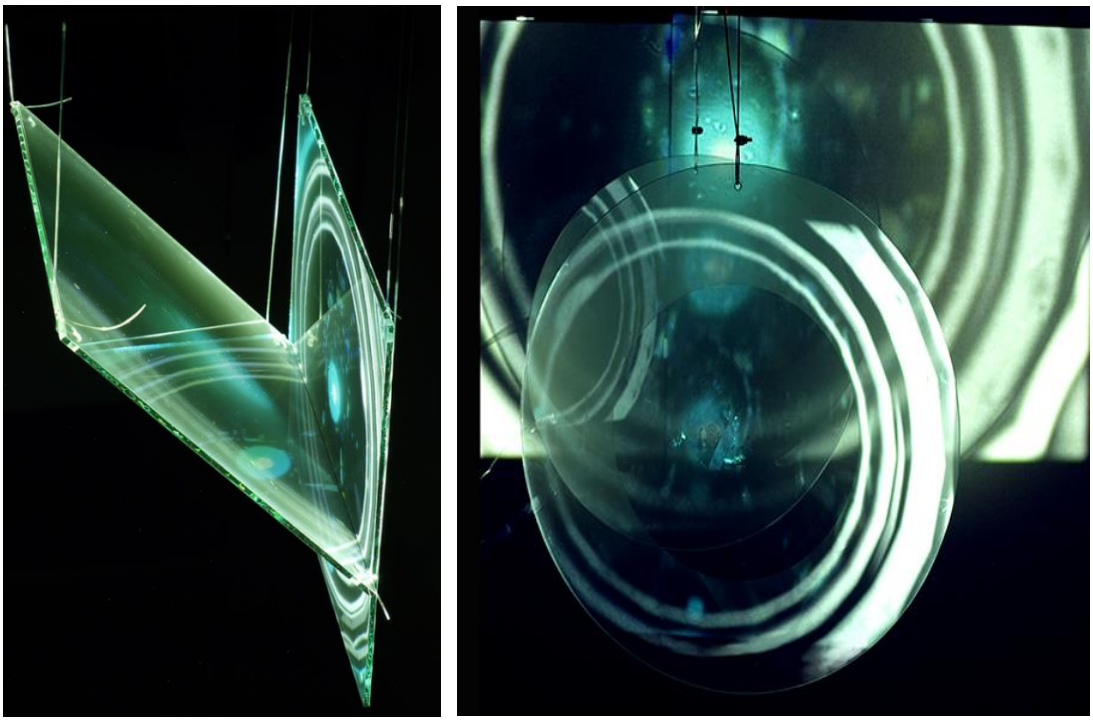


Figure 58. Claire Hughes, 2016, Photographs courtesy of Denise Gandy.
Testing of animations and materials towards *Why Anything?*

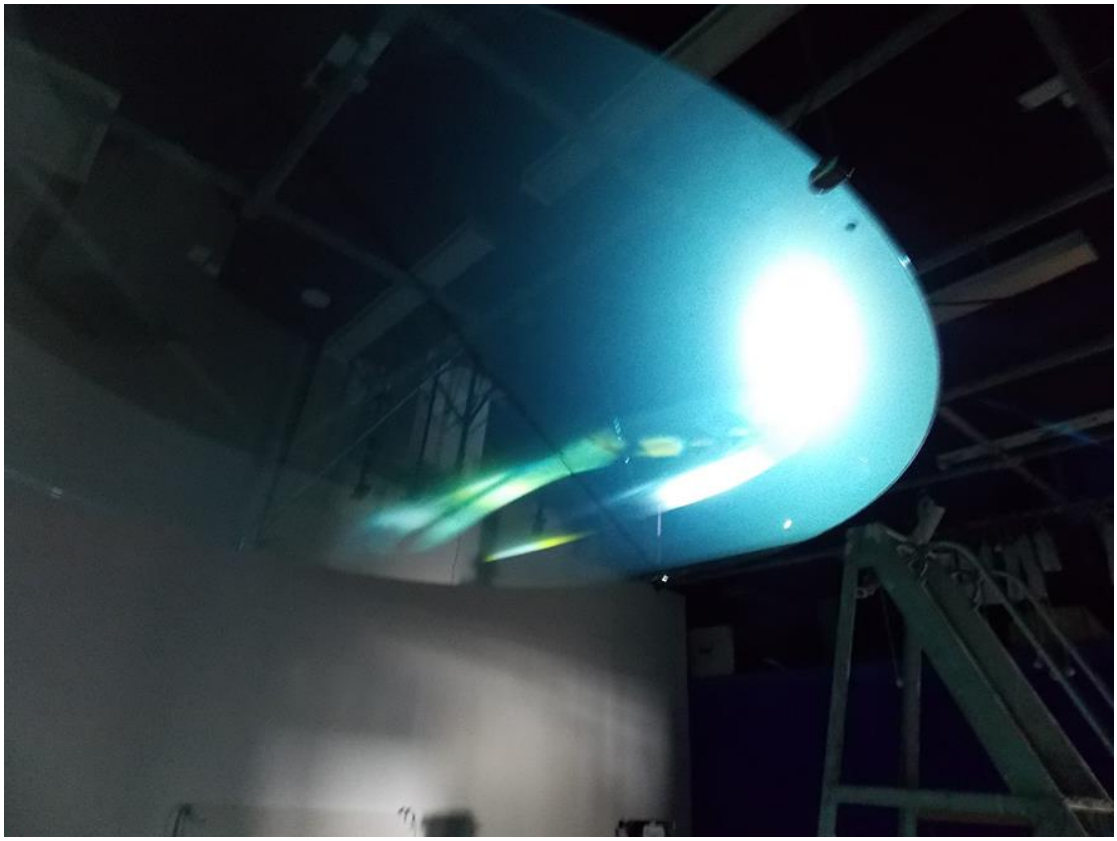


Figure 59. Claire Hughes, 2016, Suspending glass disk horizontally with projections.

Because of the properties of the rear projection film, images were able to sit on the glass, reflect onto angled glass and also pass through the glass, creating images on the walls. A small change in air currents could cause the suspended glass to rotate slightly resulting in large changes to the images on the wall, referencing chaos theory.[427] While chaos theory is largely left behind with a narrowed focus, the reflections and refractions are integrated into quantum entanglement in *Entangled.*

The first trials of black and white to contrast with colour and signify the largely black writing of equations were with the use of mathematical symbols. While Char Davies presented coding and text in the formation of Cartesian coordinates to indicate the supplanting of these in her work, I purposefully used Lorentz equations which supersede Newtonian science and mathematically describe spacetime within the theory of relativity to suggest even more to be

[427] Please see Appendix 6 for brief explanation of Chaos theory.

developed in the future. I presented these equations, which were themselves a mathematical summary of patterns of science, as visual patterning on 2-dimensional flat screens and 3-dimensional virtual spheres, to contrast dimensionality. This was my first exploration into patterns, referencing mathematics as the language of science as discussed earlier, and which later developed into more abstract forms in my VR installation.

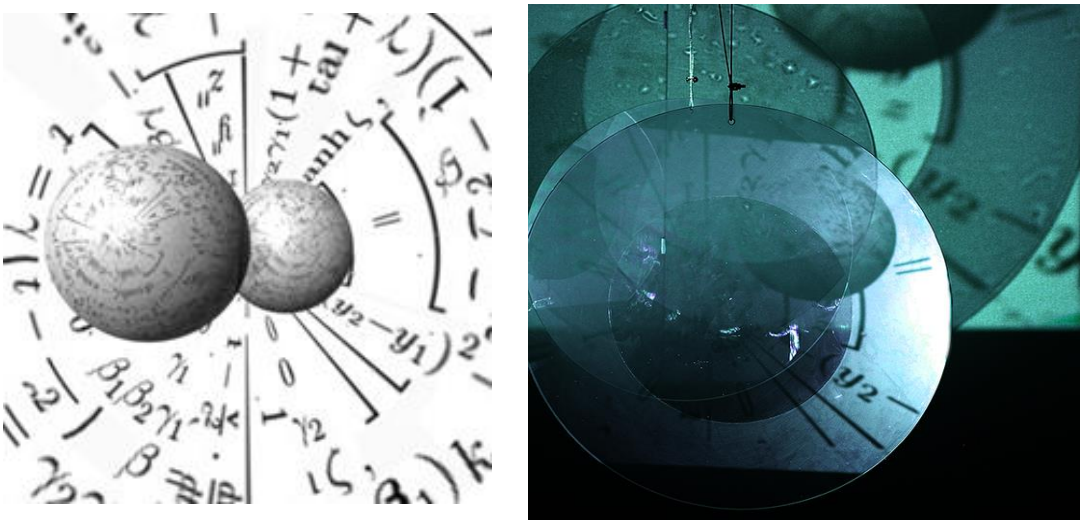


Figure 60. Claire Hughes, 2016, using mathematical equations.
Left: Screenshot. Right: Photograph courtesy of Denise Gandy.

Some very literal representations were explored and deemed too obvious and illustrative. For example an hour glass was introduced to make a connection with the spacetime curve and also an image of the Hadron Collider appeared within the hour glass. This was a forerunner of the travel through apparatus in VR, however, without the immersive capabilities of VR technology this was illustrative and not experiential.

Figure 61. Claire Hughes, 2016, Screenshots of animation with broken glass.

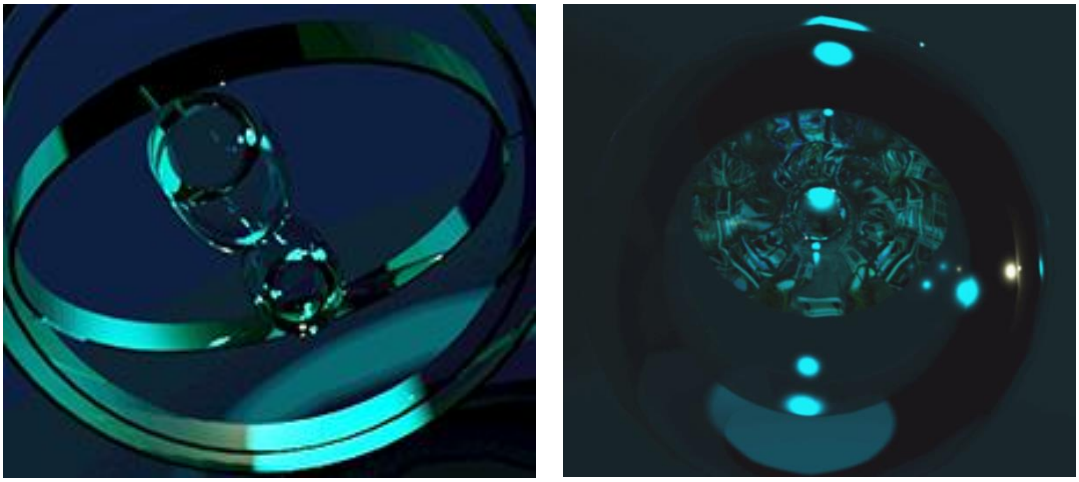


Figure 62. Claire Hughes, 2016, Screenshots of animations with gimbal, hour glass and hadron collider image.

Some animations did not show up well as projections on the glass. The broken glass was effective on the screen, but when projected on the glass it did not provide the clarity I required, however, it did lead to experimentation of the cracked apparatus within VR.

This was a key point in the development of my work as I was able to leave behind illustration of scientific theories and investigate the implications of them. The broken glass aimed to signify the breaking of theories and the danger of accepting the simple reality as we know it, an idea that was extended in the VR, with cracking of the Klein bottles to reference the danger of taking quantum into a macro environment. Investigating ways of showing implications of scientific theories also lead to the animation of the spacetime curve. This was transformed from the flat graph of Newtonian physics to the curved representation of gravitational pull by the rotating gimbal. Finally it was totally mangled to represent further possible changes to the understanding of space and time.

Animations were projected onto a series of glass disks with various configurations and types of rear projection film. Once again I was able to achieve a phantom image, however, because it was not very noticeable, it spurred me on to investigating VR as a means to providing immersive virtual experiences.

The culmination of these investigations using projections onto glass resulted in the simplification of the animations from a multitude of ideas to only the gimbals and the spacetime curve.[428]

Matter Matters

Matter Matters was a work designed for entertainment on a large scale for the Lux Light Festival in Wellington in 2017. The computer animation was projected onto a 6m high water screen that was located in the lagoon in Wellington Harbour. This played four times an hour over ten days of the festival with an estimated 100,000 to 150,000 viewers.

The animation starts with a loud bang, which reverberates around the waterfront, with an explosion from a central point as in Big Bang simulations, however, here the objects exploding are precious gems. The loud bang sound was designed to gain attention within the extensive area of the waterfront.

Figure 63. Claire Hughes, *Matter Matters,* 2017, Lux Festival, Wellington, Photograph courtesy of Denise Gandy.

[428] This was a finalist in the Wallace Awards in 2016.

Figure 64. Claire Hughes, *Matter Matters,* 2017, Lux Festival, Wellington, Photographs courtesy of Denise Gandy.

Referencing scientific entanglement, the sapphires form in pairs, and this is taken into a waltz. Each gem moves as the mirror image of its partner, as in the dance and also in the sense of entanglement of particles where each particle has opposite properties of the other. The sapphires dance in a circle on top of a rigid spacetime curve, and at the end of the sequence a giant diamond emerges from the centre.

The size of the diamond references its hierarchical position as a gem, which is also alluded to in the vertical layering of the gems after the big bang animation. At the time of designing this work, I was researching the hierarchical nature of knowledge and the silencing of science at various times in recent history.[429] This was a humorous take with the scientific diagram of the spacetime curve producing the diamond, which was positioned at the top of the hierarchy of the gems, therefore linking science with the hierarchy. Because of the transparency of the water screen, dark coloured backgrounds in the animation resulted in the buildings behind becoming part of the scene. In the lagoon setting, from many vantage points, the diamond dwarfed the multi-storied buildings that could be seen through it.

The rubies, which are not the top of the hierarchy, formed a cancan dance; a lower form of dance to the waltz, which has sexual overtones and is usually done by showgirls. I elongated the rubies and animated them to the cancan music to give the effect of legs kicking upwards. People commented that they found this the most humorous part of the animation and it was noticeable that the cancan music along with the increasing tempo drew attention to the work.

The animation not only sat on the water screen, but as with the rear projection film on the glass, it allowed the light to go through and the images were the then projected onto the buildings and the ground behind the viewer. The projector was located at one side of the lagoon and because of the distance from the projector to the buildings on the opposite side, these images were magnified to the size of the buildings. However, they were not clearly defined images on the buildings and were at their best when the movement and colour were the strongest.

Reflections on the sea were an anticipated part of the installation and in fine weather these were very clear and added planned aspects to the work. In particular was the spacetime curve animation which had purposefully been designed to go to the bottom of the screen, to visually attach to the reflection in the water. This provided an intertwining of the projected image and

[429] Shaun C. Hendy, *Silencing Science*, BWB Texts (Wellington, New Zealand : Bridget Williams Books, 2016, 2016).

its reflection, a further example of entanglement and a play with both dimensionality and properties of reality that we cannot clearly see.

When the wind blew, the reflections were not as noticeable, however, the spray of the water screen provided a new 3-dimensionality to the screen. With the dissolution of the screen, animations fragmented onto the new shapes formed by the water. The image resolution was strong enough for the work to be viewed in strong winds, whereas the other works displayed on the water screen were at times difficult to decipher because they were projected videos which did not have sufficient clarity or contrast.

During these windy episodes the sound was important in providing a link to the animations. For example when the cancan music played it made it easier to understand the movements. This was my first work collaborating with sound specialists: Roy Philips created the dance music and Isaac Lundy the haunting sounds for the remainder of the work. This led me to working more closely with Lundy for my next project in VR which was planned to be more serious.

Figure 65. Claire Hughes, *Matter Matters,* 2017, Lux Festival, Wellington, Photograph courtesy of Denise Gandy.

The sequence of the animation of the spacetime curve received the highest amount of praise both informally and in critiques. This was developed from *Why Anything?* where the gimbals mangled the spacetime curve, whereas in *Matter Matters* the gems destroyed the spacetime curve as part of the cancan dance. Again this was set up to reference the need to leave behind current theories as concepts of space and time are superseded. After the cancan sequence, the white animation of the spacetime curves was established by making the gems invisible with only the spacetime curve animation visible; a technique to be used later in *Entangled* for the shadows. Segments were edited with parts reversed to make a continuous wave-like animation, complementing the water environment, while also referencing wave theory of light. The high contrast of white on the black background allowed reflections to form on the water, providing another dimension of waves on waves.

Many aspects of *Matter Matters* achieved the aims. The water screen enabled an impressive scale and I observed viewers videoing the work which appeared on social media, indicating a good communication platform. The sound was effective in gaining attention and linking aspects together, with two disparate types of sound, the dance music and the atmospheric electronic sound. These provided a disjointed yet cohesive audio, an idea I took into the VR work with more subtle differences. The success of the white animation of the spacetime curve confirmed its place in the VR installation where it plays in both the physical and virtual spaces.

These positive aspects also created issues I wanted to overcome. It was not an intimate experience and aesthetic subtleties were difficult to achieve. The nature of the water screen meant that the animation was not crisp enough to develop intricacies in the images. The immersive and interactive factors were not strong and denied a deeper experience that I was aiming for. These reasons and the factors discussed previously in *Matter Matters* formed the basis of my decision to explore VR technology and exploit the strengths of this medium towards my goals of a nuanced experiential artwork.

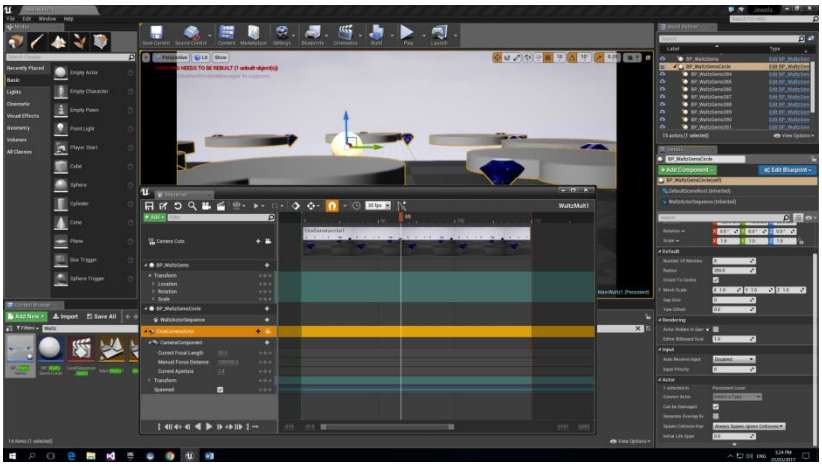
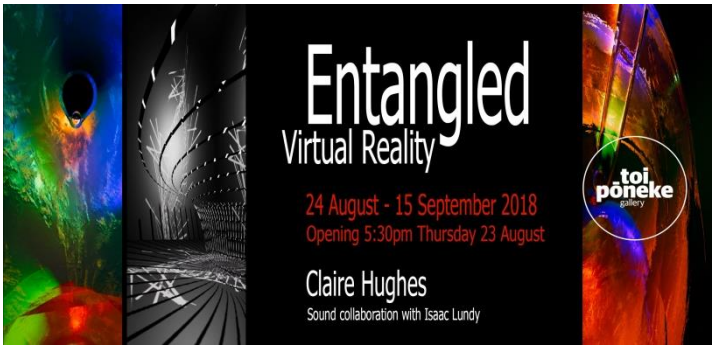


Figure 66. Claire Hughes, *Matter Matters,* 2017, Design of dance sequences.

Appendix 2: *Entangled* supporting material



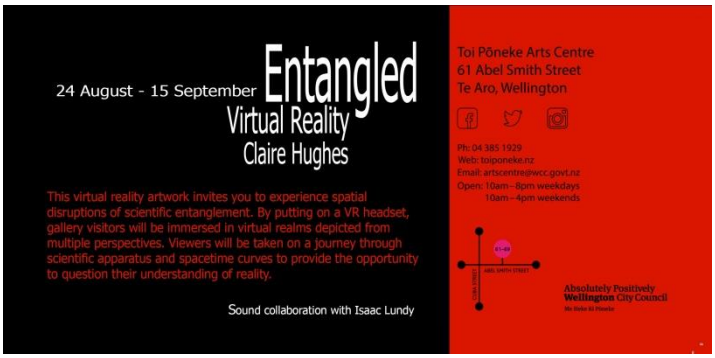


Figure 67. Claire Hughes, 2018, Invitation for *Entangled* Exhibition.

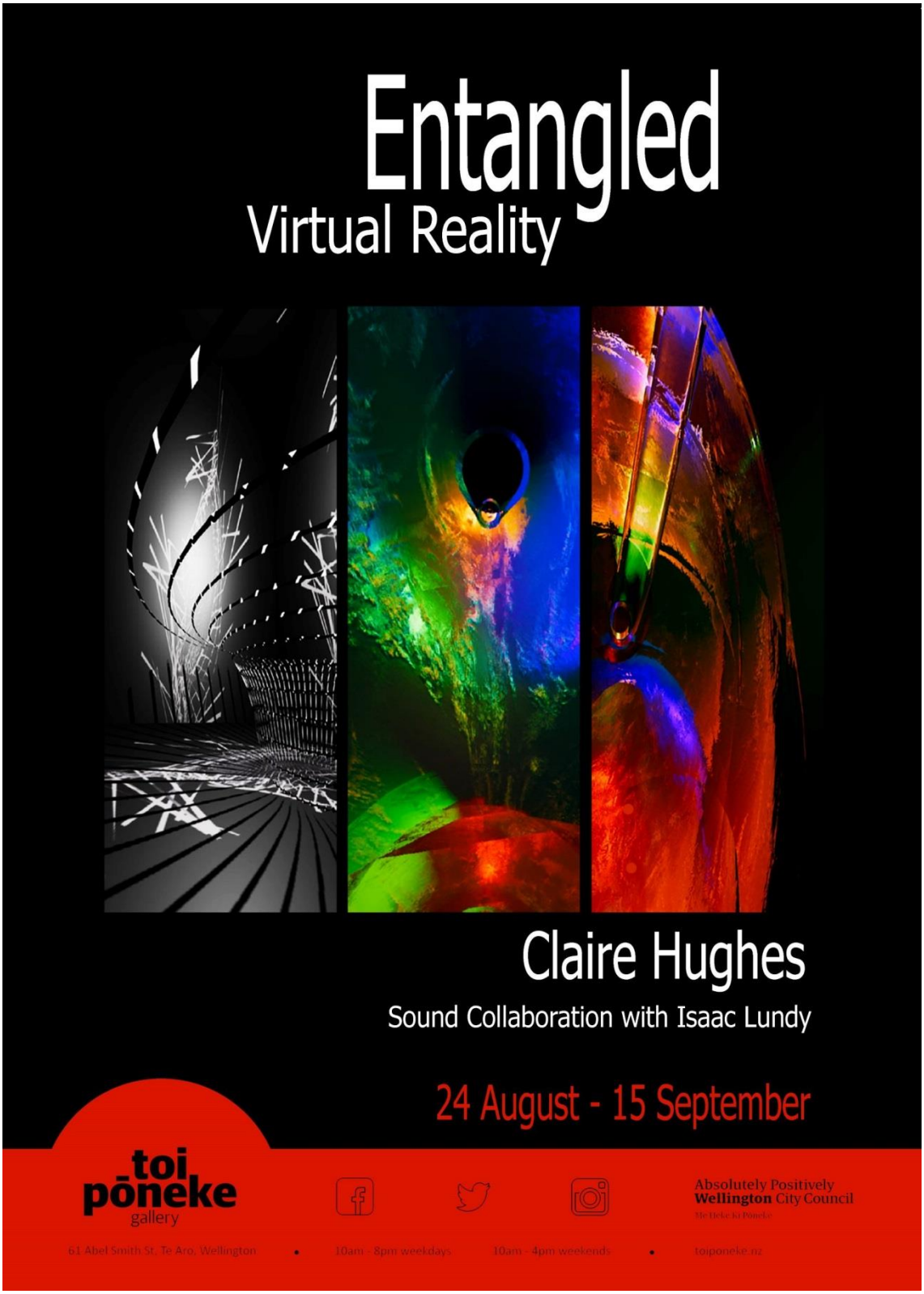


Figure 68. Claire Hughes, 2018, Poster for *Entangled* Exhibition.

Figure 69. ***Questionnaire***

This questionnaire is only for people over 16 years. It is anonymous and will be used to inform my writing for my university studies. I would appreciate any feedback, and you do not have to answer all the questions. Thank you very much.

1. What was your favourite part of the virtual reality?

2. When you first looked down the curved spacetime curve, how did it make you feel?

3. Did you feel more part of the scene when it was black and white or when it was in colour? Any reasons?

4. When the glass apparatus was very small, what are some words you could use to describe how it made you feel?

5. When the apparatus was very large, what are some words you could use to describe how it made you feel?

6. Where you surprised at any time during the scene? If so when?

7. Did you notice triggering any events or causing shadows?

8. Have you heard of entanglement associated with science before?
If yes, what thoughts did this work provoke for you?

9. Any other comments

Demographic data if you are happy to provide it to aid with my analysis

Gender

Age Range 16 – 20 21 – 35 36 -50 Over 50

How often do you play computer games? Never Once a year Once a month Once a week Most days

How often have you used virtual reality? Never Once Up to 5 times 6-10 More than 10

Appendix 3: Additional information on Virtual Reality Technology

VR technology enables the viewer to wear a headset that appears to provide a 360 degree view in 3-dimensions by the use of tracking systems. It achieves this by placing two screens in front of the viewer's eyes that provide stereoscopic images separately to the left and right eye, as our eyes do naturally, giving us the sense of depth of field. The headset tracks the movement of the viewer and provides images to coincide with the direction they are looking and provides opportunities for interaction within the scene.

The roots of this technology can be considered to go back to 280 A.D. when Euclid recognised that each eye receives slightly different images.[430] The use of stereoscopic images to give the illusion of 3-dimensional objects was discovered 180 years ago by Charles Wheatstone who developed what he named a 'stereoscope',[431] which became so popular in the Victorian era that Zoe Clayton claims that nearly every Victorian home had one. [432] From almost the beginning of film in 1890, studios were attempting to make 3D experiences, initially playing the films on two separate screens which were viewed through a stereoscope. The first 3D short film is considered to be *L'arrivee du train* by the Lumiere brothers in 1903, which some people reported as being so realistic that they thought they were going to be run over by the train.[433] This could be considered as an experiential precursor for the intensity of the immersive and interactive encounters that first time VR users reported in response to my exhibition *Entangled.*

It was the US military that produced the first Head Mounted Display (HMD) in 1960 and NASA's developments in the 1980s resulted in tracking headsets that were introduced to gaming arcades, however at this stage still at the cost of around $100,000. From the turn of this century computer technology has rapidly advanced, in particular graphics cards, computer speed, storage and smartphone technology, which have all accelerated the development of VR capabilities. In 2014 Google released the $20 cardboard holder for the smartphone, allowing

[430] 'History of Stereo Photography', accessed 11 January 2019, http://www.arts.rpi.edu/public_html/ruiz/stereo_history/text/historystereog.html.

[431] John Hannavy, *Encyclopedia of Nineteenth-Century Photography* (Routledge, 2013).

[432] Zoe Clayton, 'Stereographs • V&A Blog', *V&A Blog* (blog), 29 January 2013, https://www.vam.ac.uk/blog/caring-for-our-collections/stereographs.

[433] http://au.ign.com/articles/2010/04/23/the-history-of-3d-movie-tech.

for stereoscopic vision with downloadable YouTube videos and a free app to make your own images, however this had limited quality. At the end of 2015, Samsung combined with Oculus' release of Samsung Gear VR to work with the Galaxy phones, which provided head tracking and a large range of games. A little earlier, Oculus was developing the Oculus Rift, with development kits released in 2013 and 2014 after being purchased by Facebook. 2016 was an important year for VR, as makers Oculus, HTC Vive and PlayStation VR rushed to launch the new technology. These were all driven by gaming, and all had specifications and prices that determined their success. VR use continues to escalate with *South China Morning Post* reporting the prediction that in the next five years there will be 86 million VR headsets used in China, while the prediction for the US is 68 million. Vive's top executive in China, Alvin Wang Graylin, has predicted that we will become dependent on VR, in a similar way to our cellphones. Chris Chesher states, "VR is a very expensive technology, and has emerged within institutional contexts: NASA, military researchers, video game manufacturers, universities, software and hardware developers, and entertainment industries.

An enormous financial investment has been made into 'gaming', which clearly demonstrates its importance within the field of VR. Michael Zyda, a director of USC Viterbi School of Engineering, defines video games as "a mental contest, played with a computer according to certain rules for amusement, recreation or winning a stake." [434] He extends this definition to 'serious' video games with the addition that they "further government or corporate training, education, health, public policy, and strategic communication objectives."[435] The development of major games can take years and large teams to achieve the final outcome with design, art and sound specialists, programming coders and technical and development teams to bring the project together. Today some people earn their living by not only developing games, but by professionally playing in tournaments, streaming games skills and providing instructional courses. Because of this uptake, interactivity, which is a strong focus of gaming, has dominated VR development at the expense of depictions of reality. This often results in graphics that appear artificial, such as laminates for bricks and timber in Dark Souls 3, (2016), and Tombraider (2013) and plants often do not move and appear to be replications of the same mesh, as in Dark Souls 3 and Destiny (2014). This saves processor and graphics card capabilities for the use of interaction. Portraying glass is also an aspect that is heavy on processor speed and I carefully built up my project optimising level of detail (lod) and post-processing

[434] Michael Zyda, 'From Visual Simulation to Virtual Reality to Games', *Computer (00189162)* 38, no. 9 (September 2005): 25–32, https://doi.org/10.1109/MC.2005.297, 25.

[435] Michael Zyda, 'From Visual Simulation', 26.

capabilities to enable the large models of glass apparatus; an aesthetic that I aimed for which is very different from gaming programs.

Taking a hands-on approach to using VR has provided me with opportunities that I may not have achieved otherwise, however it also came with challenges. While I had already gained experience in 3-D modelling, this investigation was my first foray into VR technology. I used one of the most sophisticated platforms, Unreal Engine 4 (UE4), which, although it was first released in 1998, still has constant updates to improve stability and performance. Even in 2016 there was limited support on-line and in the community compared with now. I had previous coding experience but even so the visual coding was not always intuitive and support was often challenging to obtain which meant that at times I had to forge my own way with workarounds. For example, I commissioned some software to enable the webcam to work in the VR, as at the time this feature was unstable in UE4. While a large range of materials are provided, I downloaded additional plugins to achieve the effects I wanted. Additionally UE4 was developed primarily for gaming and so while it would have been easy to add explosions, fires, sparks and shooting experiences, to achieve my aesthetic and conceptual aims involved time-consuming development. The lighting required constant testing and experimentation to create the desired effects of lighting and shifting even one light could change a scene to unwanted mixtures of colours.

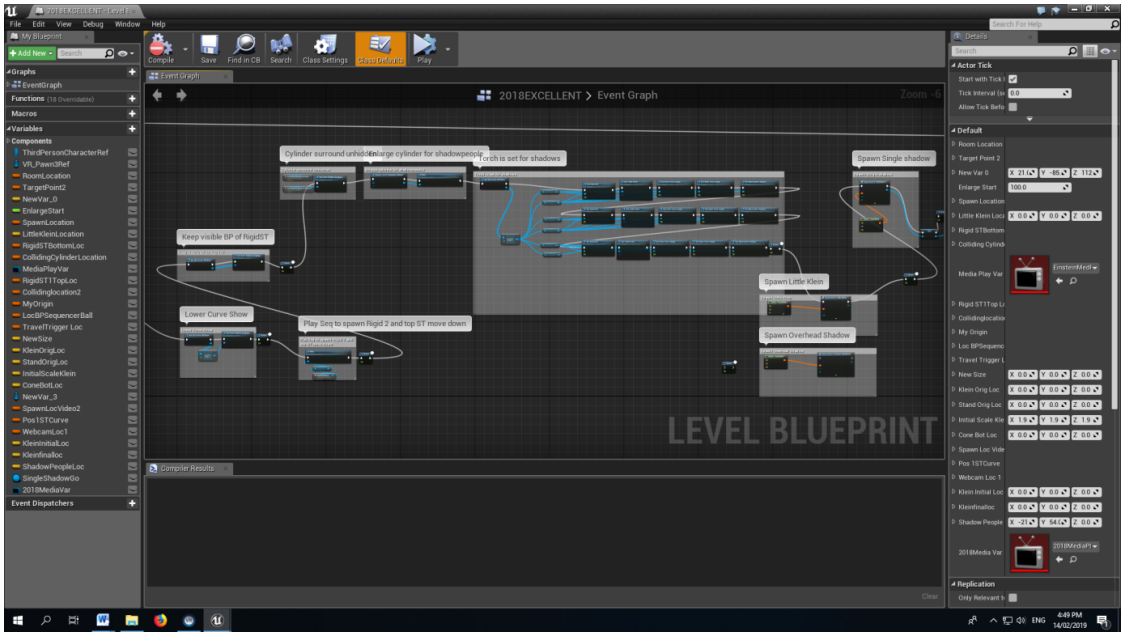


Figure 70. Claire Hughes, 2018. An example of coding used for *Entangled.*

The huge learning curve was productive because by overcoming these barriers I was able to pursue unexpected effects and prioritise salient features of this constructed environment. Experimenting with the lighting and textures produced landscapes that I was not aware could be attained. I tested many textures before deciding on the frosted textures on the glass and this came to life with particular lighting set-ups. I trialled many scales of size to gain the illusion of large spaces and by positioning the viewer within certain areas, this was accentuated. To create shadows I required a form for them to appear on and after inserting various shapes I found that the cylinder allowed me to create a landscape where the shadows created the illusion of perspective. The cylinder also created shadows of people that could become huge and distorted depending on the position of the viewer. To obtain the wet environment, I toned down the available water effects to make it more visually subtle, yet still unsettling.

Many iterations in VR were trialled as I prioritised a more subtle aesthetic approach. For example, I created a VR test piece that had a giant steel apparatus spin around in front of the viewer, resulting in many people who viewed it responding with a ducking movement. While I investigated the avenue of frightening scenes used in such films such as *Jaws 3D* and *Friday the 13th Part3: 3D,* I agree with Brendon Connelly who states that immersion would be more persuasive "if the whole point wasn't just 'fish are jumping out of the screen'".[436] Connelly quotes examples of more subtle techniques that are more powerful, which he describes as "tiny soft-touches of steering". In *Puss In Boots* (2011), where the 3D effect gives the feeling of leaning forward, he says that most people will not notice the technique, but that it gives "something uniquely 3D-powered to your personal point of view, your emotions, your sympathies". This is more aligned with my intentions of using VR to make an artwork, resulting in my electing not to use elements for their novel impact, an often repeated criticism of artworks using VR. In a review by Jonathan Jones in The Guardian (2015), he states that in Jon Rafman's London exhibition it is the technology that is astonishing, not the art and that if he had been trying to convey something original, then the gimmicks may have been acceptable.[437]

[436] Brendon Connelly, 'How the Film Industry Blew It with 3D', Den of Geek, accessed 12 October 2017, https://www.denofgeek.com/uk/go/41729.

[437] Jonathan Jones, 'Oculus Rift Will Change the World, but Can It Change Art?', *The Guardian*, 8 October 2015, sec. Art and design, https://www.theguardian.com/artanddesign/jonathanjonesblog/2015/oct/08/oculus-rift-jon-rafman-art-virtual-reality.

Controllers and haptic devices (which create forces or vibrations) were also trialled and researched as part of my investigations. I coded the force-feedback into a scene, which is provided by the Vive controllers to give a vibrating sensation in the hand holding the controller. While it provided the disruptions that I was aiming for, it seemed out of character with the highly visual and aural nature of the work and rather than increasing immersion the unreal sensation detracted from it. I researched new developments in haptic feedback technology, including gloves, vests and knuckle controllers, which are still expensive and I made the decision that the project would need to have been devised with these devices in mind from the beginning rather than be 'retro-fitted' at a late stage in development. Char Davies, who I discuss in more detail later in this section, successfully used breathing sensors within her work, *Osmose,* which were a key conceptual and formal element. Originally I programed the work to incorporate the controllers and the viewer could see an artificial arm and hand with a torch, however, this reduced the sensation of immersion and made the relationship to scale too concrete and prescriptive. I tested various iterations, some considerably time consuming, (such as controller interactions) but it was only through trialling and analysis of my own experience in the work and strategic user testing, that it became clear that they were not achieving the desired effect.

I purposefully decided from the outset of this project that I would not use avatars because I wanted to involve the real body, not a virtual representation. There are examples of the successful use of avatars in VR-based art, such as the interactive work *RMB City* developed by Cao Fei on the Second Life platform, exhibited at the 2007 Venice Biennale. She is the avatar, China Tracy, who is the guide enabling the player to design cities, and according to the reviewer, Tianyue Jiang, allowing the testing of the "boundaries between virtual art and physical existence."[438] This work still has the aesthetics of gaming because of the avatar and has been developed to address issues such as communism, architecture and body representation, all of which diverge strongly from my focus.[439]

Early in my work I made the decision not to use augmented reality because the technology being in early developmental stages. Augmented reality (AR) allows the viewer to see the physical world with virtual objects overlaid on top. Pokémon brought AR to the forefront of popular culture with cartoon characters 'hidden' all over the world. Microsoft HoloLens has

[438] Jiang Tianyue, 'Cao Fei and Her Journey to a Parallel Universe | Christie's', accessed 12 July 2018, https://www.christies.com/features/Cao-Fei-and-her-journey-to-a-parallel-universe-7683-1.aspx.

[439] Fei, Cao, 'RMB City Blogs', RMB City — Online Urbanization (blog), 2008, http://rmbcity.com/about/.

been the main developer of more sophisticated software for this new technology, however when I made key decisions on whether to build my project to include AR, HoloLens was only released as a developer kit and its availability was limited to the USA and Canada. The Vive headset that I use has a camera that can enable the viewer to see the outside view, however there were technical problems with this software that have only been remedied recently. Trials have shown me that blending the camera view with the virtual images can distract from the feeling of being present in the virtual. Even at the current stage of development of AR, I would not choose to work with this technology as there are still major issues being resolved. The HoloLens has a limited field of view of approximately 35 degrees which means that the viewer can see the edges of the virtual space reducing immersibility. (Newer models promise to double the field of view to 70^{o}). Virtual overlay can appear less real because of the comparison to the physical surroundings and sometimes the virtual image disappears or gets cut off depending on how close the viewer is to the image.[440] Games for HoloLens have come on the market in 2018, however reviews show that there are many issues still to be resolved.

Both AR and VR offer to be exciting new media in the future for artists. MagicLeap and Apple are yet to release their AR technology. New developments in VR are second generation models with new displays and tracking technologies. Vive released a wireless adapter two weeks after my exhibition finished, a development that will improve the VR experience. Whole body haptic response apparel is being developed with motion capture and biometric feedback systems.[441] The latest 360 degree cameras are reasonably priced and integrate into the VR technology enabling everyday events to be captured for VR. These developments and refinements to the existing technology provide a wealth of opportunities for artists.

[440] Michelle Fitzsimmons, 'Microsoft HoloLens Hands on Review | TechRadar', 2017, https://www.techradar.com/au/reviews/wearables/microsoft-hololens-1281834/review.

[441] 'Teslasuit - Full Body Haptic Suit', Teslasuit - full body haptic VR suit, accessed 12 April 2018, https://teslasuit.io/.

Appendix 4: Presence Chart

Below is the framework that was developed from research into presence.

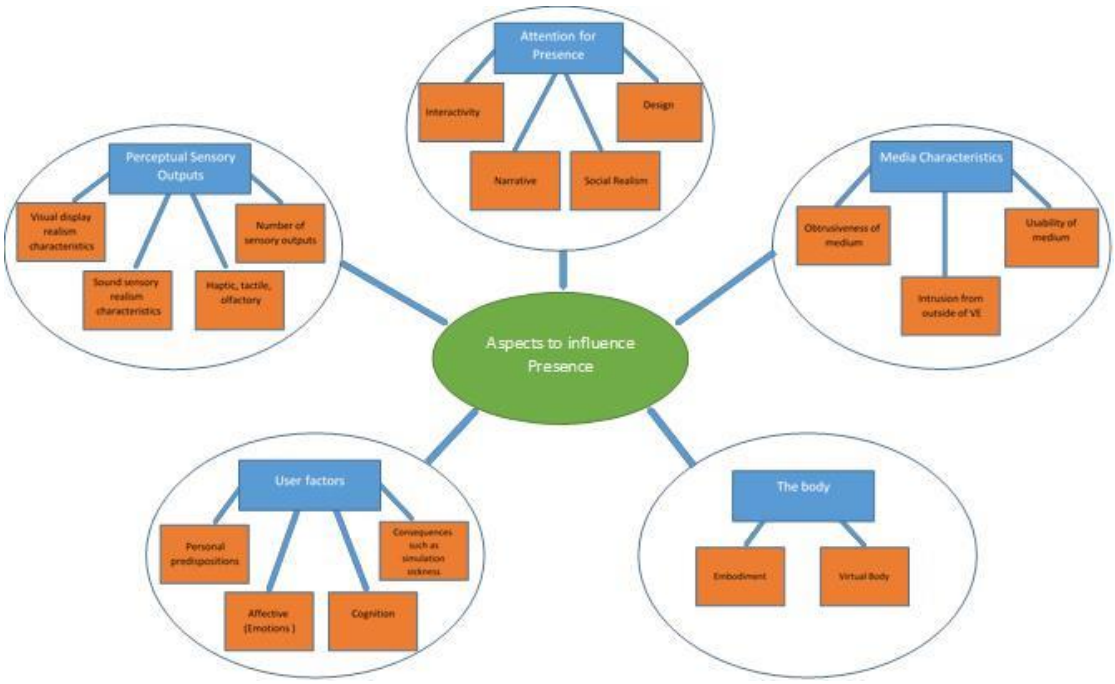


Figure 71. Claire Hughes, Presence chart.

Appendix 5: Relevant Scientific Terms

Additional Information on Entanglement

For certain pairs of particles that are "entangled", observing one particle instantly gives you information about the other particle that may be remotely distant.[442] This was termed by Einstein as "spooky action at a distance"[443] as it appears that observing one particle determines the state of the other particle. He and others were worried that this might violate the rule that nothing can travel faster than light.

K.C. Cole in her article "Wormholes Untangle a Black Hole Paradox" says, "If two quantum particles are entangled, they become, in effect, two parts of a single unit. What happens to one entangled particle happens to the other, no matter how far apart they are."[444] However, there is more to this, as it depends on the observation. Cole gives Juan Maldacena's analogy of a pair of gloves. If you find one of the pair, you immediately know that the handedness of the other one must me the opposite. At the quantum level things are even stranger. The properties of two entangled particles could not even be specified until one of them is measured when, instantly, the property of the other would be known.

Entanglement is a fascinating topic; it entwines and refutes different theories and could possibly unite the two main theories of the very small (quantum physics) and the very large (relativity and black holes). These two theories are not compatible at present and making them fit together is a major goal of modern theoretical physics. Cole analogises these two theories to art; "The smoothly warped space-time landscape that Einstein described is like a painting by Salvador Dalí — seamless, unbroken, geometric. But the quantum particles that occupy this space are more like something from Georges Seurat: pointillist, discrete, described by probabilities."[445] Cole further says, "Quantum entanglement . . . could be creating the "spatial connectivity" that "sews space together," according to Leonard Susskind"[446]

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[442] J. S. Bell and John Stewart Bell, *Speakable and Unspeakable in Quantum Mechanics: Collected Papers on Quantum Philosophy* (Cambridge University Press, 2004).

[443] Juan Yin et al., 'Bounding the Speed of `spooky Action at a Distance'', *ArXiv:1303.0614 [Quant-Ph]*, 4 March 2013, http://arxiv.org/abs/1303.0614.

[444] Cole K. C., 'Wormholes Untangle a Black Hole Paradox | Quanta Magazine', *Quanta Illuminating Science Magazine*, 24 April 2015, https://www.quantamagazine.org/20150424-wormholes-entanglement-firewalls-er-epr/.

[445] Cole K. C., 'Wormholes Untangle a Black Hole.

The Special and General Theories of Relativity

Einstein's Special Relativity Theory stated that the laws of physics appear the same to everyone in the same reference frame where everything is moving relative to everything else. But at velocities approaching the speed of light, properties such as time, mass and distance will appear different to different observers. His General Relativity Theory shows how space and time are affected by gravitational fields and predicted the existence of black holes.[447]

Quantum Theory

Max Planck is regarded as the first person to realise, in 1900, that energy is "quantised", i.e. exists in small, indivisible packets.

In 1905, Einstein realised that light too is quantised and named the particles photons.

In 1924, Louis de Broglie demonstrated that not only did light "waves" sometimes act as particles but also that assumed "particles" such as electrons, can act as waves. This was known as "wave-particle duality".

In 1925 Erwin Schrödinger developed a set of quantum equations that expressed particles' movements as probability fields.

In 1927, Werner Heisenberg proposed his Uncertainty Principle.

These ideas, and others, mark the beginning of 'Modern Physics'. Many aspects of quantum theory are very counter-intuitive and many early scientists had great difficulty accepting them. However, countless experiments have proven the theory to be correct and to a great degree of accuracy.[448]

Space-time

Einstein's General Theory of Relativity predicted not only the bending of space near large masses but that time is also distorted there. He proposed that time and space were similar in so many ways that they should be called just space-time or Minkowski space.[449] The equations using this new four dimensional space-time concept enabled the simplification of many physics

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[446] Cole K. C., 'Wormholes Untangle a Black Hole.

[447] 'Einstein's Relativity Explained in 4 Simple Steps', National Geographic News, 16 May 2017, https://news.nationalgeographic.com/2017/05/einstein-relativity-thought-experiment-train-lightning-genius/.

[448] Budnik, Paul. 'Measurement in Quantum Mechanics FAQ: *Quantum Mechanics'*, 2009, https://mtnmath.com/faq/meas-qm-1.html.

[449] John Fuller, 'How Warp Speed Works', *HowStuffWorks,* 7 March 2008, https://science.howstuffworks.com/warp-speed.htm.

theories. For example, it helped cosmology to understand how the universe works on the big level (e.g. galaxies) and small level (e.g. atoms).

In non-relativistic classical mechanics, the use of the old 3D or Euclidean space instead of space-time is good enough, because time is treated as universal with a constant rate of passage which is independent of the state of motion of an observer. But in a relativistic universe, time cannot be separated from the three dimensions of space. This is because the observed rate at which time passes depends on an object's velocity relative to the observer. Also, the strength of any gravitational field slows the passage of time for an object as seen by an observer outside the field.[450]

Fundamental Particles

In 1897 J. J Thomson discovered the first subatomic particles, which were later named electrons. In 1911 Ernest Rutherford showed that the atom consisted of a positive nucleus surrounded by electrons, and in 1913 Henry Moseley defined atomic number, and in the same year 1913 Niels Bohr developed the theory of atomic structure.

In the 1930s, all matter was thought to be made out of electrons, neutrons and protons, but by the 1960s it was considered that there were over a hundred fundamental particles. In 1961 the Standard Model was proposed which showed many of these previously considered fundamental particles to actually be made of a smaller set of particles, usually called elementary particles, which have no known internal structure. The Standard Model grouped elementary particles into two classes, bosons and fermions. Bosons often transmit forces and include photons, which are the fundamental particles of light, and the now famous Higgs boson, which gives mass to other particles. Fermions include quarks and leptons; quarks make up other particles such as protons and neutrons and the electron is an example of a lepton. Most elementary particles have a corresponding anti-particle which is identical except for having opposite charge.

The theory of supersymmetry predicts another collection of elementary particles that are not part of the Standard Model but these have not been observed yet.[451]

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[450] Robert Lewis, 'Time Dilation | Explanation, Examples, & Twin Paradox', Encyclopedia Britannica, 16 July 2018, https://www.britannica.com/science/time-dilation.

[451] Fermilab, *What Is Supersymmetry?*, 2013, https://www.youtube.com/watch?reload=9&v=0CeLRrBAI60.

The Large Hadron Collider

The Large Hadron Collider (LHC) accelerates particles around a 27 kilometre ring located beneath France and Switzerland near Geneva. It consists of superconducting magnets and accelerating structures to enable particles to collide with each other at a high enough energy to discover information at a subatomic level.[452]

Figure 72. The Large Hadron Collider, https://home.cern/resources/360-image/accelerators/virtual-tour-lhc

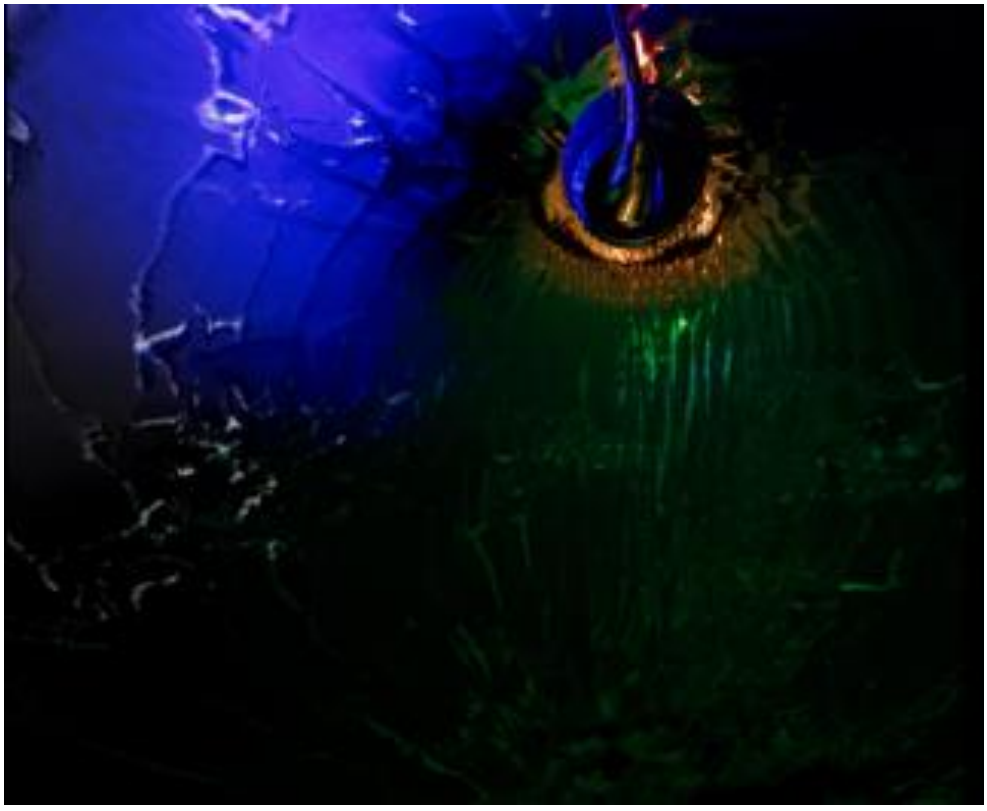

Figure 73. Claire Hughes, *Entangled,* 2018, Screenshot of broken enlarged Klein bottle.

[452] 'The Large Hadron Collider | CERN', accessed 4 August 2018, https://home.cern/science/accelerators/large-hadron-collider.