Astro-animation:
Gesture, Metaphor and Creative Practice in Astronomy Communication

Volume 1

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“The world is not what I think but what I live through.”
Maurice Merleau-Ponty, *Phenomenology of Perception*

Abstract

This thesis investigates Astro-animation as a practice-based, participatory approach to public astronomy communication. Astro-animation is defined here as an embodied, analogue mode of science communication in which gesture, metaphor and animation-making support the exploration of astronomical ideas. In this thesis, astronomy communication refers to the public and informal communication of astronomy, particularly to non-specialist audiences, teenagers and participants from underrepresented groups. Although astronomy communication has expanded through scientific visualisation, immersive environments and art–science initiatives, there remains limited provision for collaborative, embodied and materially grounded engagement through making. Existing formats often prioritise viewing, explanation, or data interaction over participatory interpretation. This thesis addresses that gap by developing Astro-animation as a mode of inquiry through which astronomical ideas are explored collaboratively through making.

The study examines how astrophysical concepts are articulated and transformed into visual, temporal and participatory forms of inquiry. Gesture shifts from analytic focus to design principle and structuring element, while metaphor shapes visual form, timing and concept development within animation practice. Studio-based experimentation informed the development of animation-making approaches for non-specialist audiences.

Methodologically, this practice-based research is informed by Science Capital, which frames how access to resources, prior exposure to science and arts-based learning, confidence, recognition and belonging shape young people's engagement with astronomy. The research adopts a mixed-methods design integrating creative practice with interviews, surveys, observation and reflexive thematic analysis. It is organised into three interlinked strands. Strand 1 develops Astro-animation through creative practice and collaboration with NASA scientists, culminating in the film *The Movements of the Universe*. Strand 2 translates these principles into the Astro-animation Toolkit, developed with scientists and artists. Strand 3 implements the Toolkit in community-based and informal learning settings, including libraries, festivals and school-based workshops, with particular attention to teenage engagement.

The thesis makes conceptual, methodological and practical contributions. It shows how animation can function as a mode of inquiry within a mixed-methods, practice-based research design, in which movement, timing, transformation and visual interpretation form part of the analytical process. Practical outputs include *The Movements of the Universe*, a series of participatory workshop films and the Astro-animation Toolkit, which provides a model for workshop design and delivery. Findings indicate that scientists' gestures and metaphors provided generative material for animation design, shaping movement, rhythm, timing and visual form; that these principles informed the development of an adaptable Toolkit; and that participatory animation-making can engage teenagers and participants from underrepresented groups through creative exploration of complex astronomical processes. Astro-animation is therefore positioned as a model for inclusive informal science communication.

Declaration

I hereby declare that no portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification at this or any other university or institute of learning.

Signed: _____

Date: _____

Acknowledgements

This thesis comes at the end of a long journey. It has marked a meaningful period during which my practice, work and personal life have come together in unexpected and beautiful ways. Looking back, I feel very grateful for the people who accompanied me throughout this process.

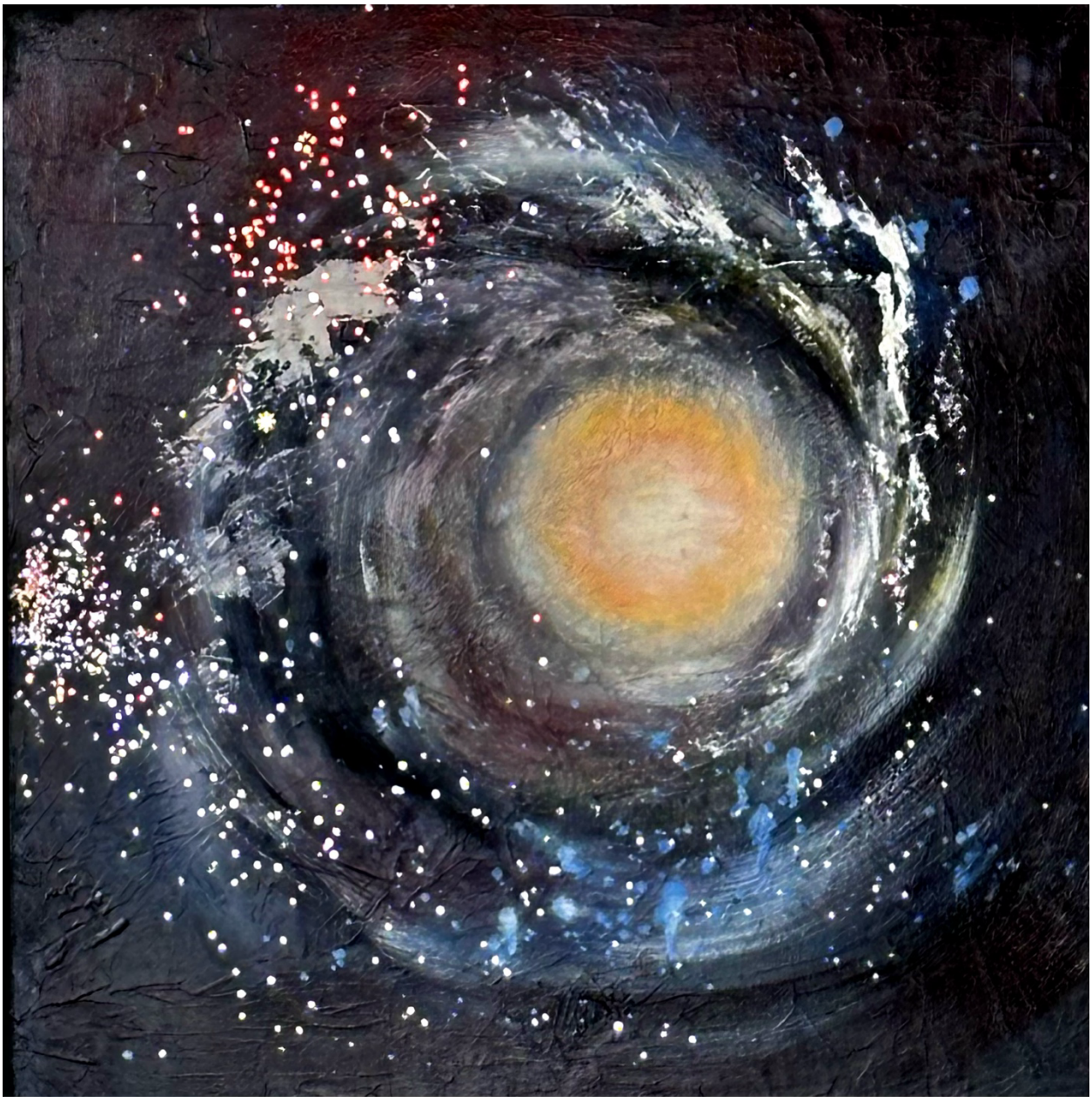
My first thanks go to my supervisors, Mark Roughley, Dr Sarah Bennett and Dr Tracey M. Benson, for their generosity, guidance and encouragement. Their feedback helped me clarify my thinking and their willingness to trust the value of bringing animation, astronomy and participatory practice together meant a great deal to me.

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I owe a great deal to the students at MICA, whose creativity and willingness to experiment continually reminded me why Astro-animation matters. I would also like to thank the American Astronomical Society, as well as the families, teenagers, librarians, educators, artists and community participants who took part in the workshops. Their drawings and imaginative responses gave this research its direction and heart.

Living and teaching in Baltimore has deeply shaped both my practice and this thesis. I am thankful to the Maryland Institute College of Art for providing a space where teaching and my PhD research could grow together. I am also grateful to the Transart Institute, to my cohort there for their support and companionship and to LJMU. My thanks also go to the Zaentz Foundation for supporting my film.

Finally, I want to thank my family, especially my mother, Claudine Bagnès, for her curiosity, passion and belief in me throughout this long journey. I am also grateful to my friends for their love and support. They helped me keep sight of the end of this work successfully.



Painting by my mother, Claudine Bagnès, inspired by the galaxy NGC 1232. Used with permission.

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List of Presentations, Screenings, Exhibitions and Awards

Presentations, Workshops and Exhibitions

Arcadias, L. (2023) ‘Workshopping art/science activities for an Astro-animation STEM exhibition’, poster presentation, HEAD 20 Meeting, High Energy Astrophysics Division, American Astronomical Society, Hilton Waikōloa Village, Waikōloa, Hawai‘i, 26–30 March.

Arcadias, L. (2023) ‘Astro-animation: workshopping animation and science activities for a STEAM exhibition’, paper presentation, Animafest Scanner X: Symposium for Contemporary Animation Studies, World Festival of Animated Film, Zagreb, Croatia, 5–10 June.

Arcadias, L. and Corbet, R. (2023) ‘Flying by Pluto’, Astro-animation workshop, Dot Astronomy Conference, New York, 6 October.

Arcadias, L. and Corbet, R. (2023) ‘Astro-animation: how artists and scientists envision the universe’, panel presentation with Emma Booth, Figuring the Invisible: Animation and Science Outreach in Contemporary Audio-Visual Culture, Hochschule Luzern, Lucerne, Switzerland, 14–17 December.

Arcadias, L. (2024) ‘Astro-animation workshop’, online workshop, LJMU MA Art in Science / MALSAD students, Liverpool John Moores University, 28 May.

Arcadias, L. and Corbet, R. (2024) ‘The Eclipse’, Astro-animation splinter session, HEAD 21 Meeting, American Astronomical Society High Energy Astrophysics Division, Horseshoe Bay, Texas, 10 April.

Arcadias, L. (2024) ‘Astro-animation: a bridge between artistic expression, astrophysics and public engagement’, paper presentation, 2CO4 Barcelona, Barcelona, Spain, 3–5 July.

Arcadias, L. and Corbet, R. (2024) ‘Astro-animation workshop and presentation’, Transart Institute / Liverpool John Moores University Summer Intensive, Liverpool, 23 July.

Arcadias, L. and Corbet, R. (2024) ‘From animation to astronomy: a comparative analysis of early optical instruments’, presentation, 20th International Convention of the Magic Lantern Society of the United States and Canada, Long Beach, California, 19–21 September.

Arcadias, L. and Corbet, R. (2024) ‘Sunspot’, presentation and Astro-animation workshop, Figuring the Invisible: Animation and Science Outreach in Contemporary Audio-Visual Culture, University of Padova, Padova, Italy, 20–21 November.

Arcadias, L. (2025) ‘The Eclipse’, presentation, 245th Meeting of the American Astronomical Society, National Harbor, Maryland, 14 January.

Arcadias, L. and Corbet, R. (2025) ‘Jupiter’, Astro-animation workshop with teenagers, Montgomery County Public Library, Maryland, 14 May.

Arcadias, L. (2025) ‘The Eclipse workshop’, presentation, EAS 2025 European Astronomical Society Annual Meeting, Cork, Ireland, 23–27 June.

Arcadias, L. (2025) ‘Astro-animation: a bridge between artistic expression, astrophysics and public engagement’, presentation, 36th Annual Society for Animation Studies Conference, London, 7–10 July.

Arcadias, L. (2025) ‘Astro-animation: films and workshop drawings’, exhibition, Faculty Sabbatical Exhibition, Maryland Institute College of Art, Baltimore, 22 August–14 September.

Arcadias, L. (2025) ‘The Eclipse’ and ‘Strange News from Pluto’, Convergence, British Science Festival, Liverpool, UK, 10–14 September.

Festival Screenings and Awards

The Movements of the Universe:

The Movements of the Universe (2026) the Outer Rim International Science Fiction Film Festival. 19 Aug. **Winner: Best Microdoc film.**

The Movements of the Universe (2026) San Francisco SCIENCE FICTION Short Film & TV Awards 13 September 2026. **Best Science Fact Film.**

The Movements of the Universe (2026) SCINEMA Science Film Festival, Australia. 15 to 23 August 2026. Finalist

The Movements of the Universe (2025) American Documentary and Animation Film Festival, USA, 25 March 2026.

The Movements of the Universe (2025) Maryland International Film Festival, USA, 26 March 2026.

The Eclipse

The Eclipse (2024) Sweaty Eyeballs Animation Festival, Baltimore, USA, 18 October.

The Eclipse (2024) The Iron Mule Short Comedy Film Festival, New York, USA, 3 February 2025. **Audience Award.**

The Eclipse (2024) Boston SciFi Film Festival, Boston, USA, 12 February 2025.

The Eclipse (2024) International Animation Festival “Soleil”, Bulgaria, 5 June 2025.

The Eclipse (2024) Annecy International Animation Film Festival, Annecy, France, June 2025.

The Eclipse (2024) San Francisco Science Fiction Short Film and TV Awards, USA, 15 September 2025. **Best Science Fact Film.**

The Eclipse (2024) Festival International du Court-métrage Scientifique de Riom, France, 21 November 2025.

The Eclipse (2024) French Duck Film Festival, France, 2025. **Finalist**.

The Eclipse (2024) Aguilar Film Festival, Palencia, Spain, December 2025.

The Eclipse (2024) Mecal Barcelona International Short and Animation Film Festival, Barcelona, Spain, 2025.

The Eclipse (2024) Maryland International Film Festival, USA, 26 March 2026.

The Eclipse (2024) Sacramento Independent Film Festival, USA, 25 March 2026.

The Eclipse (2024) FantaSci Short Film Festival, Orlando, USA, May 2026.

Definitions

Analogue animation

Analogue animation refers to animation created through physical, non-digital processes in which images are produced frame by frame by hand or through direct manipulation of materials. In this thesis, the term describes a hand-drawn process that is later digitised through scanning and sequencing for editing and assembly.

Astro-animation

Astro-animation is defined here as the integration of animation with astronomical and astrophysical concepts as both a creative practice and a participatory mode of science communication. In this thesis, astronomy functions as an umbrella term encompassing both observational astronomy and astrophysics, reflecting their interdependence in research and communication. Astro-animation engages this broader disciplinary scope while often drawing directly on specific astrophysical concepts.

Astronomy communication

In this thesis, astronomy communication refers to the public and informal communication of astronomical ideas, images and concepts with non-specialist audiences. It does not refer to specialist communication between professional astronomers. The term is used to describe public engagement, outreach, informal learning and participatory activities that make astronomy accessible through visual, embodied, creative and collaborative methods.

Lightning talk

A lightning talk is a brief, structured presentation that introduces key scientific concepts in a concise, accessible way. In this thesis, lightning talks function as an initial framing device within the Astro-animation Toolkit, providing participants with the conceptual and visual information needed to engage in the workshop activity. They may be delivered by a scientist or by a facilitator with sufficient scientific knowledge to communicate the material accurately and clearly. Their purpose is to establish shared understanding, orient attention and support subsequent animation-making without requiring extensive prior knowledge.

Meaning-making

Meaning-making refers to the process by which participants develop understanding through interpretation and creative action. In Astro-animation, meaning is produced through gesture, drawing, sequencing and collaborative animation-making as participants engage with scientific ideas in visual and material form.

Participants

Participants refer to the individuals and groups involved in Astro-animation activities across the research process, including creative workshops, public engagement events and evaluative studies. Depending on the research strand, participants may act as collaborators, audience members, co-creators, or evaluative contributors.

Underrepresented groups

Underrepresented groups are understood as individuals and communities who may have had limited access to astronomy communication, informal science learning, arts-integrated science activities and related role models or resources. The term refers particularly to teenagers and families engaged through community-based partnerships with libraries, schools and local organisations. This definition is informed by Science Capital, which frames participation in science as shaped by access, prior exposure, confidence, recognition and belonging.

Introduction

In the summer of 2017, I saw a total eclipse for the first time. I was in Sun Valley, Idaho, on a clear afternoon, gathered with others in a desert-like clearing beside a small lake. Families were spread out with their eclipse glasses when the light shifted. The air cooled, birds and insects fell silent and a small bite of shadow began to slide across the Sun. The crescent rapidly grew until the Sun was fully covered. For a few minutes, it was dark and still. I remember feeling the chill on my skin and how I dropped my eclipse glasses for a moment and immediately regretted it. Then, just as quickly, the light returned, the warmth came back and the birds started calling again. In the middle of that change, something unexpected occurred: strangers who moments earlier had been quietly waiting began talking to each other, sharing impressions and comparing what they had felt. It became a collective experience, both intimate and shared. The impact of that moment was powerful. It remains surprisingly present even now.

I chose astronomy because its distant, dynamic and often invisible phenomena raise questions of movement, scale and representation that are central to animation. The eclipse described above made these questions tangible: I understood the alignment of the Sun, Moon and Earth and experienced the event through changes in light and temperature and through the responses of those around me. Merleau-Ponty's statement, 'The world is not what I think, but what I live' (2012, p. lxxx), appears as the epigraph to this thesis and helps explain why the eclipse mattered to me. This experience shaped my relationship with astronomy as something that could be felt and shared as well as understood scientifically. It also informed my interest in using animation to represent distant astronomical processes through movement and visual sequence.

Astronomical processes such as orbital motion, stellar evolution and solar activity unfold across distances and timescales that cannot be observed continuously at a human scale. Our understanding of them remains open to revision as new evidence becomes available. Images, diagrams and models give these processes visual form, while gestures can communicate movements and spatial relationships that cannot be observed directly or from a single viewpoint (Azevedo and Mann, 2018; Gaudreau et al., 2020). Animation can slow down,

accelerate, repeat or enlarge representations of these phenomena and translate graphic and gestural forms into visual sequences. These characteristics make astronomy a productive context for exploring scientific ideas through movement, gesture and animation.

I was also drawn to astronomy because people often encounter its distant phenomena through images produced from scientific data. These images are shaped by decisions about colour, scale and processing. This mediation is examined further in Chapter 1, in the section 'From Projection to Mediated Astronomical Imaging'. Arcand et al. (2013) explain how colour can organise information collected at wavelengths that the human eye cannot see, while Smith et al. (2011) show that visual and explanatory choices influence how non-experts interpret astronomical images. Artistic practice explores this mediation in different ways. Charles and Ray Eames's film Powers of Ten (1977) guides audiences through changes of scale, while Semiconductor's Brilliant Noise (2006) retains the grain, particles and instrument artefacts involved in producing images of the Sun.

Astronomy can inspire wonder and invite people to engage with science outside formal education, including those who may not initially feel that astronomy is relevant or accessible to them (Pompea and Russo, 2020). Astro-animation brings these visual and participatory possibilities together through collaborative making, inviting participants to explore scientific ideas through their own images and movements. Astronomy therefore provides both the subject of the workshops and a context for exploring how scientific grounding, creative interpretation and collaborative participation work together.

Astronomy is also encountered through culturally specific narratives and knowledge systems that connect celestial observation with memory, identity, place and social meaning. In Western and Central Desert Aboriginal traditions, the Seven Sisters Tjukurrpa follows ancestral women pursued across Country by a male ancestral being; the narrative is carried through interconnected songlines, places, performance and visual art (Neale, 2017). In Māori knowledge, Matariki, the Pleiades, is associated with the Māori new year, remembrance, environmental cycles, food production, wellbeing and navigation, although accounts and the number and names of the stars vary among iwi (Mātāmua, 2017). Contemporary initiatives such as the *Shared Sky* project have brought Indigenous artistic knowledge into dialogue with

astronomical science (Square Kilometre Array Observatory, 2024). Scholarship surrounding the SKA nevertheless demonstrates that such engagement also involves questions of land, representation, local participation and cultural authority (Walker, Chinigò and Dubow, 2019). These examples show that astronomy communication is culturally situated and that participatory approaches must consider whose knowledge is represented and how.

Historically, visual and material technologies have shaped how celestial phenomena are observed, modelled and communicated. Devices such as the camera obscura, telescope, magic lantern, orrery and planetarium translated distant or abstract phenomena into observable, projected, mechanical, or immersive forms. These technologies shaped how audiences encountered the universe through image, motion, scale and shared viewing. This history matters for Astro-animation because it shows that astronomy communication has long involved mediation, interpretation and visual construction.

Art can provide additional ways of engaging with cosmic phenomena. Works such as *Dark Matter Garden* (Miller et al., 2015) and *HALO* by Semiconductor (2018) translate astrophysical concepts into sensory encounters. Institutional initiatives, including CERN's Arts at CERN programme, support collaboration between artists and scientists, while exhibitions such as *Dark Matter: 95% of the Universe is Missing* invite interpretive engagement with scientific themes. Accessibility-focused projects further broaden public engagement, particularly for blind and visually impaired audiences. *The Tactile Universe* (2020) produces 3D-printed astronomical models and *Touching the Stars* uses NASA data to support multisensory exploration of astronomical structures (Arcand et al., 2019).

Despite these developments, existing approaches rarely bring together astronomy visualisation, animation practice and participatory public engagement as an integrated method. CGI simulations, planetarium environments and scientific animations often support clarity, immersion and visual comprehension, but are usually presented as completed outputs. Citizen science initiatives enable public contribution, but participation is often structured around observation, classification, or data interaction rather than creative interpretation. Art–science installations can foster affective and sensory engagement, but they are frequently designed as curated experiences in which audiences encounter rather than produce the work. As a result,

there remains limited provision for approaches that allow participants to explore astronomical ideas through gesture, metaphor, drawing, sequencing and collaborative animation-making. This thesis addresses that gap through the development of Astro-animation. It positions animation as a practice-based, participatory method through which astronomical understanding can be explored, interpreted and produced. Astro-animation foregrounds creative making as a mode of inquiry and communication.

My work as a Professor of Animation at the Maryland Institute College of Art (MICA) in Baltimore has focused on developing Astro-animation as a form of participatory astronomy communication. Since 2014, I have co-led an Astro-animation course at MICA in collaboration with Dr Robin Corbet from NASA Goddard Space Flight Center and the University of Maryland, in which students produce scientifically informed animations for public communication settings. Films produced through the course have been presented at science and STEAM events, including NASA Goddard's International Observe the Moon Night. The course has received support from the National Endowment for the Arts and has been evaluated for art–science integration, with findings published in *Leonardo* (Arcadias and Corbet, 2022). Selected films are available at astroanimation.org.

This course provided an important foundation for the doctoral research, but the PhD extends Astro-animation beyond the college classroom. Living and teaching in Baltimore has heightened my awareness of wider educational disparities, including uneven access to science- and arts-related learning opportunities. Reporting in Maryland identifies continuing inequities in access, participation and provision across districts and disciplines, including uneven availability of media arts and other arts opportunities (Maryland State Department of Education, 2023; Arts Education in Maryland Schools, 2024). These disparities matter because arts-integrated science activities often depend on access to specialist teachers, equipment, enrichment programmes, museum partnerships, transport and informal learning networks. Young people with fewer opportunities to encounter science through creative, hands-on and culturally responsive activities may be less likely to see astronomy as accessible, relevant, or connected to their own forms of expression (Archer et al., 2015; Moote et al., 2020).

In my work with students, scientists and community groups, I observed that gesture, metaphor and collaborative animation-making could open new ways of engaging with astrophysical ideas, particularly for participants with limited prior confidence in science. I also recognised that these processes had developed intuitively and had not yet been clearly theorised or systematically evaluated. Science Capital helps frame this concern by showing how scientific knowledge, experiences, role models, resources and a sense of belonging shape whether young people see science as "for me" (Archer et al., 2015). This led to the central enquiry of the PhD: how might Astro-animation be developed as a participatory, gesture-informed approach to astronomy communication?

Astro-animation responds to these concerns through collaborative making. This focus also reflects the research's practice-based methodology. As an animator and educator, I investigate astronomy communication through creative practice itself. Astro-animation is approached here as an analogue, hand-drawn process that is later digitised through scanning and sequencing. The animated films, participatory workshops and Astro-animation Toolkit function as research methods, creative outputs and public-engagement tools through which the research question is explored.

Research question

The research is guided by the following question:

> *How can participatory Astro-animation, drawing on gesture, metaphor and collaborative animation-making, engage teenagers and participants from underrepresented groups in astronomy communication?*

Research aims

To address this question, the thesis pursues three aims:

1. To examine how scientists' gestures and metaphors inform the design of Astro-animation and to analyse their cognitive and communicative roles in explaining astrophysical concepts.

2. To investigate how animation-making supports understanding, curiosity and emotional engagement in informal learning environments.
3. To develop a methodological framework integrating artistic practice, qualitative analysis and public engagement within an interdisciplinary model.

Methodology

Using a practice-based methodology (Candy and Edmonds, 2018), the research combines creative inquiry with qualitative methods to develop a model for inclusive informal astronomy communication. Science Capital (Archer et al., 2015; Moote et al., 2020) informs the study's approach to informal learning, access and underrepresentation by framing participation in terms of confidence, recognition and opportunity.

The research adopts a mixed-methods design that integrates creative practice with interviews, surveys, observation and reflexive thematic analysis. This enables the study to examine both the development of Astro-animation and participants' responses across different settings. It is organised into three interlinked strands. Strand 1 develops Astro-animation through collaboration with NASA scientists, culminating in the film *The Movements of the Universe*. Strand 2 translates these principles into a structured Astro-animation Toolkit, developed with scientists and artists. Strand 3 implements and evaluates the Toolkit in schools, libraries and festivals, with particular attention to teenage engagement. Across all three strands, animation-making functions as a method of investigation, a mode of analysis and a form of public engagement.

Thesis structure

The thesis is presented in two interdependent volumes. Volume 1 contains the written thesis. Volume 2 is an online digital portfolio including films, the Astro-animation Toolkit, workshop materials and visual documentation. It can be accessed using the QR code or URL below. The two volumes connect the written analysis, creative outputs and participatory practices developed through the research.



Scan the QR code to access the online digital portfolio

or visit https://arcadiasphd.com

Volume 1 is organised into an Introduction and six chapters. The Introduction establishes the personal, philosophical and contextual foundations of the study. Chapter 1 situates Astro-animation within its historical, theoretical and participatory contexts, tracing a lineage from early optical devices and projection systems to contemporary scientific visualisation and art–science practice. Chapter 2 outlines the research design and methodological framework. Chapters 3 to 5 examine each strand in depth: Chapter 3 documents the creative process behind *The Movements of the Universe*; Chapter 4 traces the development of the Astro-animation Toolkit through iterative testing and feedback; and Chapter 5 evaluates its implementation in community settings through surveys, interviews, observation and thematic analysis. Chapter 6 synthesises the findings, discusses the contribution to knowledge, implications, limitations and future research and concludes by reflecting on the broader significance of Astro-animation within creative, educational and public engagement contexts.

Chapter 1: Astro-animation in Context: Visualisation, Animation and Participatory Engagement

Chapter 1 examines the historical, visual and participatory contexts from which Astro-animation emerges. It traces how celestial phenomena have been mediated through optical devices, projection systems, scientific imaging and animation. It then considers animation's affordances for representing motion, transformation, gesture and affect, before identifying the gap to which Astro-animation responds: a participatory model that shifts the emphasis from viewing to making.

1.1. Historical Roots of Astro-animation

The desire to make the universe visible long predates digital visualisation. Early astronomical and optical tools relied on movement, projection and sequential images to observe celestial phenomena. The camera obscura, used by astronomers and artists alike, directed light into a moving image, while the magic lantern transformed painted slides into illuminated motion through dissolves, overlays and storytelling sequences (Dupré, 2008). These devices presented celestial events as processes that could be understood through the organisation of light over time.

Astronomical instruments likewise embodied animative principles. The orrery, a mechanical model of the solar system, used interlocking gears to choreograph planetary motion, enabling viewers to observe gravitational relationships as synchronised, time-based movement (see Figure 1.1). In doing so, it translated cosmic dynamics into an embodied mechanical simulation and foregrounded motion as a mode of understanding.

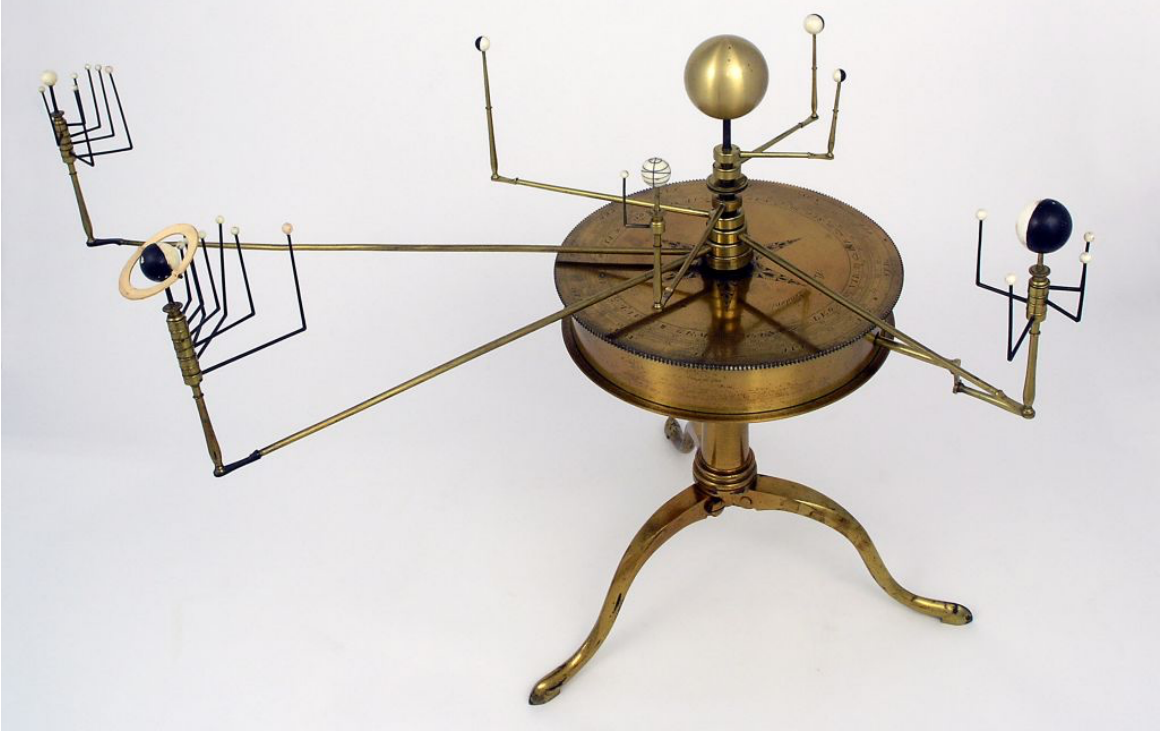


Figure 1.1: Orrery – mechanical model of the solar system demonstrating planetary motion through geared rotation. Photograph: Craig McHugh, Birmingham Museums Trust / Thinktank Birmingham. Licensed under CC BY-SA 4.0 via Wikimedia Commons. Cropped from the original.

Sequential observation further supported early forms of animated thinking. Galileo's sunspot sketches (1612) traced solar rotation over days and weeks, while Janssen's photographic revolver (1874) and Marey's chronophotographic rifle (1882) captured change across time, shaping both scientific method and later visual aesthetics (Mannoni, 2000). In the twentieth century, Zeiss mechanical planetariums (from 1923) animated the heavens across domed ceilings, while scientific films, from Max Fleischer's The Einstein Theory of Relativity (1923) to James Blinn's NASA visualisations, extended astronomical depiction into cinematic and later digital forms. Contemporary practices such as NASA's Scientific Visualization Studio and the James Webb Space Telescope (JWST) image-processing pipeline continue this trajectory, translating invisible wavelengths and abstract datasets into legible moving images.

While many of these systems present communication as one-way delivery, limiting opportunities for shared or participatory meaning-making, analogue animation techniques such as hand-drawn, stop-motion and cut-out practices encourage tactile engagement and

experimentation. Their iterative methods position participants as makers, allowing them to explore cosmic concepts through motion and abstraction.

By placing Astro-animation within this lineage, from camera obscura and chronophotography to planetariums, CGI and animation, this chapter argues that astronomy and animation share a foundational concern: both seek to understand the universe by bringing ideas into motion. Tracing this history reveals a continuum from observational instruments to participatory practices and highlights the importance of motion, mediation and participation for the development of Astro-animation.

1.1.1. Early Optical Devices and Sequential Motion

Some of the earliest attempts to make the cosmos visible emerged through optical experimentation. Among these, the camera obscura, a darkened chamber that projects an inverted image through a pinhole or lens, played a fundamental role. Known as early as the fourth century BCE, its principles were later refined by Leonardo da Vinci, who compared the device to the human eye and by Johannes Kepler, who adapted it for safe solar eclipse observation using a portable tent-like setup (Karanjia and Sadun, 2016; see Figure 1.2).

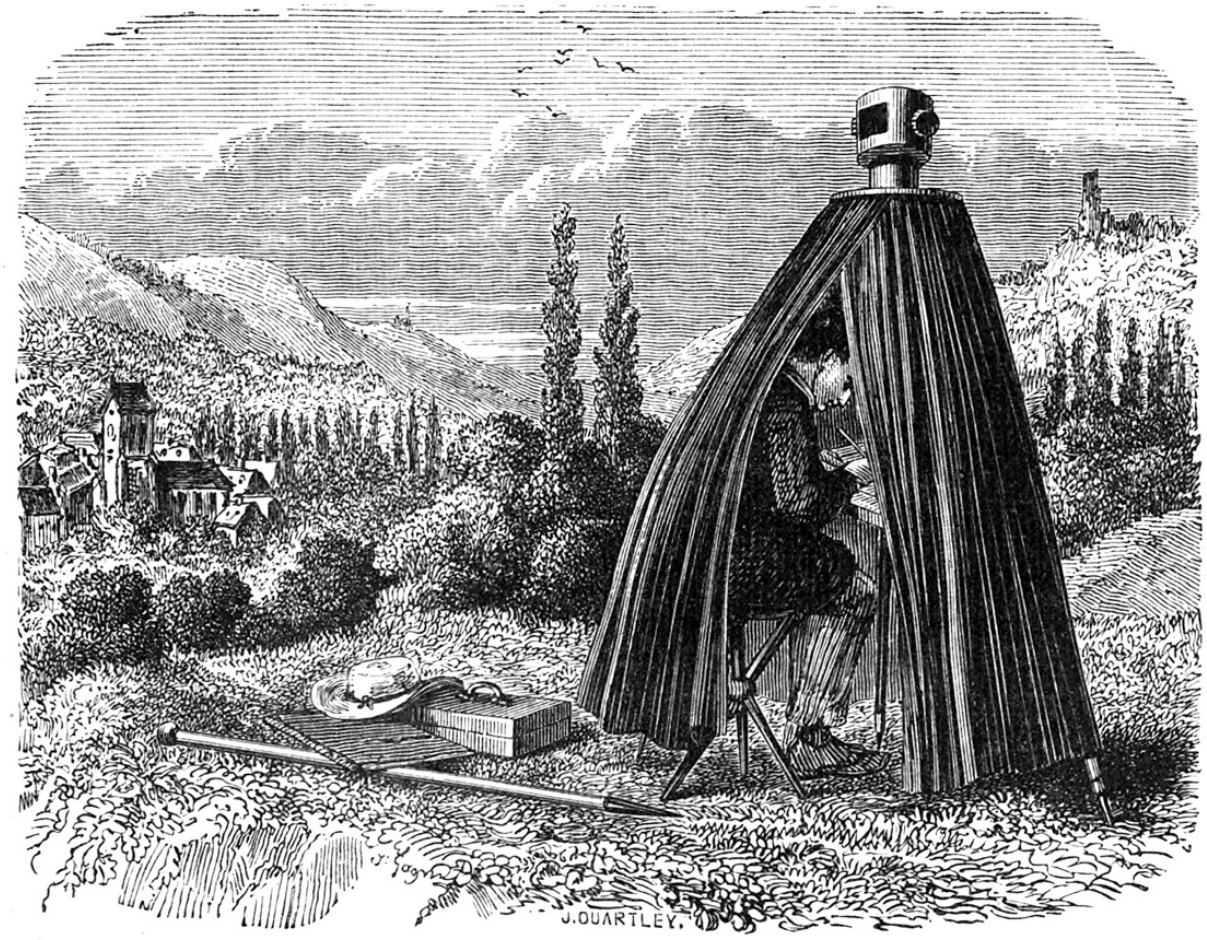


Figure 1.2: Portable tent-style camera obscura. From Adolphe Ganot, Cours de Physique (1858), engraving by Gagniet and Quarteley. Public domain image, via Wikimedia Commons.

By enabling accurate and safe observation of solar events, the camera obscura became an essential tool for early astronomers. Its underlying logic, transforming light into an image through controlled projection, informed later devices such as the magic lantern and continues to shape astronomical instruments that translate otherwise invisible wavelengths into perceptible form (Dupré, 2008; Park et al., 2008).

This principle of understanding motion through sequences of images is evident in Galileo Galilei's Istoria e Dimostrazioni Intorno alle Macchie Solari (1613). Over forty-two days in 1612, Galileo made thirty-six drawings of sunspots, each recording subtle changes in position and shape across the solar disc. When viewed in sequence, these drawings show the gradual

movement of the spots and, by extension, the rotation of the Sun, as later studies have demonstrated (Noyes, 2016; Molaro, 2013). More recently, Lee, Park and Moon (2021) used deep learning to generate modern satellite-style data from Galileo's 1612 sunspot drawings, showing how historical sequential observations can be reinterpreted through contemporary computational methods. Motion becomes observable not through a single image, but through the accumulation and transformation of systematic observations over time (see Figure 1.3).

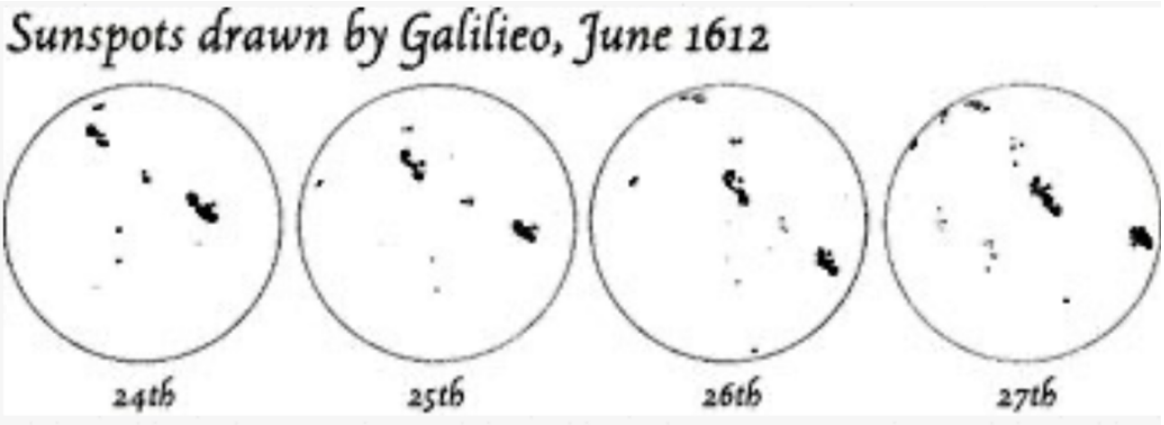


Figure 1.3: Galileo's sequential drawings of sunspots observed on 24–27 June 1612. These sketches record shifts in position across the solar disc and contributed to early recognition of solar rotation. Public domain image, adapted from Galilei, Istoria e Dimostrazioni Intorno alle Macchie Solari (1613).

Jules Janssen extended sequential observation through his photographic revolver, developed to record the 1874 transit of Venus (Canales, 2002; see Figure 1.4). Although the instrument did not ultimately produce images of lasting scientific value, it represented an important step in the development of time-based astronomical imaging. Étienne-Jules Marey later formalised this method through chronophotography, overlaying successive phases of motion onto a single photographic plate to analyse change with greater precision (Marey, 1894). As Braun (1992) demonstrates, Marey's work reframed movement as a sequence of measurable intervals, transforming motion into an object of scientific analysis.

Marey's movement studies soon migrated into artistic practice. Giacomo Balla's Dynamism of a Dog on a Leash (1912) reinterpreted sequential motion as a rhythmic visual pattern. These developments established a dialogue between measurement and metamorphosis that continues to inform scientific visualisation and animation.

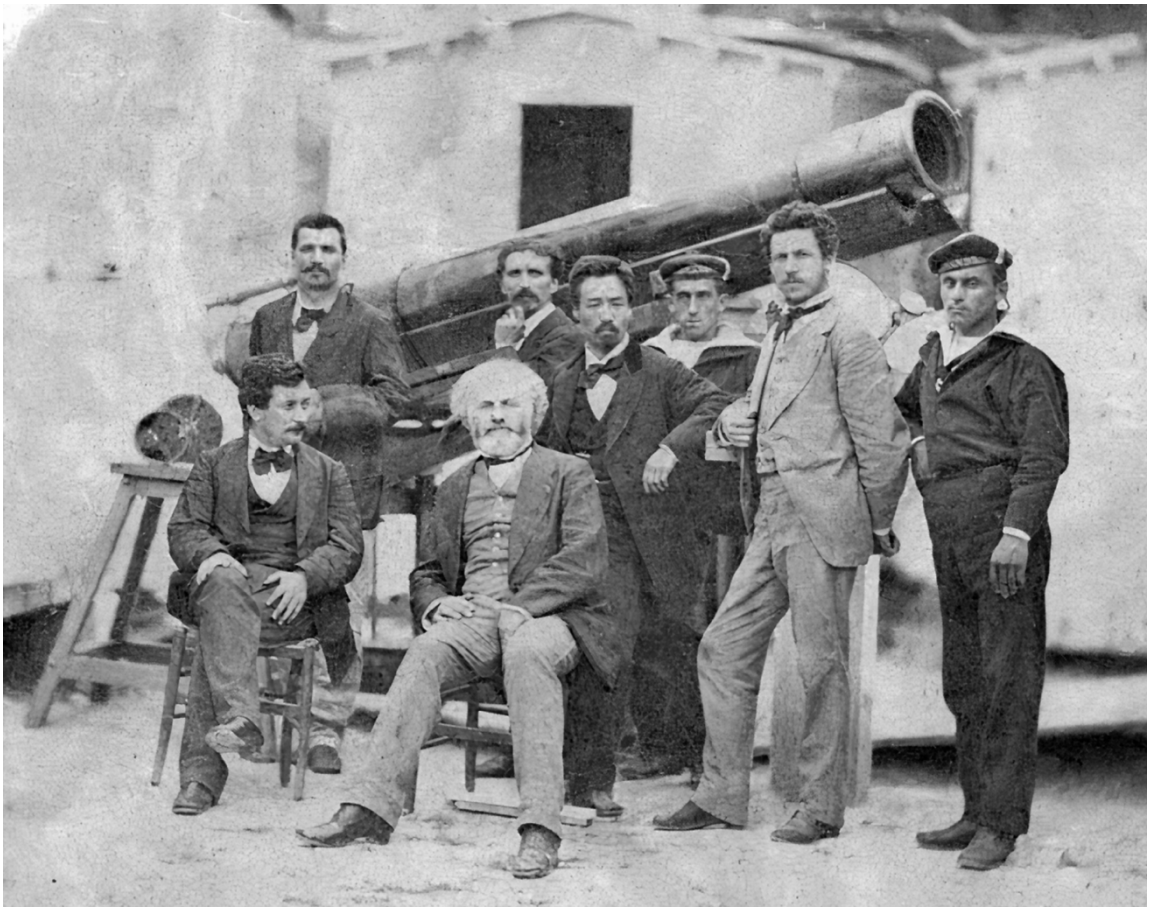


Figure 1.4: Jules Janssen with members of the 1874 Transit-of-Venus commission, Paris, 1874. Public domain; via Wikimedia Commons.

While Marey concentrated on terrestrial motion, particularly human and animal locomotion, his techniques influenced broader scientific methods. Astronomers studying solar activity, meteor trajectories and cometary motion adopted related sequential approaches to analyse change over time. The technical principles behind Marey's instruments also contributed to scientific cinematography and time-lapse imaging, a tradition that persists in modern astronomical visualisations from missions such as the Solar and Heliospheric Observatory (SOHO), the Solar Dynamics Observatory (SDO) and the James Webb Space Telescope (JWST) (see Figure 1.5).

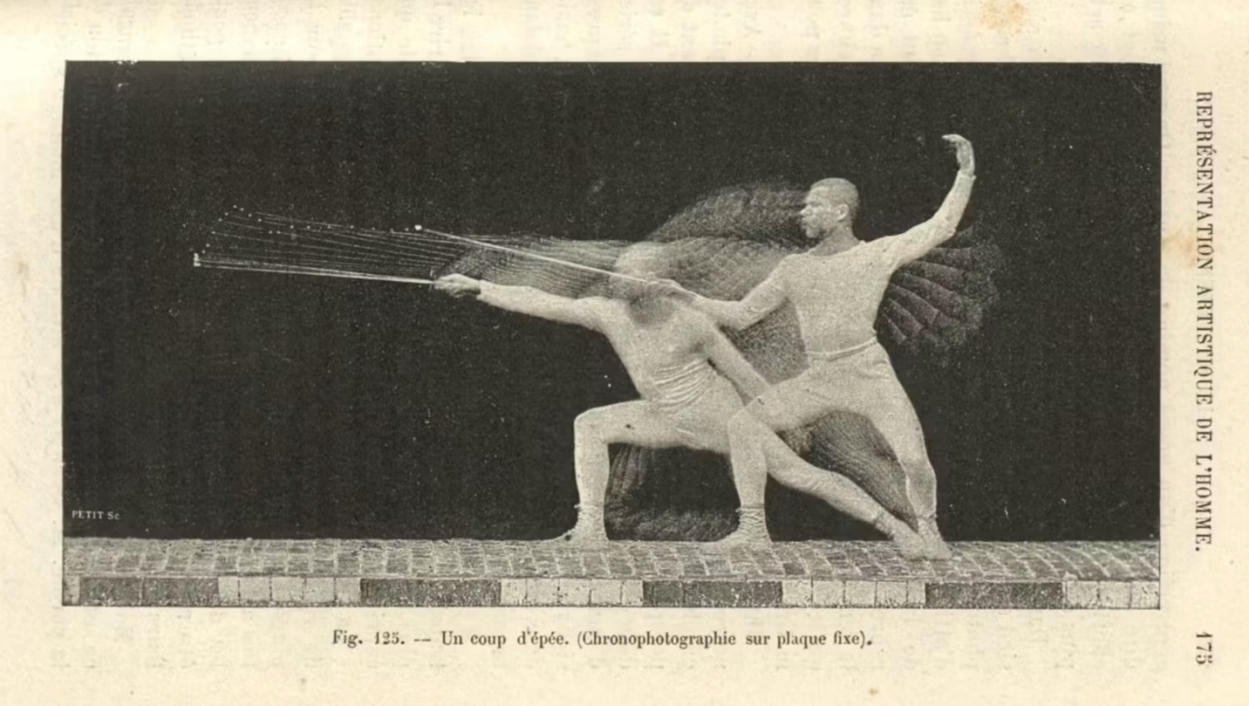


Figure 1.5: Étienne-Jules Marey, chronophotographic study of a fencing lunge (Un coup d'épée), c. 1890. From La Méthode graphique (Paris: G. Masson). Public domain.

The experiments of Janssen and Marey established sequential observation as a way of seeing in which time becomes visible. Astronomy adopted this principle in the early twentieth century when Clyde Tombaugh detected Pluto using a blink comparator and it continues to do so in the twenty-first century, when NASA creates time-based sequences from still images, including the New Horizons flybys of Pluto (Stern et al., 2015). In both cases, meaning emerges through comparison over time, allowing motion to be inferred from incremental change.

This visual logic reappears in my Astro-animation *Strange News from Pluto* (2024), a participatory Astro-animation film developed through workshops with diverse participant groups. Motion emerges through collective drawing and sequencing, constructed from discrete, hand-drawn variations. The film echoes historical practices of sequential astronomical observation while reframing them as embodied processes of meaning-making. Scan QR code (Figure 1.6) to watch the film.



Figure 1.6: QR code linking to the workshop film Strange News from Pluto (2024).

1.1.2. Projection, Simulation and Public Interactions with Astronomy

Projection-based forms of astronomical display shaped how observation was organised and experienced. Jonathan Crary's concept of historically produced 'techniques of the observer ' frames vision as a situated activity shaped by material and cultural conditions (Crary, 1990). Applied to astronomical visualisation, this perspective highlights how devices such as the magic lantern and planetarium structured viewing positions, temporal rhythms and interpretive expectations. Astronomical images were therefore shaped by the instruments, processing methods and viewing contexts through which they were produced and interpreted.

As projection technologies evolved, astronomy expanded beyond observatories into shared public venues. In the eighteenth and nineteenth centuries, the magic lantern enabled the projection of astronomical images to audiences without direct access to telescopes. Lantern lectures combined optical demonstrations with visual explanation, showing planetary movement, lunar phases and eclipses through hand-painted glass slides designed for collective viewing.

Works such as Philip Carpenter's *Compendium of Astronomy* (1825) exemplify this method. The accompanying slides depicted planetary systems and celestial mechanics with meticulous attention to colour and detail, balancing instructional clarity with visual appeal. Projection served as an educational tool that sustained public interest and curiosity in astronomy (see

Figures 1.7–1.8). These images informed viewers while also stimulating imagination through vivid colour and careful artistry.



Figure 1.7: Magic lantern astronomy slides from A Compendium of Astronomy by Philip Carpenter (1825). Hand-painted glass slides depicting planetary systems and lunar phases. Public domain image, courtesy of the Science Museum Group Collection.

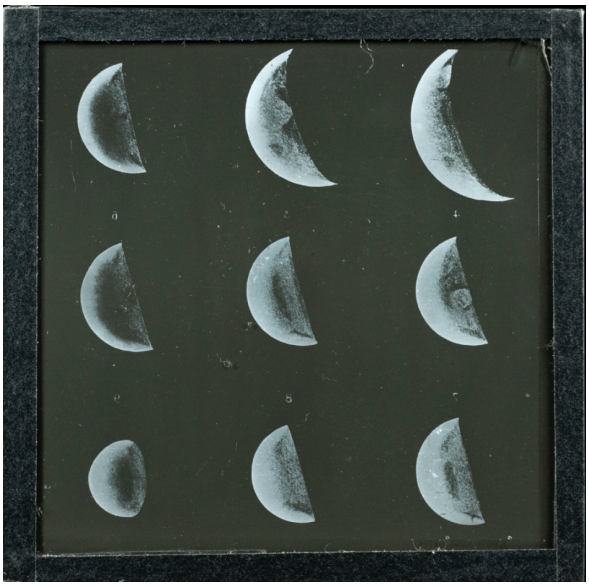


Figure 1.8: Nineteenth-century magic lantern slide depicting the phases of the Moon, widely used in astronomy lectures and classrooms. Public domain image, courtesy of the Science Museum Group Collection.

Earlier projection devices anticipated aspects of this logic. Eighteenth-century magic lantern and solar microscope demonstrations projected microscopic specimens at enlarged scale, transforming observation into shared visual experience. Movement, projection and magnification rendered otherwise unseen phenomena visible and situated scientific knowledge within collective viewing practices (Mannoni, 2000; see Figure 1.9). Devices such as the solar microscope presented scientific observation as a public and embodied activity, foregrounding projection and scale as central to meaning-making.

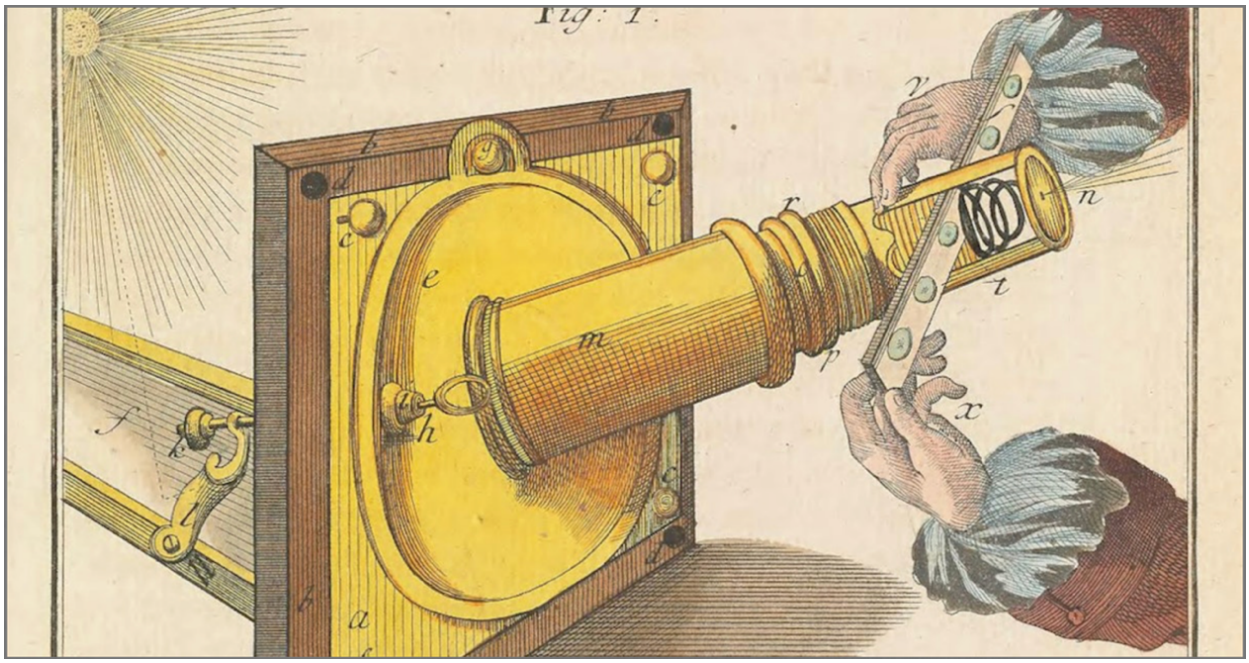


Figure 1.9: Solar microscope optical demonstration (1764–68), from Martin Frobenius Ledermüller's Mikroskopische Gemüths- und Augen-Ergötzung (Microscopic Delights of the Mind and Eyes). Public domain.

Technological advancements further expanded the scope of lantern shows. The introduction of limelight, produced by heating quicklime in an oxygen–hydrogen flame, created brighter illumination, allowing projection in larger venues. Lantern shows shifted from relatively intimate demonstrations to mass public events, with lectures attracting hundreds of spectators (Baugh, 2022; Wynants, 2020; see Figure 1.10). Astronomy became a shared cultural experience, combining scientific explanation with visual spectacle.

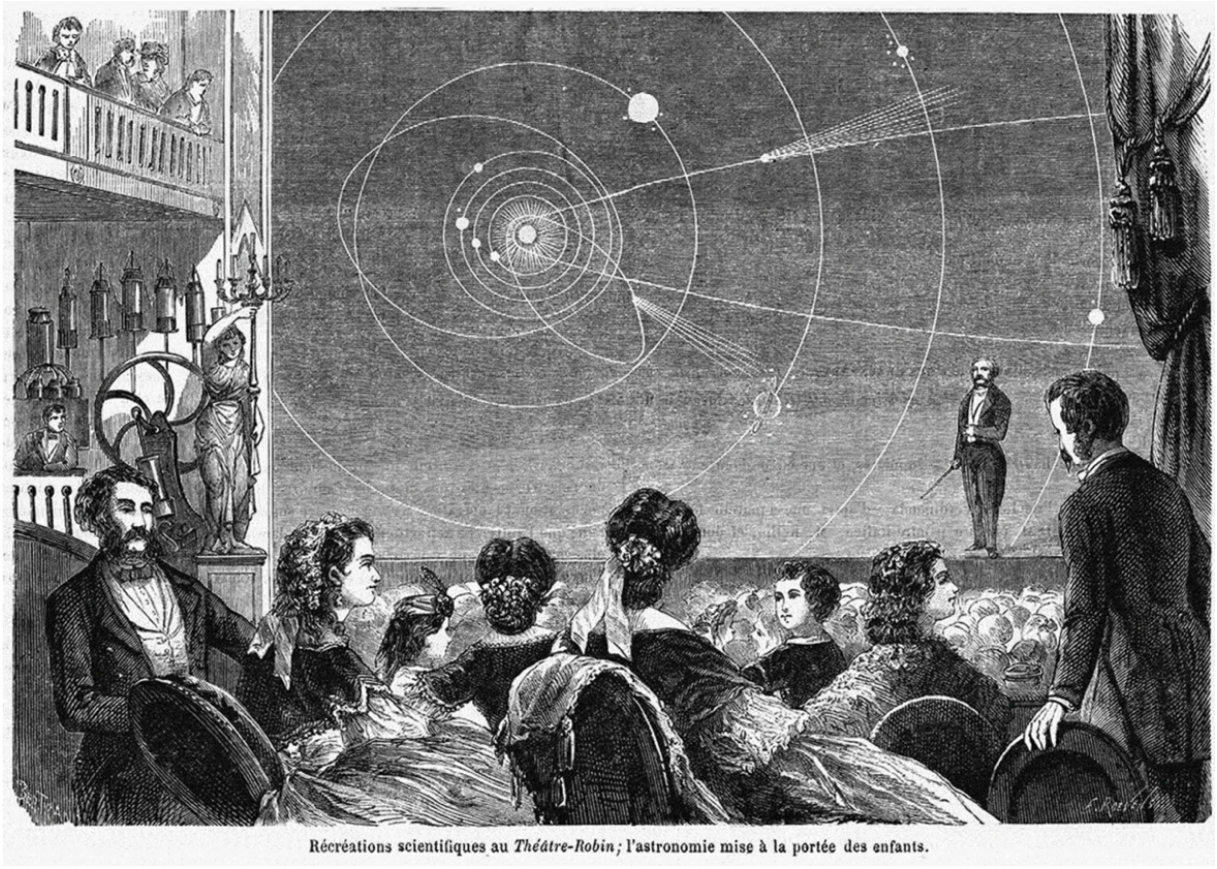


Figure 1.10: Récréations scientifiques au Théâtre-Robin: l'astronomie mise à la portée des enfants. Wood engraving, Le Monde illustré, 20 August 1864. Public-domain image via Gallica, Bibliothèque nationale de France.

By the early twentieth century, projection technologies had evolved into immersive systems that transformed public engagement with astronomy. The Zeiss planetarium projector, first showcased in Jena in 1923 and subsequently installed in cities such as Munich and Chicago, signalled a shift in astronomical representation (Petersen, 2003). Unlike lantern slides, these mechanical-optical devices projected precise star fields onto domed ceilings, allowing audiences to experience celestial motion as a continuous spatial phenomenon (see Figure 1.11).

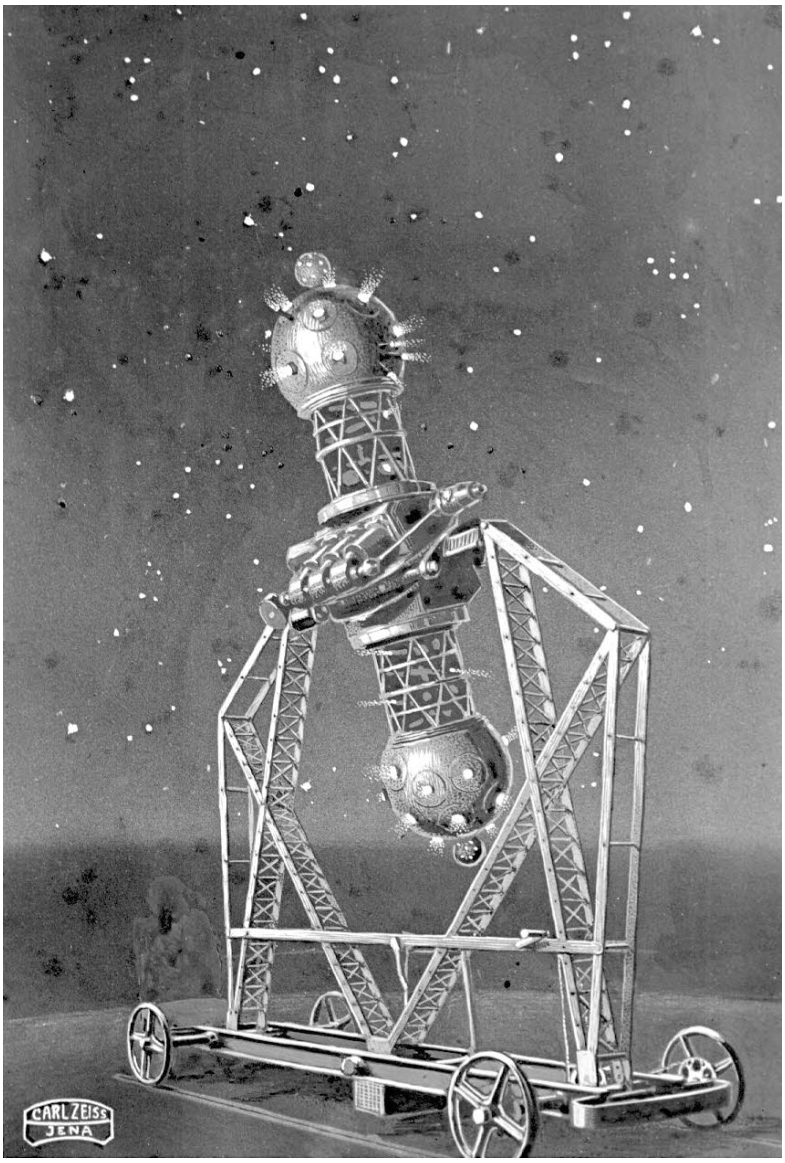


Figure 1.11: Zeiss Mark II planetarium projector (1926), Carl Zeiss, Jena.
Image courtesy of ZEISS Archive. Used with permission.

Planetariums introduced a new model of public education focused on immersion and spatial awareness (Petersen, 2003). With the development of digital fulldome projection, hemispherical domes could combine computer-generated animation, narration and astronomical visualisation to support the presentation of complex three-dimensional relationships (Lantz, 2011; Yu et al., 2015). While these environments fostered a strong sense of presence within the cosmos, communication largely remained one-directional. Audiences

observed simulated celestial movement but did not participate in its creation or interpretation. This spectatorial model shaped twentieth-century astronomy education and continues to influence contemporary projection systems. It also points to a key question for this thesis: what forms of representation might move beyond observation and enable more active, interpretive engagement with astronomical phenomena?

1.1.3. From Projection to Mediated Astronomical Imaging

The logic of projection extends beyond public display technologies into the broader history of astronomical imaging. Celestial phenomena are not simply observed but made visible through visual systems that organise scale, orientation and temporal flow. In this sense, astronomical vision is constructed through techniques that shape how phenomena are rendered perceptible and intelligible.

The camera obscura demonstrated how light could be directed and transformed into images, establishing a conceptual foundation for increasingly sophisticated optical instruments (Dupré, 2008). As observation extended beyond visible light, new constraints emerged. Higher-energy wavelengths such as X-rays cannot be focused by conventional optics and most non-visible radiation is absorbed by Earth's atmosphere. To address these constraints, scientists developed alternative techniques, including grazing-incidence multilayer optics for high-energy X-ray imaging (Craig et al., 2000; see Figure 1.12).

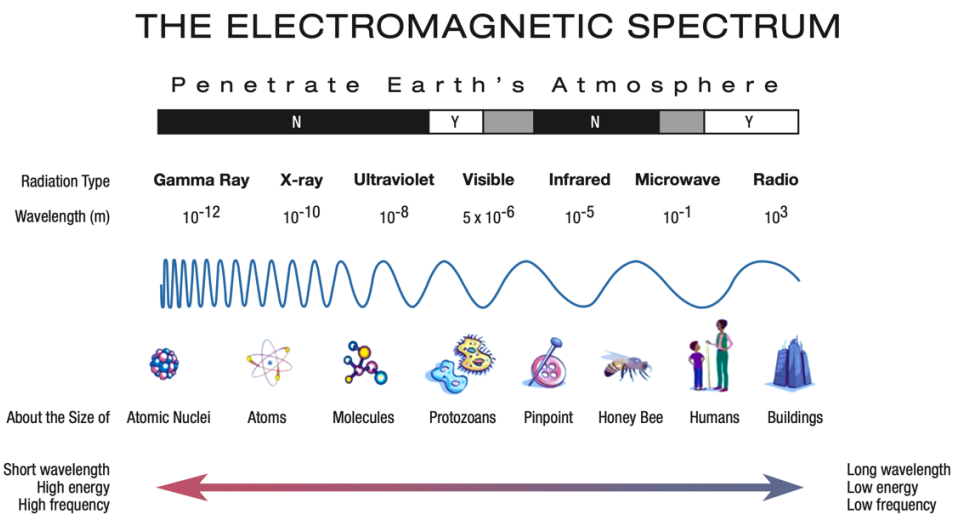


Figure 1.12: The electromagnetic spectrum, showing atmospheric transparency and relative wavelengths. Image Credit: NASA/ Center for Astrophysics | Harvard & Smithsonian (n.d.). Public domain.

These developments signal a shift from optical projection to computational inference. Contemporary astronomical images often combine data from multiple instruments, locations and timescales. The Event Horizon Telescope exemplifies this approach. Operating as a distributed global network using very-long-baseline interferometry, it produced the first image of the black hole M87* in 2019, followed by Sagittarius A* in 2022 (EHT Collaboration, 2019; 2022; see Figure 1.13).

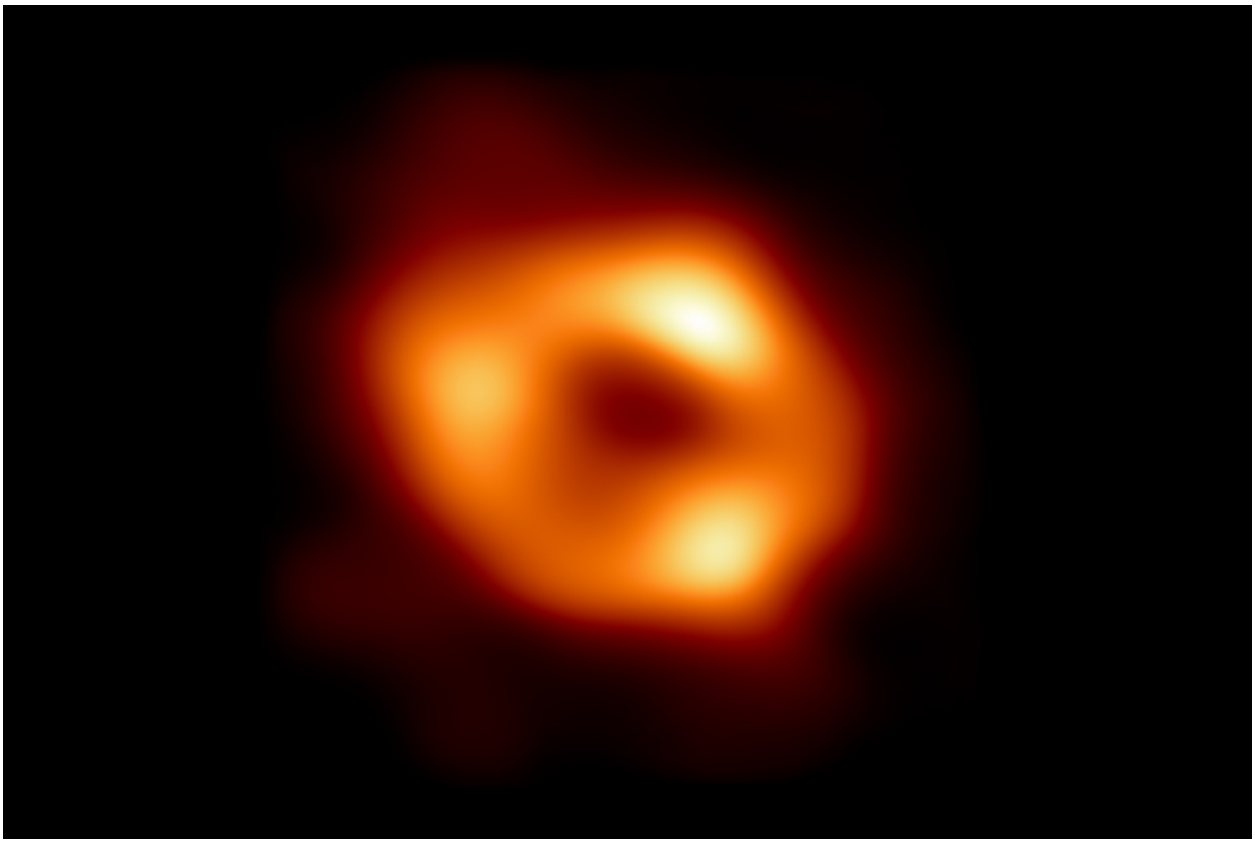


Figure 1.13: First image of Sagittarius A, the supermassive black hole at the centre of the Milky Way (2022). Event Horizon Telescope Collaboration. Licensed under Creative Commons CC BY-ND 4.0.*

Such images translate patterns derived from radio signals and statistical reconstruction into visible form. False-colour techniques assign visible hues to non-visible wavelengths in order to emphasise structure and contrast, as seen in images from the Hubble and James Webb Space Telescopes (Hurt et al., 2019). Three-dimensional reconstructions extend this process by inferring depth and spatial relationships from two-dimensional observational data. Astronomical visualisation therefore involves interpretive transformation as well as measurement. Data are rendered intelligible through choices of colour, scale, orientation and temporal aggregation. This mediation reflects the need to represent phenomena beyond direct human perception (Kessler, 2012; Hurt et al., 2019).

By placing Astro-animation within this lineage, from camera obscura and chronophotography to planetariums, CGI and contemporary astronomical imaging, this chapter argues that astronomy and animation share a foundational concern: both seek to understand

phenomena by bringing ideas into motion. Tracing this history reveals a continuum from observational instruments to mediated visualisation and, ultimately, to participatory practice. This establishes the importance of motion, mediation and interpretation for the development of Astro-animation. The next section turns more directly to animation, examining its affordances for representing astronomical phenomena through movement, transformation, gesture, affect and collaborative meaning-making.

1.2. Affordances of Animation for Astronomical Representation and Engagement

This understanding of astronomical vision as mediated helps clarify the relevance of animation. Like astronomical imaging, animation builds visibility through choices of form, order, movement and change. Drawing on Gibson's (1979) concept of affordances, understood here as the possibilities for action offered by a medium, this section examines what animation makes possible in relation to astronomical representation and engagement. Buchan (2013) positions animation as a pervasive cultural and visual form whose operations extend beyond entertainment into scientific, educational and experimental contexts. In astronomy communication, this makes animation especially useful for rendering change, transformation and relational movement perceptible through sequence and timing. Animation can therefore support embodied and interpretive forms of understanding while also opening exploratory and affective ways of engaging with astronomical phenomena (Wells, 1998; Bissonnette, 2019).

1.2.1. Temporal Reasoning and Transformation

The affordance of transformation is particularly significant because astronomical knowledge is often produced by converting measurements, signals and abstract relationships into perceptible visual form (Hurt et al., 2019; Kessler, 2012). Hurt et al. (2019) emphasise the constructed nature of astronomical imagery, showing how choices of colour, scale, contrast and composition help translate data into forms that can be interpreted visually.

Animation provides a means of shaping these transformations through sequential change (Buchan, 2013). It enables abstract concepts to be translated into motion and perceived

as unfolding processes. This is especially important in astronomy, where many phenomena are better understood as processes rather than fixed states. Animation constructs change through sequential composition, allowing movement, duration and transformation to be designed frame by frame. At its simplest level, it organises still images into sequences that create the perception of movement. Paul Wells defines animation as 'the artificial creation of movement through the manipulation of still images', emphasising its constructed and abstract qualities in contrast to live-action representation (Wells, 1998). Bendazzi (2015) similarly characterises animation as the production of moving images through successive frames, while Furniss (1998) clarifies that animation creates movement by arranging individual frames rather than by recording motion directly. Together, these accounts underscore animation's designed temporality: its ability to slow down, exaggerate, compress, or transform time through creative choices.

Early pioneers in animation explored motion and metamorphosis as fundamental properties of the medium, using frame-by-frame transformation to visualise processes that resisted stable representation. In France, Émile Cohl developed a graphic language grounded in continuous transformation. Works such as *Fantasmagorie* (1908) and *Les Joyeux Microbes* (1909) employ continuous metamorphosis, with figures dissolving, reforming and changing shape across frames. Cohl used animation to present form in a state of ongoing change, with movement emerging through continuous transformation. This made animation especially effective for representing abstract or scientific processes that unfold over time, including those that cannot be directly observed. Change therefore became a structuring principle of animation, one later taken up in scientific and educational contexts.

Throughout the twentieth century, animation and science intersected in multiple settings. In France, microbiologist Jean Comandon used time-lapse and microcinematography to document and popularise scientific discovery, revealing botanical growth in *Naissance des plantes* (1929) and collaborating with animators on public-health films during the First World War and interwar period (Vignaux, 2009; 2011). In this broader history of what animation scholars Cook et al. (2023) describe as 'useful animation', the medium served practical and explanatory functions across fields such as science, medicine and education. In the United States, Max Fleischer extended these possibilities by applying animated transformation to

scientific explanation. In *The Einstein Theory of Relativity* (1923), simplified animated figures and schematic motion were used to visualise abstract physical concepts, including curvature, relativity and dimensional distortion. Fleischer prioritised conceptual clarity over visual realism, demonstrating how animation can externalise relationships that are difficult to convey through static diagrams or mathematical notation.

Later developments expanded animation's capacity for scientific storytelling. John and Faith Hubley combined hand-drawn animation with poetic narration in *Of Stars and Men* (1962), translating cosmological ideas into visual metaphors structured through rhythm and transformation. Across these practices, animation functioned as both an expressive medium and an investigative tool. Metamorphosis enabled the visualisation of change and emergence across time and scale, establishing animation as a mode of structured temporal representation that would later support science communication and participatory practices such as Astro-animation.

These historical and scientific applications also raise questions about how animation constructs and communicates evidence, connecting them with debates in animated documentary.

1.2.2. Astro-animation in Relation to Animated Documentary

The field of animated documentary raises an important question for Astro-animation: how can animation represent real subjects that are absent, inaccessible or difficult to record? These may include events for which no footage exists, experiences without a visible form or processes beyond the reach of a conventional camera. Through drawing, movement, sound and editing, animation constructs visual accounts of these subjects and shapes how they are understood. Honess Roe (2011; 2013) identifies three functions that animation can perform within documentary. Mimetic substitution recreates something that could not be filmed; non-mimetic substitution represents a real subject without resembling live-action footage; and evocation expresses subjective, emotional or perceptual experience. Her framework draws attention to what animation can make visible when live-action recording is unavailable or insufficient.

In astronomy, animation can be used to visualise cosmic processes, give form to data and theory and to evoke how encounters with the universe are perceived and felt. The relationship nevertheless has limits. Animated documentary often discusses evocation in relation to memory, testimony or internal experience, whereas Astro-animation begins with scientific sources and concepts. A participant's work may express a meaningful personal response, while its scientific accuracy depends on how the imagery relates to the source concept. This distinction connects to the accuracy–engagement continuum introduced later in this chapter, which considers scientific grounding and creative interpretation together. Source material, expert input, facilitation and reflection help preserve the connection between creative interpretation and the underlying science. Honess Roe's categories clarify the representational possibilities of animation, while questions of scientific grounding and public engagement require an additional framework.

Honess Roe (2016, p. 20) later calls for a more '360-degree' discussion of animated documentary. She argues that its representational possibilities should be considered alongside questions of documentary status, clarity, truthfulness, audience response and technical execution. This critical perspective helps me position Astro-animation in relation to the field and identify its distinct participatory and science-communication aims.

Samantha Moore's doctoral research offers a more direct methodological comparison. Out of Sight: Using Animation to Document Perceptual Brain States (2015) examines experiences such as prosopagnosia and phantom-limb sensation that cannot be photographed directly. Moore worked through a repeated cycle of interview, animation, participant response and revision. Acting as 'collaborative consultants', participants could correct or reshape the work so that it more closely represented their experience. The animation's credibility therefore came from a documented process of consultation rather than a photographic trace.

Participant approval can make a representation more faithful to the described experience, while the animator continues to shape it through decisions about selection, timing, style and editing. The resulting work is an interpretation agreed between participant and animator rather than a direct record. This distinction is important for Astro-animation: the

workshop films provide evidence of how participants engaged with and interpreted astronomical ideas; they do not provide evidence about the phenomena themselves.

Moore's Loop (2016), made in collaboration with Serge Mostowy's laboratory, applies this method to research on septin assembly and intracellular infection. By incorporating scientists' drawings and discussions, the film shows how metaphor, sketching and imaginative models help them conceptualise processes that remain partly unseen. This relates to Strand 1 of Astro-animation, in which scientists used gestures and spoken metaphors to describe abstract movement.

When Loop is considered as public science communication, its variety of drawings and analogies may make it difficult for a non-specialist to distinguish established knowledge from hypotheses or personal interpretations. Within its laboratory context, this plurality supports collaboration between the animator and scientists. For communication beyond that setting, however, it increases the need for framing that helps viewers understand the status of the different images and interpretations. Loop therefore provides a valuable model of collaborative scientific representation while demonstrating the importance of additional framing and opportunities for participation when working with public audiences.

As discussed in Section 1.2.1, Cook, Cowan and Curtis (2023) describe useful animation as work shaped by a practical purpose, institutional context and intended audience. Their account provides a framework for comparing Comandon and Lortac's Pour résister à la tuberculose, soyons forts (1918) with Moore's Loop (2016). Produced as part of a public-health campaign, Comandon and Lortac's film uses an allegory of a strong body resisting disease to communicate a direct message (Vignaux, 2009; 2011). Its clarity comes from presenting tuberculosis largely as an individual struggle, with limited attention to transmission or social conditions. Loop, developed within a scientific laboratory, retains uncertainty, multiple viewpoints and the evolving nature of research. Viewed through Cook, Cowan and Curtis's framework, the films demonstrate different forms of usefulness: Comandon and Lortac organise knowledge for direct public instruction, while Moore makes the collaborative development of scientific understanding visible.

Astro-animation draws on elements of both approaches. Like useful animation, it has an applied purpose: supporting astronomy communication through an adaptable workshop structure. Following Moore's approach, it also treats animation as a developing object that can be discussed and revised. The method extends this process to non-specialist audiences, who create images and contribute their own metaphors, questions and visual decisions. The completed films document these interpretations, while the Toolkit makes the workshop structure available for use in different contexts. Its usefulness lies particularly in the facilitated process through which participants explore astronomical ideas together.

Taken together, these comparisons position Astro-animation in relation to animated documentary and useful animation. Scientific visualisation provides source imagery and scientific grounding, which Astro-animation brings into a participatory process of making, discussion and reflection. The accuracy–engagement continuum introduced later in this chapter offers a way to consider how scientific grounding, metaphor and possible misconceptions operate within that process. I therefore propose Astro-animation as a participatory, practice-based method for engagement with astronomy.

1.2.3. Gesture, Metaphor and Visual Interpretation

Animation's capacity to visualise motion and transformation also connects it to embodiment, gesture and metaphor. In science communication, animation can translate abstract ideas, affective experience and perceptual reasoning into visual form. Donald Crafton's concept of 'the hand of the artist' (1979) and Henri Focillon's *Éloge de la main* (2019) foreground the hand as both an artistic and intellectual instrument, positioning making as a form of thought. In analogue animation, gesture operates as both a mode of production and a visible trace of cognition. Irregular line, texture and frame-by-frame variation can reveal the presence of the hand, making the image feel interpreted.

Because animation constructs movement and transformation over time, it can also translate gestures, metaphors and scientific ideas into animated processes (Buchan, 2013). Gesture may become a generative source for visual form, as when an expanding and contracting hand movement is developed into stellar pulsation, or a compressive gesture into the

visualisation of gravitational collapse, drawing on gesture as a mode of thought and expression (McNeill, 1992). More broadly, a hand movement may inform the direction, rhythm, or shape of motion, while a metaphor may help determine how an abstract idea is visualised, shaping the movement or structure through which it is understood (Lakoff and Johnson, 2003; Goldin-Meadow, 2003). A scientific concept may therefore be expressed through transformation, pacing and spatial change. Through this unfolding, animation can make abstract processes perceptible in visual and temporal form. The role of gesture and metaphor as cognitive and visual frameworks is developed later in Chapter 2, Section 2.3.6.

1.2.4. Experimentation, Affect and Collaborative Meaning-Making

Animation is also a constructed and interpretive medium. Meaning emerges through choices of timing, sequence, exaggeration, omission and transformation. As a time-based and revisable form, it affords exploratory engagement with ideas still in development, since forms can be tested, adjusted and reworked through iterative practice (Schön, 1983; Haseman, 2006). This allows scientific ideas to be explored through revision, play and repetition, foregrounding process, experimentation and emerging understanding. Its sequential form supports provisional thinking by allowing possibilities to remain open as movement, timing and visual relations are developed over time (Wells, 1998; Furniss, 1998). It also supports exploratory engagement by allowing participants to try out ideas without requiring immediate scientific precision, reducing the fear of error that can inhibit participation (Young et al., 2014). This can create more accessible conditions for engagement, particularly where science is associated with correctness, expertise, or the risk of failure (Cooper et al., 2018).

Animation can also communicate affect. Through rhythm, pacing, scale, metamorphosis and visual tension, it can express awe, curiosity, uncertainty, wonder, or instability in ways that are difficult to convey through static images or technical explanation alone (Bissonnette, 2014). An animated black hole sequence, for example, may use intensifying motion, visual compression and rhythmic acceleration to shape how gravitational force is both understood and felt. In this sense, animation affords affective expression alongside conceptual exploration. Finally, animation has the potential to distribute authorship across participants, especially in

workshop contexts where the work develops collaboratively. Because animated sequences can be built through multiple frames, drawings and decisions, they allow ideas to be negotiated collectively over time. In participatory contexts, these qualities may create conditions for collaborative meaning-making and, in some cases, shared authorship, as visual forms are developed through collective acts of construction and interpretation (Bishop, 2012). These participatory dimensions become more central in the later discussion of Astro-animation practice. At the same time, animation's capacity to transform, simplify and intensify scientific material raises questions about accuracy, interpretation and audience engagement.

1.3. Scientific Accuracy, Awe and Spectatorial Engagement

Animation can communicate scientific ideas clearly and vividly, but it also raises a recurring question: how much simplification is acceptable when complex concepts are translated for broader audiences? In science communication, this creates an ongoing tension between scientific accuracy and audience engagement. If an animation remains highly precise, it may be difficult for non-specialists to follow. If it becomes too simplified or stylised, it may be more engaging but risk misunderstanding or distortion. Scott Curtis (2023), a scholar of animation and media history, discusses this tension through scientists' criticisms of the *Bell System Science Series* (1956–62), whose animations were seen by some as oversimplifying atomic structures. In response to such debates, Curtis identifies four primary functions of animation: explanation, exploration, experimentation and engagement. These functions involve different degrees of abstraction and simplification. Some animations aim to explain established knowledge as clearly as possible, while others allow viewers to explore possibilities, experiment with ideas, or become emotionally and imaginatively engaged. This helps position Astro-animation within a broader field of science communication. While Astro-animation shares animation's explanatory and engaging capacities, it also places particular emphasis on participation and metaphor as part of how understanding is formed.

To situate Astro-animation within these debates, Table 1.1 presents a model developed for this thesis. Drawing on science communication literature and representative examples,

including press and public communication formats, it maps how different modes of communication balance precision, accessibility, interpretation and reach, while also tracing the point at which simplification becomes oversimplification or scientific inaccuracy. The table shows that scientific communication does not operate according to a simple division between 'accurate' and 'inaccurate.' Instead, different forms of communication negotiate these priorities in various ways, depending on the audience and purpose. A peer-reviewed scientific paper, for example, prioritises precision for specialist readers, while a press release or popular science story may simplify more in order to reach wider audiences.

Science Level	Audience	Goal	Example
Scientifically Rigorous	Technical /specialist	Absolute precision for research and academia	Peer-reviewed research paper
Scientifically Correct	Expert audience	Maintain rigour while remaining accessible to peers	Nature/Science news items
Scientifically Faithful	Informed public / science-literate readers	Communicate with minimal simplification	Scientific American
Scientifically Simplified	General audience	Accessibility with intentional simplification	Institutional press releases
Scientifically Digestible	Mass communication	Maximise reach and ease of understanding	General newspaper science stories
Scientifically Inspired	Broad public / cultural audiences	Evoke awe, wonder and imagination	Van Gogh's Starry Night; planetarium shows
Scientifically Oversimplified	Children / popular media	Entertain at the risk of misconception	Bell System Science Series (1956–62)
Scientifically Inaccurate	General / targeted	Pseudo-science or ideological distortion	Astrology; conspiracy theories

Table 1.1: Model developed for this thesis, mapping levels of scientific accuracy against modes of public engagement.

The model presented in Table 1.1 draws on multiple strands of science communication literature. Fischhoff (2013) and Curtis (2023) inform the distinctions around simplification and public engagement, while the category Scientifically Inspired is proposed here in dialogue with work on awe and imagination (Keltner and Haidt, 2003; Disberg, 2025). The category

Scientifically Inaccurate is informed by research on misinformation and distortion in public knowledge contexts (Lewandowsky et al., 2017).

This continuum is visualised in Figure 1.14, which presents a spectrum of representational strategies balancing scientific precision and accessibility according to context. The pyramid illustrates how different modes of communication negotiate the relation between precision and accessibility. From top to bottom, it shows how highly specialised forms of communication prioritise precision for narrow audiences, while broader public-facing modes become more accessible through greater simplification and abstraction. The Scientifically Inspired category occupies a transitional position, foregrounding awe and imagination while remaining grounded in scientific ideas. In astronomy, where phenomena often exceed direct human perception, this balance becomes particularly significant.

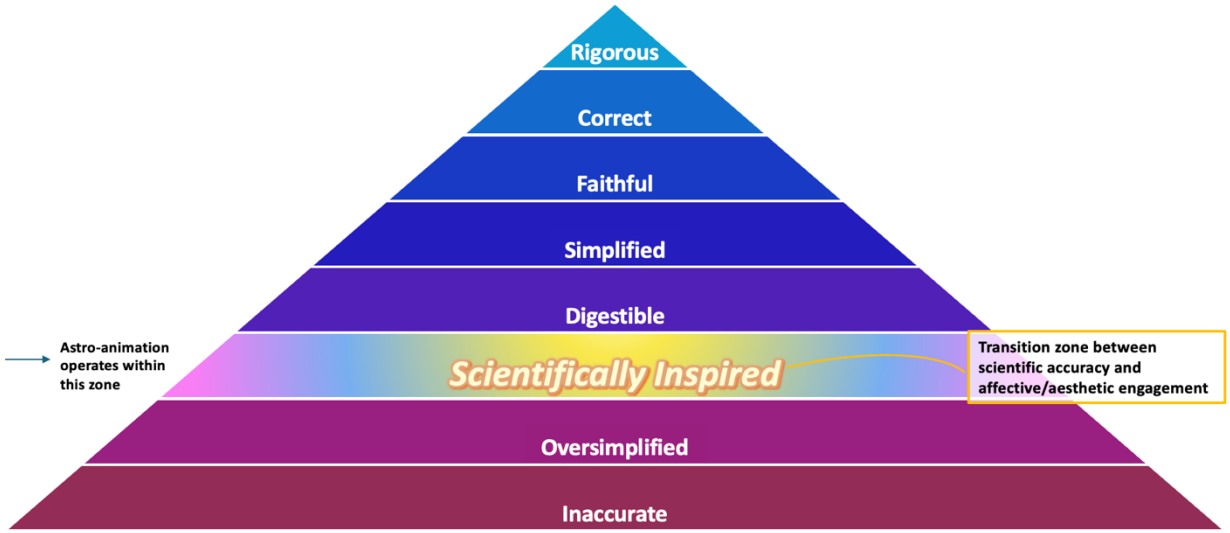


Figure 1.14: Continuum of Scientific Accuracy and Public Engagement, showing a spectrum of representational strategies balancing scientific precision and accessibility according to context.

Within this continuum, the category Scientifically Inspired is especially relevant to astronomy communication. Because many astronomical phenomena cannot be experienced directly, they are often encountered through mediated images, simulations, animations and artistic interpretations. These forms can attract attention by evoking scale, wonder and imagination. They can also open aesthetic and interpretive ways of engaging with phenomena that exceed direct human perception. Their affective power needs to be supported by

explanation, reflection, or participation so that emotional engagement can develop into conceptual understanding.

Awe arises when people encounter something so vast that it challenges their existing understanding and requires a shift in perspective (Keltner and Haidt, 2003). In astronomy communication, animations of black holes, exoplanets and cosmic evolution frequently evoke this response, which can motivate curiosity and inquiry (Valdesolo et al., 2017). However, awe does not automatically produce understanding. Highly stylised imagery can foster misconceptions or create an illusion of comprehension when affect is not accompanied by structured interpretation. As Disberg (2025) observes, astrophysical imagery often activates imagination before comprehension, underscoring the need for approaches that connect spectacle to conceptual clarity without eliminating aesthetic interpretation.

A more precise account of this engagement requires attention to affect. Affect theory has been developed across multiple disciplines, including cultural theory, feminist theory, media studies, philosophy and neuroscience, with key contributions from scholars and is synthesised in *The Affect Theory Reader* (Gregg and Seigworth, 2010). In science communication, responses to astronomical imagery often begin at a pre-reflective level, including bodily arousal, tension, or curiosity, before developing into articulated interpretation (Damasio, 1999; Immordino-Yang and Damasio, 2007).

Drawing on the work of neuroscientist Antonio Damasio (1999), affect refers to basic regulatory bodily processes that register changes in internal state. Emotions emerge as patterned physiological and expressive responses, including gesture and posture. Feelings arise when these emotional states are represented in conscious awareness and integrated with reasoning and memory. Within this framework, feeling functions as a bridge between bodily response and reflective thought, connecting perception to interpretation. Figure 1.15 visualises this model of life regulation, illustrating the progression from basic bodily processes to emotion, feeling and higher-order reasoning. These levels operate in dynamic feedback, connecting bodily regulation to conscious thought and imaginative projection.

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Figure 1.15. Levels of Life Regulation

This adapted diagram has been omitted from the publicly available thesis because permission to reproduce or adapt the original for open-access publication has not been obtained.

Source: Damasio, A.R. (1999) *The Feeling of What Happens: Body and Emotion in the Making of Consciousness*. New York: Harcourt Brace, p. 54.

Research in educational neuroscience supports this integration. Immordino-Yang and Damasio (2007) argue that emotion and cognition operate in continuous interaction, shaping reasoning, attention and learning. Understanding relies on the brain's ability to register bodily states and incorporate them into meaning-making processes. From this perspective, affect is not secondary to learning but one of its conditions.

In astronomy communication, these dynamics are particularly apparent. Celestial phenomena often exceed everyday perceptual scales, requiring mediation through imagery,

metaphor and narrative. Initial affective responses, such as awe or curiosity, can direct attention and motivate inquiry, but they do not in themselves constitute understanding. Conceptual development depends on forms of practice that translate bodily responses into structured interpretation.

This dynamic is visible in two contrasting representations involving Kip Thorne, the theoretical physicist and 2017 Nobel Prize recipient whose work bridges gravitational physics, visualisation and public communication. While *Interstellar*(2014), for which Thorne served as science consultant, renders relativistic phenomena through immersive cinematic visualisation, *The Warped Side of Our Universe* (2023), developed by Thorne and Lia Halloran, adopts a more openly artistic and interpretive mode that balances scientific rigour with aesthetic expression (see Figure 1.16).

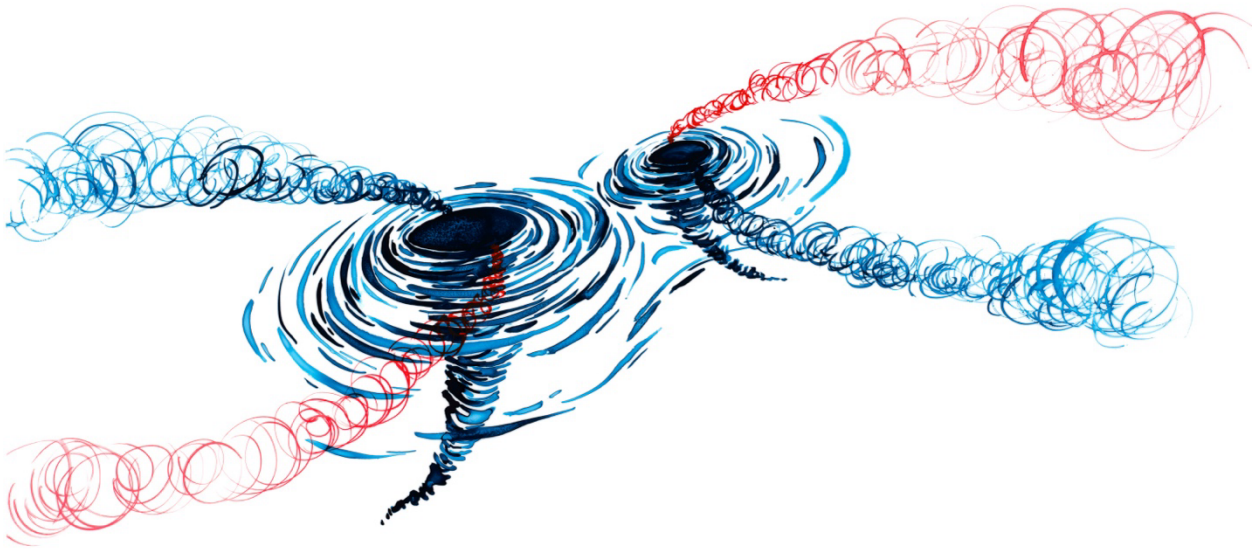


Figure 1.15: Illustration of two black holes colliding (2023), Lia Halloran. Watercolour created for The Warped Side of Our Universe, a collaboration with physicist Kip Thorne. Copyright Lia Halloran 2023. Used with permission.

As Thorne observes, 'the aesthetics are in the visual images associated with the mathematics' (Thorne and Halloran, 2023). This suggests that imagery can communicate theoretical relationships resistant to diagrammatic representation. In this sense, aesthetic

representation does more than embellish scientific ideas; it can provide an alternative means of approaching relationships that are otherwise difficult to grasp. Recent art-science scholarship, including the work of astronomer and art-science practitioner Marc J. Kuchner (2022), similarly argues that collaborative knowledge production depends on negotiating the different priorities of artistic and scientific practice through mutual exchange and shared expertise.

These examples show that astronomy communication often depends on mediated forms of visual and affective engagement. Such approaches can evoke scale, wonder and conceptual complexity, while also raising questions about the relationship between aesthetic experience, scientific understanding and audience participation.

1.3.1. Astro-Artworks: Immersive but Spectatorial

This relationship becomes especially visible in contemporary astro-artworks. The previous section traced how astronomy became publicly accessible through projection, simulation and data visualisation. These modes of display expanded collective encounters with the cosmos, but largely did so through forms of spectatorship. Over the past two decades, collaborations between artists and scientists have extended this terrain by producing artworks that translate astrophysical ideas into sensory and spatial experience. Through multisensory form, these works make cosmic phenomena perceptible beyond observatories and science centres. Yet they are often structured around observation within predetermined environments, positioning audiences primarily as viewers rather than co-creators.

The following examples illustrate how immersion, metaphor and multisensory design can expand public engagement with astrophysical ideas. *unfold* (2016), created by artist Ryoichi Kurokawa in collaboration with astrophysicist Vincent Minier of CEA Irfu, Paris-Saclay, exemplifies this approach (Kurokawa with Minier, 2018). Combining three-dimensional visualisations of molecular clouds with a vibrating transducer floor, the installation creates an immersive audio-visual environment that engages viewers through image, sound and bodily sensation (see Figure 1.17).

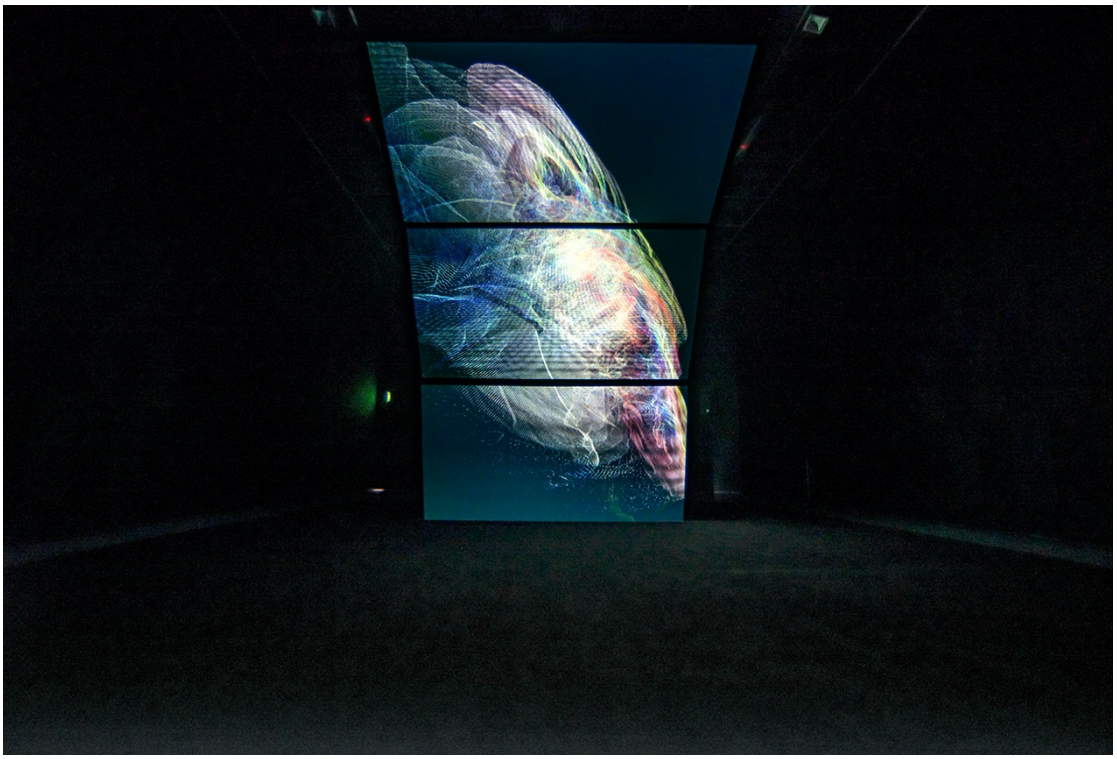


Figure 1.16: unfold (2016), Ryoichi Kurokawa with Vincent Minier. Courtesy of FACT Liverpool / Jon Barraclough. Used with permission.

HALO by artist duo Semiconductor offers a comparable synthesis of art and science. Commissioned by Audemars Piguet for Art Basel 2018, the work uses scientific data to create a cylindrical sound-and-light installation (Semiconductor, 2018; see Figure 1.18). Its fidelity to scientific data reflects a commitment to representational integrity, but this precision may also limit accessibility for non-specialist audiences. The installation encourages curiosity and contemplation through sensory immersion.



Figure 1.17: HALO (2018), Semiconductor. Image: Claudia Marcelloni.
Commissioned by Audemars Piguet for Art Basel 2018. In collaboration with CERN. Used with permission.

At a more conceptually demanding end of the spectrum, collaborations between artists and physicists continue to explore the perceptual and philosophical dimensions of cosmology. Arts at CERN has become a significant platform for such exchanges, supporting residencies, commissions and exhibitions that place artistic practice in dialogue with particle physics and scientific instrumentation (Arts at CERN, n.d.). One example is Julius von Bismarck's *Round About Four Dimensions* (2023), a kinetic sculpture that translates higher-dimensional geometry into the rotating projection of a tesseract, a four-dimensional analogue of a cube (see Figure 1.19). While intellectually rigorous, its minimalist aesthetic and conceptual demands may reduce accessibility for general audiences.

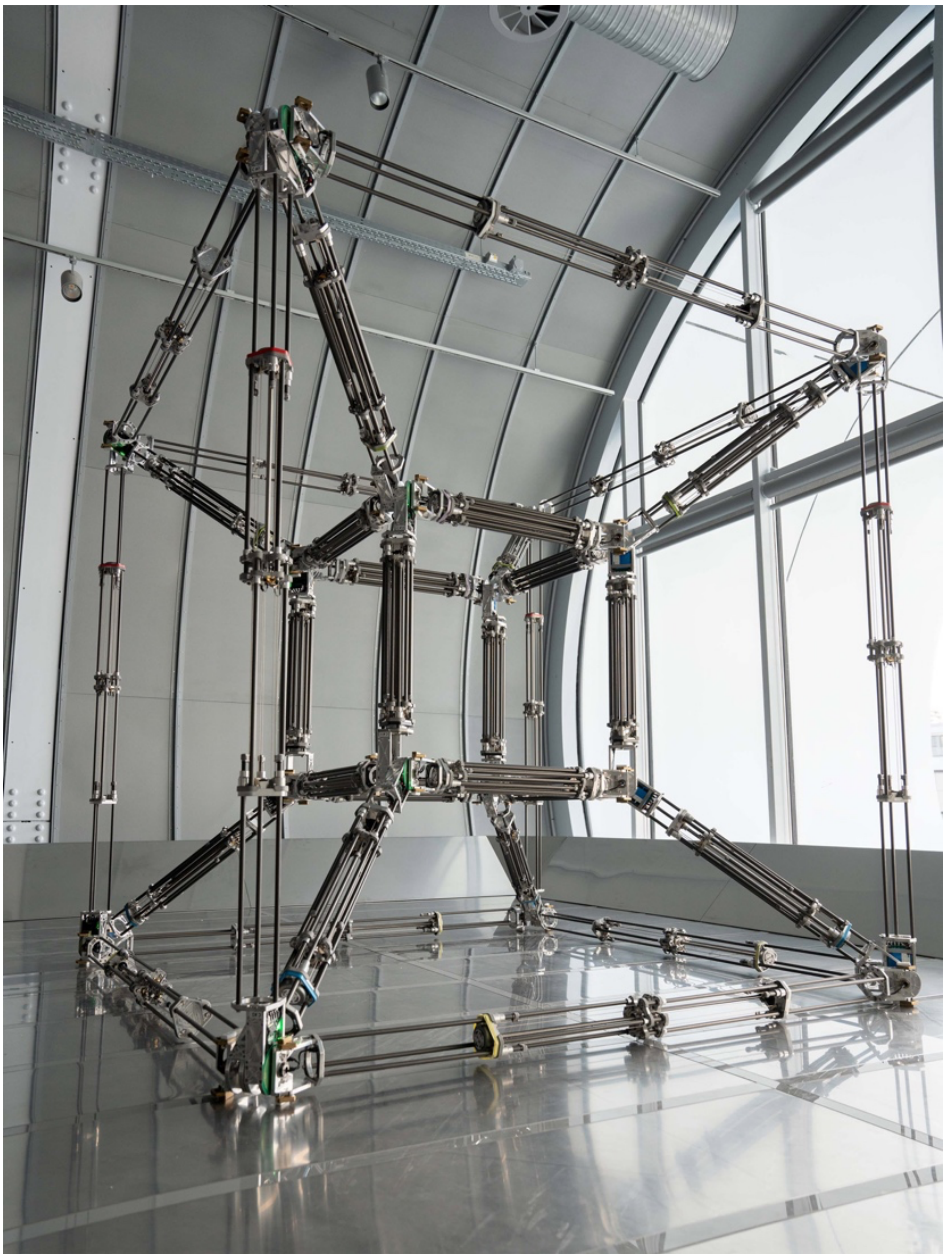


Figure 1.18: Julius von Bismarck and Benjamin Maus, Round About Four Dimensions (2023), installation view from Exploring the Unknown, CERN Science Gateway, 2023. Commissioned by Arts at CERN. © Julius von Bismarck; VG Bild-Kunst, Bonn 2025. Used with permission.

Similar tensions appear in *Dark Matter: 95% of the Universe is Missing* (Science Gallery London, 2019), an exhibition bringing together artistic responses to invisible matter. Carey Young's *Missing Mass* (Figure 1.20) turns the paradox of containing dark matter into a conceptual proposition. Yu-Chen Wang's *There's More to It Than Meets the Eye* (Figure 1.21) combines pencil drawings with scientists' personal testimonies, drawing attention to the human dimensions of particle physics. Andy Holden's *Even Darker Matter* (Figure 1.22) uses CGI and cartoon imagery to animate the unseen cosmos as a sentient presence, blurring boundaries between speculative science and poetic imagination.

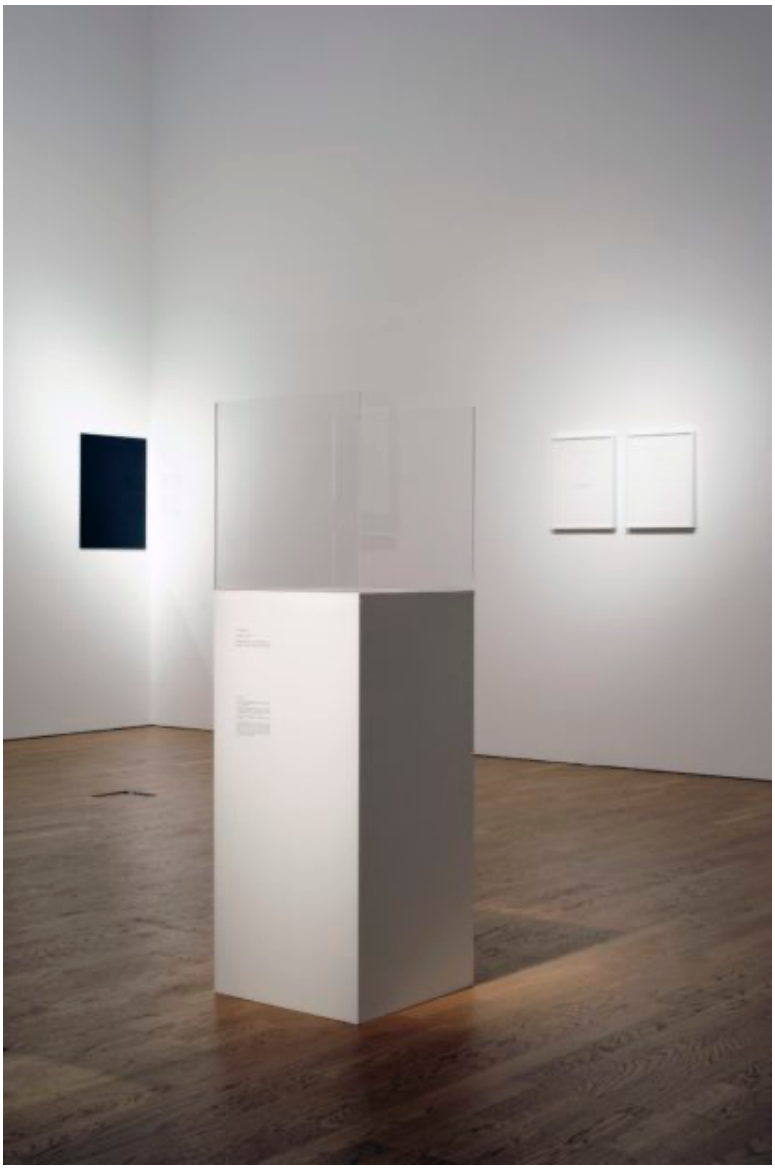


Figure 1.19: Carey Young, Missing Mass, 2010. 5,461 dark matter particles present in perspex container, on pedestal with silkscreened text. Container: 18 × 18 × 18 in. (45.7 × 45.7 × 45.7 cm); pedestal: 38 × 18 × 18 in. (96.5 × 45.7 × 45.7 cm). Installation view, Carey Young: Memento Park, March 31–July 20, 2011, Mima, Middlesbrough. © Carey Young. Photo: Thierry Bal



Figure 1.20: There's More to It Than Meets the Eye (2019) Yu-Chen Wang. Pencil drawings of particle physics machinery, exhibited at Dark Matter: 95% of the Universe is Missing, Science Gallery London. Image courtesy of Yu-Chen Wang, used with permission.



Figure 1.21: Holden, A. (2019). EVEN DARKER MATTER. [film still / installation photograph] Science Gallery London. Image courtesy of the artist, Used with permission.

Dark Matter Garden (see Figure 1.23) serves as a bridge between scientific visualisation and astro-art. Presented at the Royal Horticultural Society Flower Show Tatton Park, it used plants, light and spatial design as metaphorical means of rendering the effects of dark matter perceptible to public audiences. Its novelty lay in translating astrophysical concepts into an immersive environment outside the usual contexts of observatories and science centres, with scientists present to support interpretation. In this way, it expanded the conditions of public engagement through encounter, metaphor and explanation. The audience, however, remained positioned as observers.

Dark Matter Garden, therefore, points to the potential of art to mediate public understanding of astrophysical phenomena while also highlighting the distinction between interpretive encounter and participatory making.



Figure 1.22: DARK MATTER GARDEN (2015). Interactive installation illustrating gravitational lensing through grasses, an oculus, and a lightbox. Designed by H Miller Bros Lab with Mike Bode & Andy Newsam. Used with permission.

These contemporary artworks exemplify the richness of artistic responses to astronomical concepts. Their spatial and sensory qualities can engage audiences emotionally. In this respect, they align with Claire Bishop's account of a central tension in installation art: the viewer's role shifts between immersion and participation, but co-authorship rarely occurs (Bishop, 2005, p. 6). In *Artificial Hells*, Bishop (2012) further distinguishes between genuine collaboration and staged participation, noting that many works reproduce passive spectatorship under the appearance of inclusion. She argues that installation art constructs a 'situated spectator' who experiences the work through space and body, yet whose agency is often shaped in advance by the artist's design. This differs from the embodied reciprocity described by Merleau-Ponty (2012), for whom perception is active and relational, with meaning emerging through the body's engagement with the world. From this perspective, these installations evoke wonder through sensory engagement but offer limited opportunities for embodied perception to develop into participatory agency.

Applying Bishop's framework to these examples clarifies the limits of many contemporary art-science installations. *Dark Matter Garden*, *unfold* and *HALO* use sensory immersion and data-driven aesthetics to evoke reflection, but they do not invite audiences to contribute directly to the creation or interpretation of the work. They expand the aesthetic vocabulary of astrophysics without enabling collaborative meaning-making. These limitations foreground a key question for this thesis: how might astronomy communication move beyond spectatorship towards forms of participation in which interpretation, embodiment and creative production are shared with publics?

1.4. Creative Participation in Astronomy Science Communication

While the artworks discussed in the previous section create powerful sensory and interpretive experiences, they remain structured around spectatorship. A different set of initiatives within astronomy outreach has increasingly emphasised public engagement through observation, interaction, contribution and embodied exploration. Initiatives such as the National Schools' Observatory, directed by Professor Andy Newsam at Liverpool John Moores University, allow school students to request observations and engage with astronomical data through the Liverpool Telescope (Newsam, n.d.). RAS200 similarly demonstrates how astronomy outreach can engage citizens across cultural and social divides through community-based projects and locally situated public engagement (Miller, Bowler and Kanani, 2018). Citizen science platforms such as Galaxy Zoo, where volunteers classify astronomical images, have also enabled large-scale public involvement and generated substantial peer-reviewed scientific output (Lintott et al., 2008).

Public observing nights and telescope events further extend access to hands-on exploration. However, these forms of engagement tend to prioritise data interaction, observation, community outreach, or technical contribution over creative interpretation. As Young et al. (2014) observe, many participants, particularly teenagers, associate science with precision and the risk of error. Such perceptions may inhibit exploratory engagement and reinforce the view that scientific practice is reserved for specialists. This also connects to

Science Capital, since young people's confidence, access to science-related experiences and sense of belonging can shape whether they see science as available to them (Archer et al., 2015).

Since 2015, *Touching the Stars* (Arcand et al., 2019) has translated NASA's 3D-printed datasets into tactile models with Braille labels, enabling non-sighted audiences to explore celestial phenomena through touch. Developed in collaboration with the Perkins School for the Blind in Massachusetts and low-vision astronomy clubs, the project demonstrates how creative design can transform scientific data into multisensory learning experiences. Its participatory development process, in which users' feedback directly shaped refinements, illustrates a model of co-production between scientists, designers and audiences. Similarly, *The Tactile Universe*, created by the Institute of Cosmology and Gravitation at the University of Portsmouth, produces 3D-printed galaxies for use in schools and community events. By transforming light-based data into tangible forms, it improves accessibility for visually impaired learners while inviting all participants to reimagine knowledge of the universe through embodied experience. Both projects exemplify how inclusive design can expand the epistemological boundaries of science communication by addressing sensory difference and cognitive diversity.

Tactile astronomy projects show how access to astronomical knowledge can be expanded through embodied and participatory forms of engagement. Astro-animation builds on this ethos by treating creative interpretation as a legitimate mode of inquiry. It extends accessibility beyond physical inclusion towards epistemic inclusion, inviting participants to translate astronomical ideas through motion, metaphor and animation. This emphasis on creative interpretation provides the basis for identifying the specific gap addressed by this thesis.

Despite the expansion of astronomy communication across visualisation technologies, participatory platforms and art-science collaborations, existing approaches remain limited by the forms of engagement they afford. Planetariums and large-scale visualisation environments prioritise immersive observation, CGI simulations and scientific animations are usually presented as finished representational outputs, citizen science often frames participation through data classification or analysis and immersive art-science installations frequently

position audiences as spectators within artist-designed environments. Across these approaches, there remains limited provision for collaborative, exploratory and materially grounded engagement with astronomical ideas through making. This thesis addresses that gap through the development of Astro-animation, positioning animation as an embodied and collaborative process through which astronomical understanding can be explored, interpreted and produced.

This source review shows that astronomical visualisation extends from observation and data capture to scientific representation, public communication and participatory practice. Figure 1.24 summarises this progression.

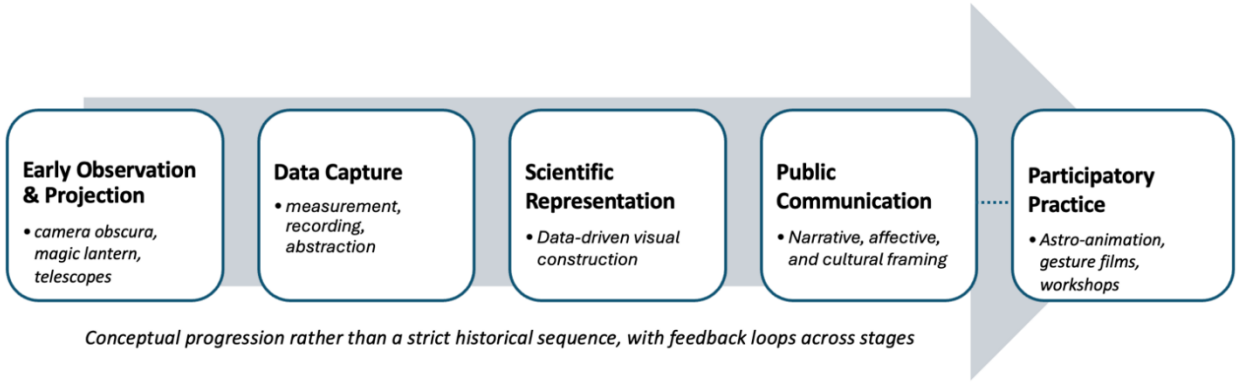


Figure 1.23: Conceptual overview of astronomical visualisation discussed in Chapter 1, tracing stages from early observation and data capture to public communication and participatory practice.

Figure 1.24 functions as a heuristic model. It emphasises relationships, feedback and recurring patterns across different forms of astronomical visualisation, while allowing the historical sequence to remain flexible.

Astro-animation is proposed in response to the limitations identified in this chapter. It shifts the emphasis from viewing to making, using animation as a method for engaging astrophysical concepts through embodied and interpretive practice. Through gesture-informed metaphor, abstract scientific ideas can be explored as visual forms shaped by movement, analogy and collective production. In this way, Astro-animation extends cognitive theories of gesture, particularly McNeill's (1992) account of gesture as a manifestation of thought and Goldin-Meadow's (2003) research on gesture and cognition, into a practice-based model of

science communication. This provides the rationale for the practice-based research design developed in the following chapter.

1.5. Summary of Chapter 1

This chapter situated Astro-animation within a history of astronomical visualisation, animation and participatory science communication. It traced a progression from early optical devices, projection systems and planetariums to contemporary scientific visualisation, art-science practice, tactile astronomy and public engagement initiatives.

The chapter showed that existing approaches expand access to astronomy in important ways, but often remain centred on viewing, observation, data interaction, or curated experience. Astro-animation addresses these limitations by foregrounding creative making as a way to engage astronomical ideas through gesture, metaphor, drawing, sequencing and collaborative animation.

This provides the foundation for Chapter 2, which outlines the practice-based, mixed-methods research design used to develop, refine and evaluate Astro-animation.

Chapter 2: Methodology and Research Design

2.1. Introduction to the Research Design

Building on the historical and conceptual foundations established in Chapter 1, this chapter outlines the research design used to investigate Astro-animation as both a creative practice and a mode of inclusive science communication. Because Astro-animation developed through collaboration with scientists, iterative animation-making and participatory workshops, the research required a methodology capable of examining both the creative process and participant experience. The study therefore adopts a convergent mixed-methods framework that integrates practice-based research, qualitative analysis and participatory workshop evaluation (Creswell and Plano Clark, 2018; Candy and Edmonds, 2018).

The design is organised into three interlinked strands that move from experimentation to refinement to application. The Astro-animation Toolkit comprises the workshop structure, prompts, facilitation methods and supporting materials developed through the research to guide participatory animation activities in informal and community-based astronomy communication settings.

2.2. Overall Mixed-Methods Research Design

The mixed-methods design was structured through three connected strands, each examining Astro-animation at a distinct stage of development. The first strand tested the method through a film-based creative experiment, the second translated the emerging principles into a Toolkit and the third applied the Toolkit in public workshop settings. This structure allowed the research to move from studio practice to facilitation design and then to community-based evaluation.

2.2.1. Strand 1: Gesture as Inquiry

Strand 1 began with the making of *The Movements of the Universe*, a film developed from interviews with NASA scientists. In these interviews, scientists explained astronomical and astrophysical concepts while using their hands to describe movement, scale, force and transformation. Their gestures became both a source of inspiration and a form of research material for the animation process.

I used the filmed hand movements as prompts for translating astronomical ideas into animation. Through this process, the film functioned as an experimental space for testing how gesture, metaphor, rhythm and timing could support the visualisation of concepts that are difficult to observe directly. This strand established the creative and methodological foundation of Astro-animation. It showed how scientists' embodied explanations could inform animation design and generated the initial principles later developed into the Astro-animation Toolkit.

2.2.2. Strand 2: Toolkit Development

Strand 2 translated the principles developed through the film into a workshop format. This involved testing how Astro-animation could be facilitated and repeated with others. Workshops with scientists, artists and art-researchers were used to refine the structure, instructions, prompts and practical materials of the Toolkit.

This phase focused on making the method clear enough for use beyond my own studio practice. It tested what participants needed in order to understand the astronomical topic, begin drawing or sequencing images and reflect on their creative decisions. The outcome was a structured Toolkit that included scientific framing, animation instruction, collaborative making, reflection and sharing.

2.2.3. Strand 3: Participatory Application

Strand 3 applied the refined Toolkit in community and informal learning settings through participatory workshops with families, teenagers and public audiences. In these settings, collaborative animation-making functioned as a hands-on mode of reasoning, interpretation

and engagement (Kolb, 1984). This phase examined how the Toolkit supported accessibility, curiosity, confidence, imaginative exploration and experiential learning among participants with varied levels of prior experience in astronomy or animation.

Together, the three strands formed a coherent mixed-methods framework that moved from creative experimentation to Toolkit refinement and community-based application (Creswell and Plano Clark, 2018). This progression is summarised in Figure 2.1.

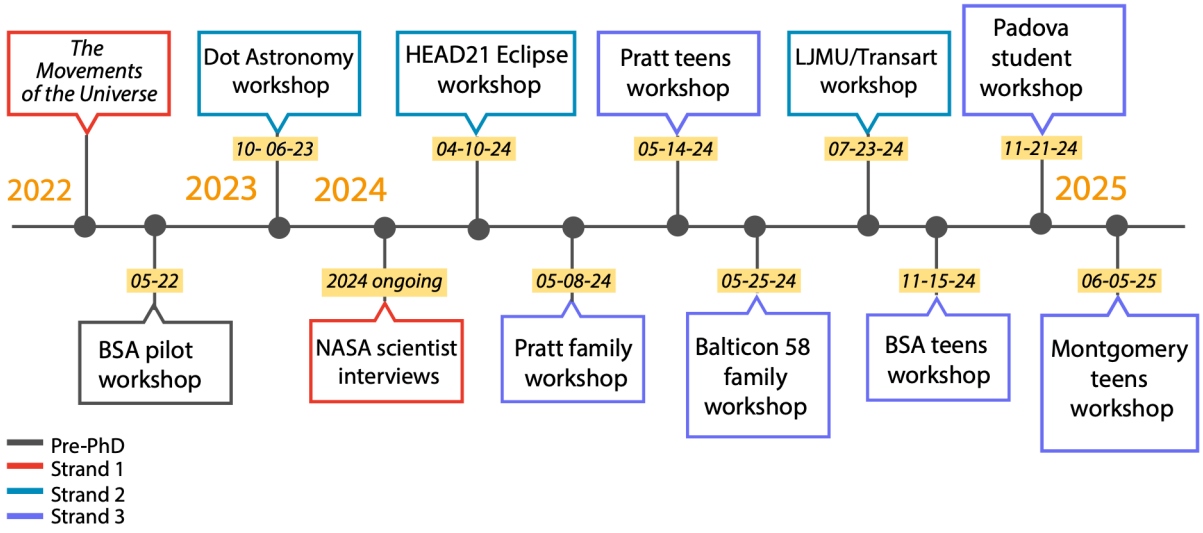


Figure 2.1: Timeline showing the development of Astro-animation across the three research strands between 2022 and 2025.

2.3. Methodological and Theoretical Frameworks

This section outlines the methodological and theoretical concepts that guide the study. It focuses on Astro-animation as creative inquiry, the role of gesture and metaphor in visual translation and participation in informal astronomy learning.

2.3.1. Practice-Based Research (PBR)

The study uses practice-based research because the central questions were explored through making and analysis. In Strand 1, *The Movements of the Universe* served as both a creative output and a research process. Drawing, animation tests, editing decisions, and visual experiments were used to investigate how scientists' gestures could be translated into animated form.

The study adopts an interpretivist orientation informed by gesture theory and practice-based research (Haseman, 2006; Candy and Edmonds, 2018). This means that gestures, drawings and animations are understood as forms of meaning-making shaped by context, interpretation, and creative decision-making. Scientists' gestures were analysed as embodied forms of reasoning that help make abstract astronomical ideas visible. Animation-making is treated as a research process because drawing, sequencing, testing, and revising images allowed scientific ideas to be explored through creative practice.

This approach connects the three strands of the study. In Strand 1, gesture informed the film. In Strand 2, the principles developed through the film were translated into the Astro-animation Toolkit. In Strand 3, participants used drawing and animation to interpret astronomical ideas. Practice-based research therefore provides a methodological framework for understanding Astro-animation as both creative practice and inquiry.

2.3.2. Undisciplinarity

Astro-animation operates across artistic and scientific modes without treating disciplines as fixed categories. The project aligns with an undisciplinary stance (Haider et al., 2018), in which methods are assembled in response to the needs of the inquiry rather than being restricted to a single disciplinary framework. In this thesis, undisciplinarity describes a research position that works across artistic practice, scientific explanation, and participatory learning.

This stance suits the research because Astro-animation developed through movement between scientific explanation, creative intuition, visual experimentation and participatory making. Gesture, metaphor, drawing, animation and scientific dialogue therefore functioned as interconnected modes of knowledge production. Disciplinary boundaries were negotiated

through practice, allowing these different forms of inquiry to shape one another throughout the research.

2.3.3. Animation Practice and Affordances

In this research, Astro-animation provides a set of affordances through which scientific concepts are interpreted and communicated. Animation-making enables sequential manipulation, allowing temporal processes to be constructed frame by frame. It also supports metamorphic transformation, through which abstract or invisible phenomena can be made perceptible through visual change over time. These qualities are especially relevant to astronomy communication because many astronomical phenomena cannot be directly observed at human scale and therefore require mediation through sequence, timing, scale and transformation.

Across the three strands, these qualities operated in different but connected ways. In Strand 1, animation functioned as a studio-based method for interpreting scientists' gestures and metaphors through visual experimentation. In Strands 2 and 3, the same principles were adapted into participatory workshop activities, where participants used drawing, sequencing and physical interaction with materials to externalise ideas that might be difficult to articulate verbally. In workshop settings, this process extended to collaborative meaning-making as participants negotiated interpretation, responded to one another's drawings and contributed to shared animated outcomes. Animation practice therefore operates in this study as method, material process, analytical tool and communicative outcome.

2.3.4. Reflexive Practice and Creative Reflexivity

Building on the undisciplinary use of artistic and scientific methods, reflexive practice provided a way to track creative decisions as they developed. Schön's (1983) concept of reflection-in-action underpinned this workflow, as animation choices were tested, revised and understood through practice. As illustrated in Figure 2.2, Astro-animation followed cyclical patterns of reflection-in-action and reflection-on-action, in which creative testing, scientific feedback and interpretive analysis continually looped back to inform subsequent decisions.

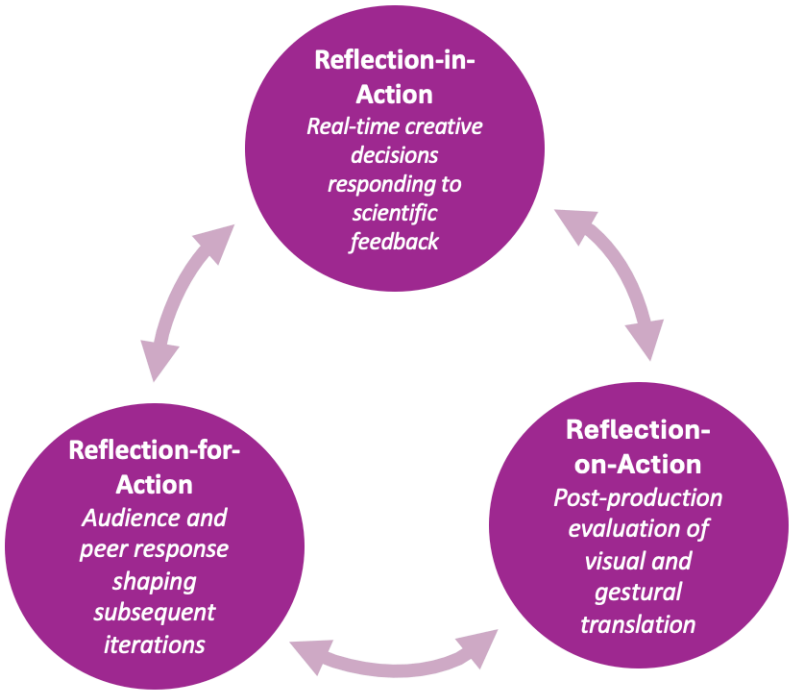


Figure 2.2: Iterative structure of reflective practice underpinning Astro-animation (adapted from Schön, 1983).

Reflection-in-action involved real-time creative adjustments; reflection-on-action entailed evaluative review after each production phase; and reflection-for-action incorporated audience and peer feedback to guide future creative cycles.

Journals and sketchbooks documented visual trials, conceptual notes, emerging patterns and responses to feedback from collaborating scientists and artists. Through this process, drawing, sequencing and animation design became ways of examining abstract phenomena such as scale, movement and transformation.

These reflective processes formed part of a wider methodological structure, summarised in Figure 2.3. The diagram shows how animation as inquiry, practice-based research, cyclical creative workflow, undisciplinarity and collaboration with scientists collectively shaped the development and documentation of Astro-animation.

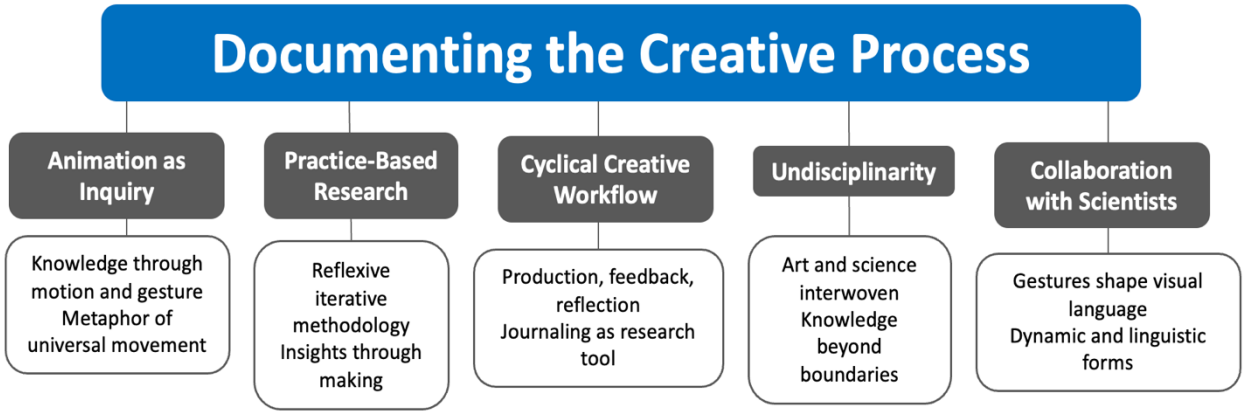


Figure 2.3: Diagram showing the key methodological elements shaping the development and documentation of Astro-animation.

This framework provides the foundation for the creative and analytical processes examined in Chapter 3. Because these cycles developed through sustained exchange with scientists, artists and workshop participants, collaboration also became a defining feature of the study.

2.3.5. Collaboration in Art-Science Practice

Collaboration was a central methodological condition of this study. Astro-animation developed through sustained exchange between scientific and artistic ways of knowing, requiring dialogue in which explanation, interpretation and visual experimentation could be negotiated across disciplinary perspectives (Wilson, 2010; Randerson, 2019). Scientists contributed specialist conceptual understanding, embodied explanation and domain-specific feedback, while animation practice contributed interpretive, visual and material processes through which those ideas could be explored and reworked. In this study, collaboration informed all three strands: the gesture-based development of animation in Strand 1, the refinement of the Toolkit with experts in Strand 2 and the participatory workshop model used with public groups in Strand 3. The following section outlines the analytical frameworks used to interpret gesture, metaphor, participant engagement and workshop design across the study.

2.3.6. Gesture, Metaphor and Translation into Design

Gesture and metaphor form the analytical backbone of this project. Gesture externalises thought through action, revealing the spatial and dynamic structures of explanation, while metaphor enables abstract astrophysical ideas to be rendered visually. To interpret these processes, the analysis drew on Lakoff and Johnson's (2003) account of structural, ontological, and orientational metaphors, which map abstract concepts onto embodied and familiar domains. For example, spacetime as fabric visualises gravitational curvature as an elastic, deformable grid; 'a black hole eats' frames accretion as a swallowing action; and orientational metaphors such as 'more is up' organise visual sequences through changes in scale, speed, or vertical movement.

The project distinguishes between verbal metaphors articulated in interviews and gestural metaphors communicated through scientists' hand movements, spatial demonstrations, and enacted analogies. Because gesture operated alongside speech, both forms were analysed together. Goldin-Meadow's (2003) research provided a foundation for understanding gesture as a visible trace of thought, including trajectory, containment, force, compression, and release.

In practice, coded metaphors and gestures were translated into animation choices such as timing, pacing, camera movement, particle behaviour, spatial organisation, and metamorphic transition. Spiral hand motions could suggest orbital dynamics, compress-and-release gestures could inform wave emission, and expansive sweeps could be developed into visualisations of cosmic growth.

Because metaphors can produce misleading visual impressions, the process included checks for potential scientific misconceptions. Visual choices were revised through artistic judgement, scientific feedback, and iterative testing. For example, spacetime curvature was represented through flowing, deforming textures and a responsive visual field, while orbital motion was designed so that paths did not imply inward decay unless scientifically accurate. In Strand 1, this metaphor-to-design process was applied to interview data from NASA scientists. It generated gesture-informed animation sequences through coding, visual experimentation, intuition, and collaborator feedback. This approach underpins the animation

process examined in Chapter 3 and informed the participatory Toolkit developed in Chapters 4 and 5. Table 2.1 summarises how recurring linguistic metaphors and embodied gestures were translated into animation parameters.

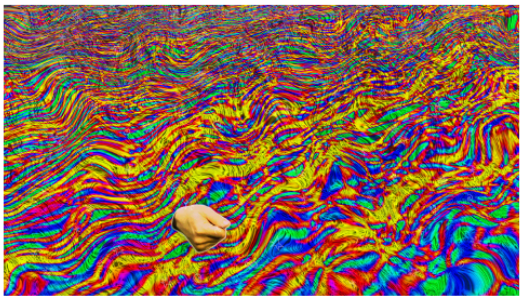
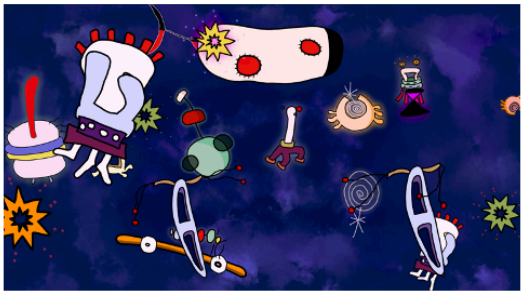
	**1-Structural:** *Spacetime as fabric*, elastic grid warps and ripples (gravitational waves). **Orientational:** Local "press/drag" = *down/near*, ripples travel *outward/forward* in time.
	**2-Ontological:** *Black holes as dancers/partners*, entities you can steer and bring together. **Structural:** *Orbit as choreography*, spiral timing/phase = dance steps
	**3-Orientational:** *Faster is up/forward/more*, tempo and frequency increase mapped to tighter, quicker motions. **Structural:** *Spin/acceleration as dance tempo*, movement quality stands in for orbital frequency.
	**4-Structural:** *Early universe as hot,* dense as clustered, vibrating forms (ontological, with orientational spread over time). **Ontological:** *Energy/particles as entities*, personified bits that bump, fuse, spark. **Orientational:** *Compressed→expanding*, tight clustering suggests density (can open out over time).

Table 2.1: Mapping linguistic metaphors and embodied gestures to animation design parameters.

2.3.7. Science Capital

While the preceding framework explains how gesture and metaphor were translated into animated form, the workshop methodology also required a framework for understanding participation in informal science learning. Science capital, developed from Bourdieu's theory of social, cultural and economic capital (Bourdieu, 1986) and elaborated by Archer et al. (2015) and Moote et al. (2020), shows how engagement is shaped by prior knowledge, attitudes, experiences, social connections and a sense of whether science is 'for me'. In informal learning environments, this framework has been used to support more equitable STEM engagement and to help audiences feel that science is relevant and accessible (Science Museum Group, n.d.).

In this research, science capital informed the interpretation of how access, confidence, recognition and prior exposure shaped participation in astronomy workshops, particularly among teenagers and community groups with limited access to arts-integrated science learning. Through collaborative animation-making, the workshops provided multiple points of entry into astronomy without requiring prior scientific expertise. Science capital helped frame Astro-animation as an inclusive form of informal science communication. Multimedia learning theory then informed practical decisions about explanation, visual clarity and workshop structure.

2.3.8. Multimedia Learning

The design and analysis of the study were also informed by Richard Mayer's Cognitive Theory of Multimedia Learning (2001, 2009, 2014) and related research on animation in multimedia contexts (Mayer and Moreno, 2002). These frameworks propose that learners construct understanding more effectively when verbal and visual information are coordinated to reduce extraneous cognitive load. Three concepts were particularly relevant to this study. The Modality Principle suggests that spoken explanation supports learning more effectively than on-screen text. The Coherence Principle emphasises limiting unnecessary visual or verbal detail that may distract from the central idea. Temporal Contiguity refers to the close timing of corresponding words and images so that explanation and visualisation are experienced together.

Within the Astro-animation workshops, these concepts informed instructional design. Spoken explanation was prioritised during lightning talks and facilitation, while written text on

slides and in workshop materials was kept brief. Visual complexity was also restrained so participants could focus on key ideas such as movement, transformation and scale without distraction. In addition, speech and animated motion were aligned as closely as possible during demonstrations to reinforce conceptual connections between explanation and image. In this way, multimedia learning theory supported clarity in workshop facilitation while leaving room for metaphor, texture, rhythm and expressive interpretation.

These analytical and theoretical frameworks informed the interpretation and design of Astro-animation and strengthened the methodological consistency of the study as a whole. The next section explains how rigour and trustworthiness were addressed within this practice-based, mixed-methods design.

2.4. Convergent Mixed-Methods Design

2.4.1. Three-Strand Mixed-Methods Framework

This section explains how the three strands operated together within the convergent mixed-methods design. Rather than functioning as separate phases, the strands formed an iterative research structure in which creative practice, expert feedback and public workshop evaluation informed one another. Insights from the film-making process shaped the development of the Toolkit, while later workshops tested how those principles functioned across expert, artistic and community settings.

Throughout the study, data collection and analysis informed subsequent decisions. Qualitative materials, including interviews, observations, reflective notes and creative outputs, were interpreted alongside survey data to examine how Astro-animation developed as both a creative method and a participatory form of astronomy communication. This relationship is

summarised in Figure 2.4, which shows how practice-based animation research, expert refinement and public engagement were connected across the three strands.

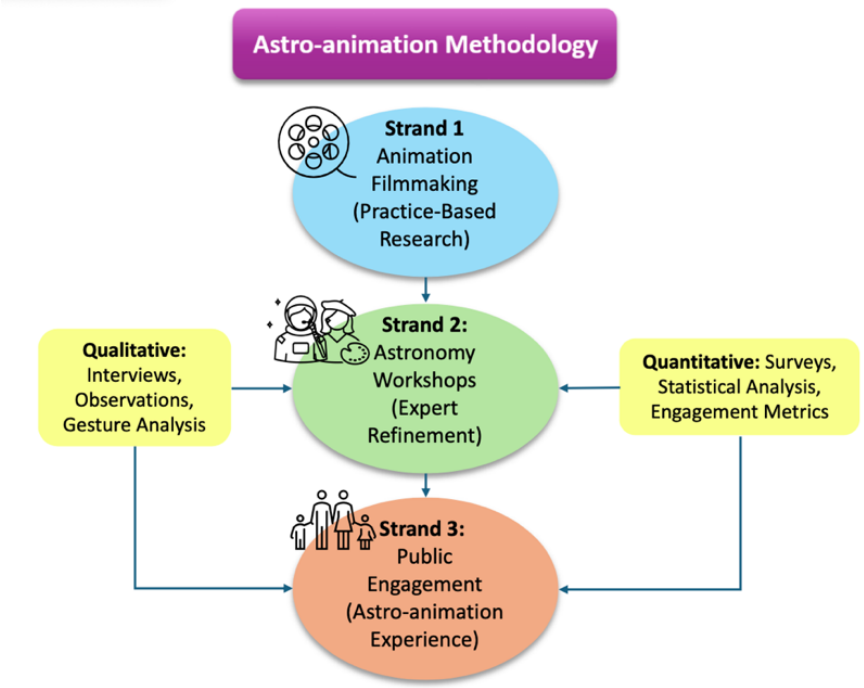


Figure 2.4: Three-strand mixed-methods framework for Astro-animation research.

2.4.2. Integration Strategy

This study adopted a convergent mixed-methods design (Creswell and Plano Clark, 2018), in which qualitative and quantitative materials were analysed separately and then interpreted together. This strategy was appropriate because Astro-animation required both inductive exploration through creative practice and structured evaluation through expert and participant feedback.

The inductive strand supported analysis of how gesture, metaphor and creative experimentation generated representational possibilities. The structured feedback strand examined how these methods functioned for expert collaborators and public participants. Bringing these materials together allowed creative insights to be tested, refined and evaluated across different contexts.

Data were integrated by comparing survey responses, observational notes, thematic patterns from interviews, facilitator reflections and researcher memos. Observational notes

focused on collaboration, gesture use, question-asking and other forms of workshop engagement. Researcher memos supported transparency by documenting contextual factors that shaped interpretation, without functioning as primary data.

Integration therefore served as both an analytical procedure and an iterative design process, synthesising perspectives on engagement and understanding while supporting Toolkit refinement. Figure 2.5 summarises how practice-based inquiry, expert validation and participatory evaluation were connected within the study.

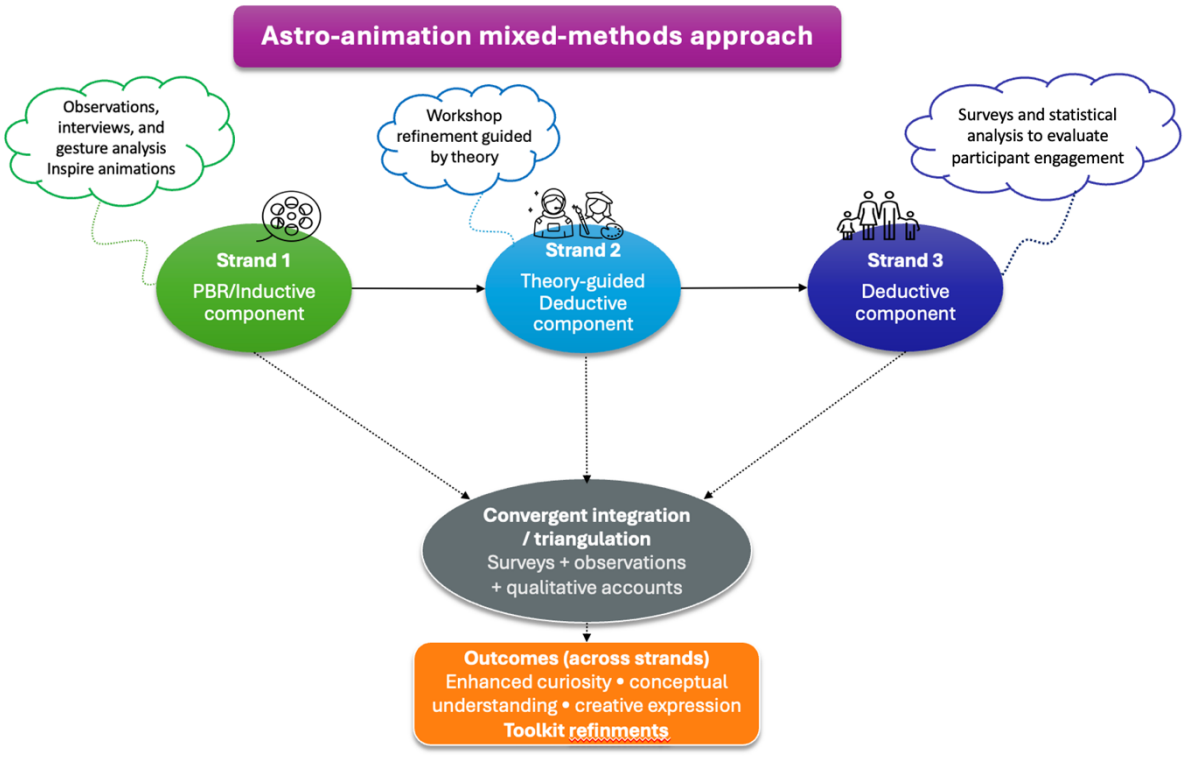


Figure 2.5: Astro-animation mixed-methods approach.

The diagram illustrates how the three strands connect creative practice, Toolkit refinement and public workshop evaluation, with findings brought together through convergent triangulation of surveys, observations, interviews and reflective materials.

2.5. Methods and Data Sources

2.5.1. Qualitative Methods

Qualitative methods were used to document creative process, expert reflection and participant experience. They supported an interpretive approach to meaning, process and context (Denzin and Lincoln, 2018).

In Strand 1, reflexive journals and sketchbooks recorded the development of the animation research, including visual experimentation, conceptual notes and emerging insights (Schön, 1983; Candy and Edmonds, 2018). In Strand 2, expert feedback was gathered through open-ended survey responses and semi-structured interviews with scientists and artists. These methods allowed participants to describe their experiences and suggestions in their own terms (Kvale and Brinkmann, 2009; Cohen, Manion and Morrison, 2018). In Strand 3, workshop observations and semi-structured interviews captured participant interaction, creative engagement and reflections at the end of each session (Emerson, Fretz and Shaw, 2011). Interviews were documented through mobile-phone audio recordings or Microsoft Word's transcription tool.

These methods provided contextual evidence of how participants and collaborators engaged with Astro-animation in different settings.

2.5.2. Quantitative Methods

Quantitative methods were used in Strands 2 and 3 to provide structured evaluative insight into expert and participant responses. In Strand 2, surveys gathered feedback from scientists and artists on the clarity, usefulness and adaptability of the developing Astro-animation Toolkit. In Strand 3, brief pre- and post-workshop surveys explored patterns of interest, confidence and engagement in relation to astronomy and animation (Cohen, Manion and Morrison, 2018). The data were analysed using descriptive statistics. Because participants were recruited through convenience sampling and because group sizes were small and varied across workshops, survey findings were treated as descriptive and directional rather than generalisable (Bryman, 2016; Cohen, Manion and Morrison, 2018). They were used to identify

trends and shifts across workshop contexts and were interpreted alongside qualitative evidence.

2.5.3. Data Sources Across the Three Strands

Different but related forms of data were generated throughout the study, allowing creative, qualitative and evaluative evidence to be interpreted through methodological triangulation (Denzin, 1978; Creswell and Plano Clark, 2018). Table 2.2 summarises the principal methods and data sources used across the three strands.

Strand	Methods	Data sources
Strand 1: Gesture as Inquiry	Semi-structured interviews, gesture observation, reflexive journaling, sketchbook documentation and animation testing	Interview transcripts and notes, gesture observations, reflexive journals, sketchbooks and animation tests
Strand 2: Toolkit Development	Expert workshops, semi-structured interviews, open-ended survey questions and iterative Toolkit revision	Workshop observations, interview data, open-ended survey responses, expert discussions and revised Toolkit materials
Strand 3: Participatory Application	Participatory workshops, workshop observation, semi-structured interviews and pre- and post-workshop surveys	Field notes, participant reflections and interviews, survey responses and creative outputs

Table 2.2: Summary of methods and data sources used across the three research strands.

Having outlined the principal methods and data sources, the next section discusses the analytical approach used to interpret the qualitative materials generated across the study.

2.6. Reflexive Thematic Analysis

2.6.1. Rationale for Reflexive Thematic Analysis

Reflexive thematic analysis was selected to interpret the qualitative materials generated through interviews, observations, open-ended survey responses, workshop discussions and reflective documentation (Braun and Clarke, 2006, 2021). It provided a flexible interpretive

approach suited to examining how meaning emerged through gesture, metaphor, creative practice and participant experience.

Braun and Clarke's framework supported theme development while recognising the role of researcher reflexivity in the analytical process. This was important in a practice-based study where creative judgement, facilitation and interpretation were closely connected.

2.6.2. Application Across the Three Strands

Reflexive thematic analysis was applied differently according to the focus of each strand. In Strand 1, it guided the analysis of interviews with NASA scientists and notes on gesture, metaphor and explanation, identifying patterns that informed gesture-informed animation. In Strand 2, it was used to examine expert interviews, workshop discussions, open-ended survey responses and facilitator reflections, focusing on Toolkit refinement. In Strand 3, it supported analysis of participant interviews, observational field notes and facilitator reflections, with attention to engagement, curiosity, confidence and imaginative response.
This approach allowed themes to develop in relation to both the data and the evolving creative practice.

2.6.3. Coding and Theme Development

Coding was undertaken through close reading, note-taking and comparison of interview transcripts, observational notes, workshop discussions and reflective documentation. It was treated as an interpretive process in which sustained engagement with the material shaped the development of themes (Braun and Clarke, 2021).

The analysis was primarily inductive, allowing patterns to emerge while remaining informed by the study's concern with gesture, metaphor, participation and visual reasoning. Initial codes were reviewed, grouped and refined as the analysis developed. Themes were generated through interpretation and reflection, guided by patterns of meaning, relevance to the research questions and the evolving creative practice.

2.7. Rigour and Trustworthiness

Rigour in this study was grounded in transparency, reflexivity and methodological triangulation, drawing on qualitative criteria of credibility, dependability and confirmability (Lincoln and Guba, 1985; Denzin, 1978). Credibility was supported by multiple forms of evidence, including comparisons across survey, observational and interview data. Dependability and confirmability were supported by detailed codebooks, analytic notes and versioned Toolkit iterations, which provided an audit trail and made interpretive and design decisions traceable (Lincoln and Guba, 1985). Reflexive memos documented how creative judgement and researcher perspective shaped interpretation, aligning with the study's practice-based orientation (Schön, 1983; Braun and Clarke, 2021).

Potential biases included facilitator influence, social desirability and novelty effects. These were addressed through anonymous surveys, neutrally worded prompts and structured observation protocols that prioritised observable behaviour over evaluative opinion. The use of three research strands further strengthened trustworthiness while acknowledging that interpretation is intrinsic to creative and participatory research. Alongside these measures of methodological rigour, ethical governance was central to the design and conduct of the research.

2.8. Ethics and Governance

This research adhered to the Liverpool John Moores University (LJMU) Code of Practice for Research (2020) and received full approval from the University Research Ethics Committee (UREC) prior to commencement (Ethics Reference No. 23/LSA/006). Ethical principles of respect, transparency, inclusivity, informed consent and participant welfare guided all stages of the study.

Ethical considerations were particularly salient for participatory workshops with teenagers and community groups. Safeguarding, consent and accessibility procedures were managed in collaboration with partner organisations, such as schools and libraries, which acted as gatekeepers for youth participation. Data were collected, stored and anonymised in

accordance with GDPR and LJMU data management requirements, with additional protections applied to work with minors. Participants were informed of the voluntary nature of participation and their right to withdraw at any time. Options for anonymity and attribution were offered according to the context and nature of contribution. Across all strands, ethical practice was embedded as both a procedural requirement and a reflective commitment aligned with the participatory ethos of Astro-animation. A full account of ethical oversight, consent procedures, data management protocols and attribution practices is provided in Appendix D.

2.9. Limitations and Delimitations

Delivering workshops in informal venues introduced natural variability in space, lighting, acoustics and technical reliability, all of which affected participation and the consistency of observation. Participants were recruited through convenience sampling via partner organisations, resulting in small and variable group sizes across sites and sessions (Bryman, 2016; Cohen, Manion and Morrison, 2018). To maintain accessibility for diverse participants, the research instruments, including brief surveys, short reflections and structured observations, were intentionally concise. This supported participation but necessarily limited analytical depth and the use of inferential statistics. Quantitative findings are therefore presented as descriptive and directional, supporting contextual interpretation of participant response patterns (Cohen, Manion and Morrison, 2018).

The study was also deliberately delimited to the intersection of astronomy, animation and informal learning. It focused on how animation-based activities structured through drawing, gesture, metaphor and collaborative making can support engagement and understanding among participants from underrepresented communities. Workshops followed a shared but adaptable framework comprising a brief conceptual introduction, guided animation-making and reflection or sharing. This structure made it possible to explore facilitative, learning-oriented and creative approaches across different contexts while maintaining methodological coherence.

The scope of the study therefore prioritised depth of insight over breadth, ensuring alignment with the central research questions. Recognising these limitations and delimitations is important for understanding both the study's scope and its methodological contribution.

2.10. Summary of Chapter 2

The sections above have outlined the study as a practice-based, mixed-methods design integrating artistic experimentation with systematic inquiry. Across three interrelated strands, Astro-animation was developed, refined and applied through an iterative relationship between creative practice, qualitative interpretation and participatory evaluation. The chapter also established the theoretical frameworks, data sources, analytical methods, ethical procedures and limitations that shaped the study. Chapter 3 turns to Strand 1, examining how collaboration with NASA scientists informed the development of gesture-informed animation in *The Movements of the Universe*.

Chapter 3: Strand 1: From Gesture to Animation

3.1. Introduction to Strand 1

Building on the methodological framework established in Chapter 2, this chapter examines how Strand 1 developed gesture-informed, practice-based inquiry through the making of *The Movements of the Universe*. It considers how scientists' gestures and metaphors were translated into animation, focusing on embodied scientific explanation and the creative decisions that shaped the film's visual language. Gestures recorded during interviews provided a key source for animated sequences that explored astrophysical concepts through motion, timing and spatial organisation, including black holes, gravitational waves and cosmic expansion.

The project progressed through observation, animation testing, scientific feedback and revision. Reflective documentation recorded emerging interpretations, while animation functioned as a method for exploring and refining scientific ideas. The chapter situates my role as animator-researcher, examines the collaborative processes that shaped the film, analyses post-production interviews with participating scientists and identifies the principles that later informed the Astro-animation Toolkit.

3.2. Researcher Positioning and Practice-Based Motivation

For me, animation has always been more than a creative outlet. It is the primary language through which I make sense of the world. Animation enables abstract ideas, emotions and complex phenomena to be transformed into tangible, temporal forms. Through drawing, sequencing and motion, I explore layers of meaning that connect scientific concepts with lived, affective experience.

Teaching animation has been integral to this approach, shaping how I articulate ideas, facilitate learning and translate complexity for diverse audiences. When the idea of combining

animation with astronomy first emerged, it felt like a tentative pedagogical experiment. What began as a classroom exercise developed into an ongoing inquiry in which imagination and scientific investigation became mutually generative. This process revealed animation's potential as a mode of inquiry that could support scientific communication in ways that resonated with both students and scientists (Arcadias et al., 2020).

My engagement with both art and science further sharpened this approach (Lepito, 2018; Randerson, 2019). In attempting to represent astrophysical phenomena and in grappling with scale, duration and spatial abstraction, I came to understand the universe as a dynamic system structured by motion, transformation and rhythm. Lepito describes animation as 'the collision of art and science' (2018), while Randerson positions experimental animation as a means of rendering cosmological processes perceptible (2019).

This position informed Strand 1. My role as animator-researcher shaped how scientists' gestures were observed, interpreted and translated into animated form. Creative decisions were documented through reflexive journaling, sketchbook work and iterative experimentation. Creative practice became the site through which questions of gesture, metaphor and scientific meaning were investigated. The following section explains how these questions were documented through journals, sketchbooks and feedback cycles during production.

3.3. Integration of Feedback and Journaling

Journaling and sketchbook work played a central role in the development of *The Movements of the Universe*, allowing scientific explanation and creative interpretation to evolve in dialogue. Immediately following interviews with NASA scientists, journals were used to record initial responses to gesture, spatial relationships and metaphorical possibilities. These notes captured impressions that were not always visible in the transcript alone, such as the rhythm of a hand movement, the emotional tone of an explanation, or the visual potential of a metaphor. They helped bridge the interview material and the later animation process.

Throughout production, journals, sketchbooks and memos documented visual tests, interpretive choices and adjustments to form, timing and motion. Reflective writing connected experimentation to inquiry, grounding decisions in cycles of adaptation, review and reinterpretation (Schön, 1983). Sketchbooks preserved drafts and design ideas, while memos tracked changes that emerged through collaborator feedback. The film therefore developed through a reflexive process in which creative decisions and scientific interpretation were continually reworked.

Feedback from NASA collaborators remained central throughout. Early drafts were shared with the scientists to assess scientific resonance, clarity and communicative impact, and their responses informed further revision. These exchanges helped identify where an animation sequence clarified an idea, where it created ambiguity, or where a metaphor needed adjustment. Feedback formed part of the research process, shaping the refinement of scientific explanation, visual interpretation and animation decisions.

Figures 3.1–3.5 present selected sketchbook pages and production collages that trace the translation of scientific concepts, including photon movement, stellar formation and gravitational waves, into visual language.

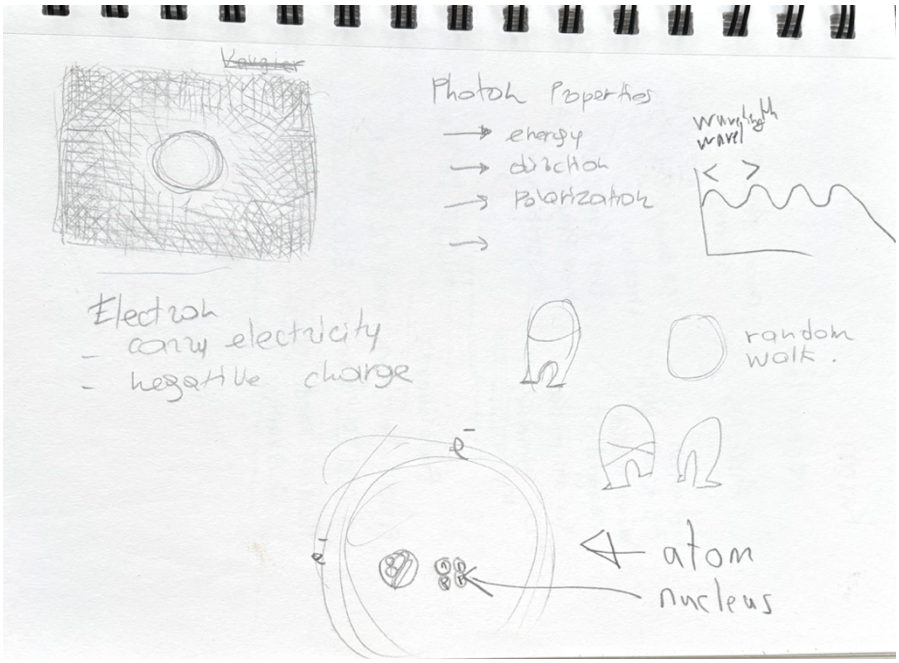


Figure 3.1: Preliminary concept drawings from the artist's journal illustrating early ideas for representing photon movement.

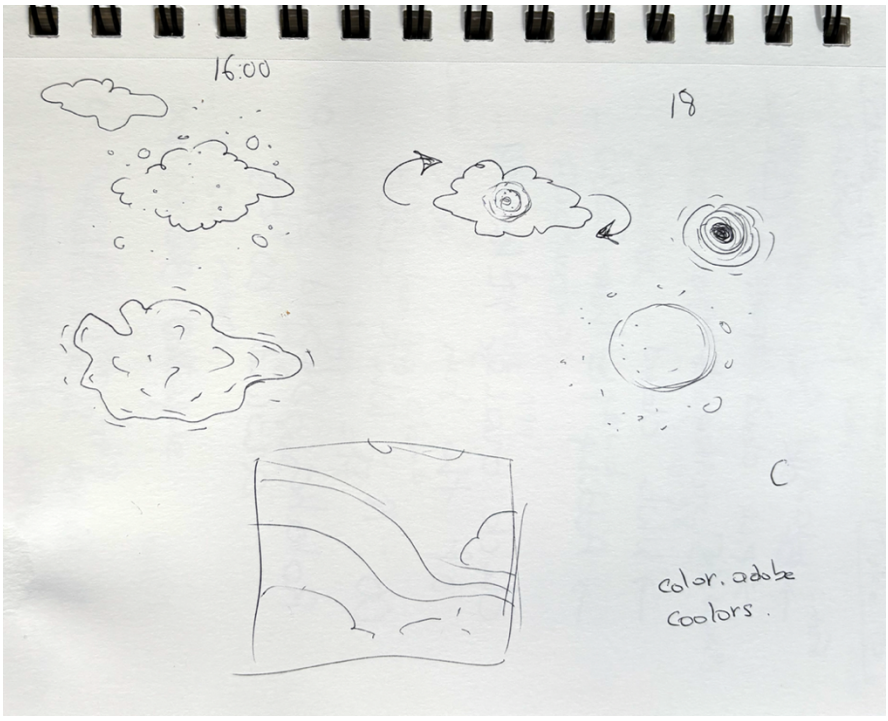


Figure 3.2: Birth of the sun, sketch from the artist's personal journal exploring early visual concepts for stellar formation.

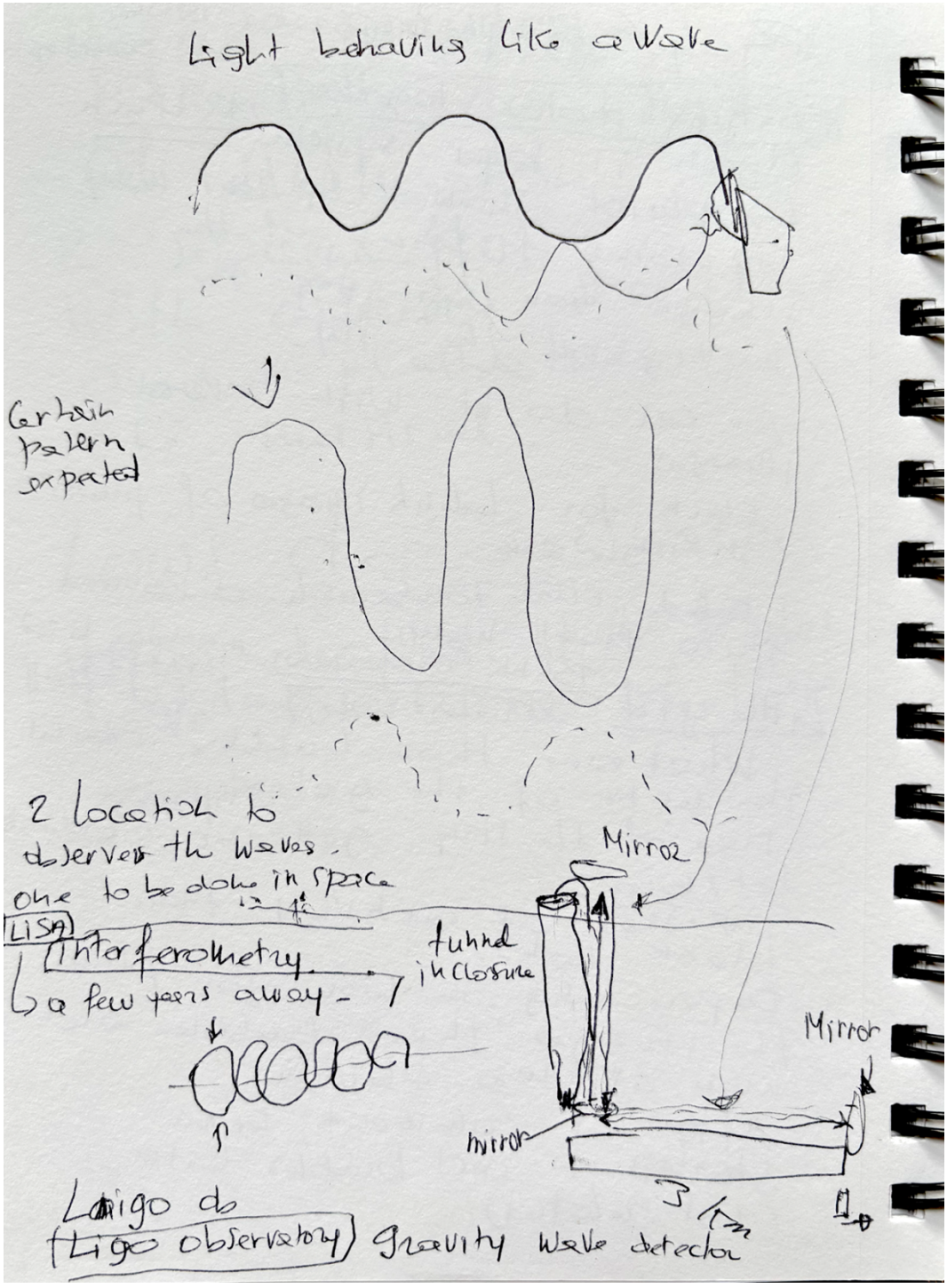


Figure 3.3: Sketch for gravitational waves, from the artist's personal journal informed by astrophysical discussions on gravitational phenomena.

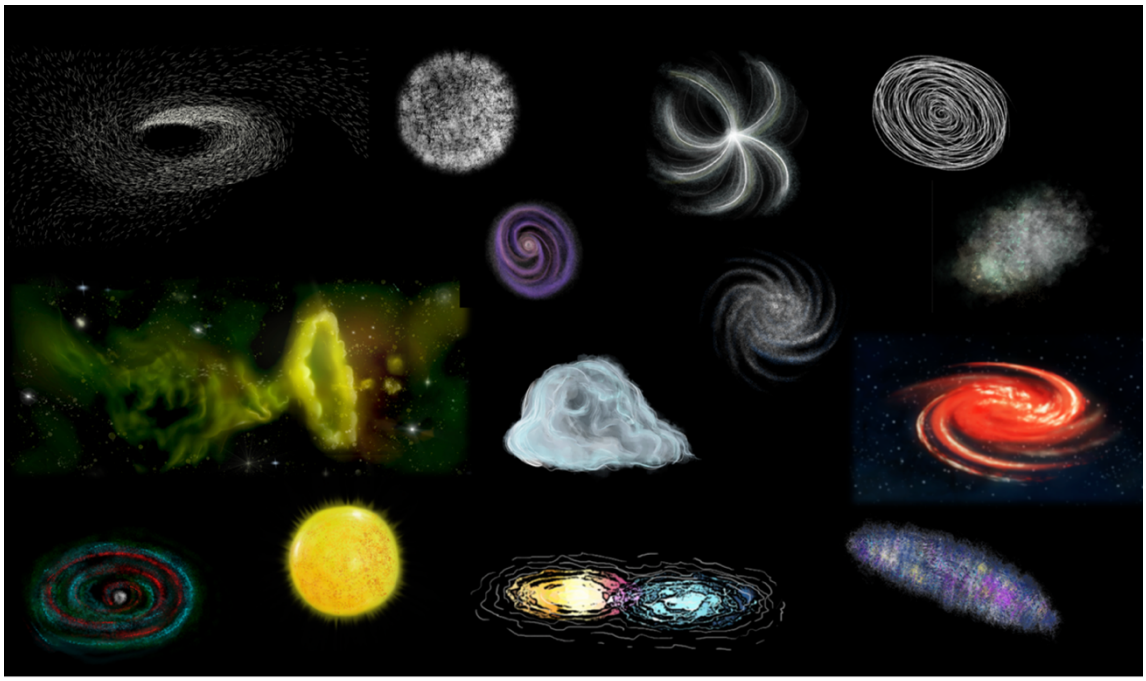


Figure 3.4: Composite Study of Celestial Bodies. Digital collage exploring galactic elements and the shift from data interpretation to expressive cosmological visualisation.

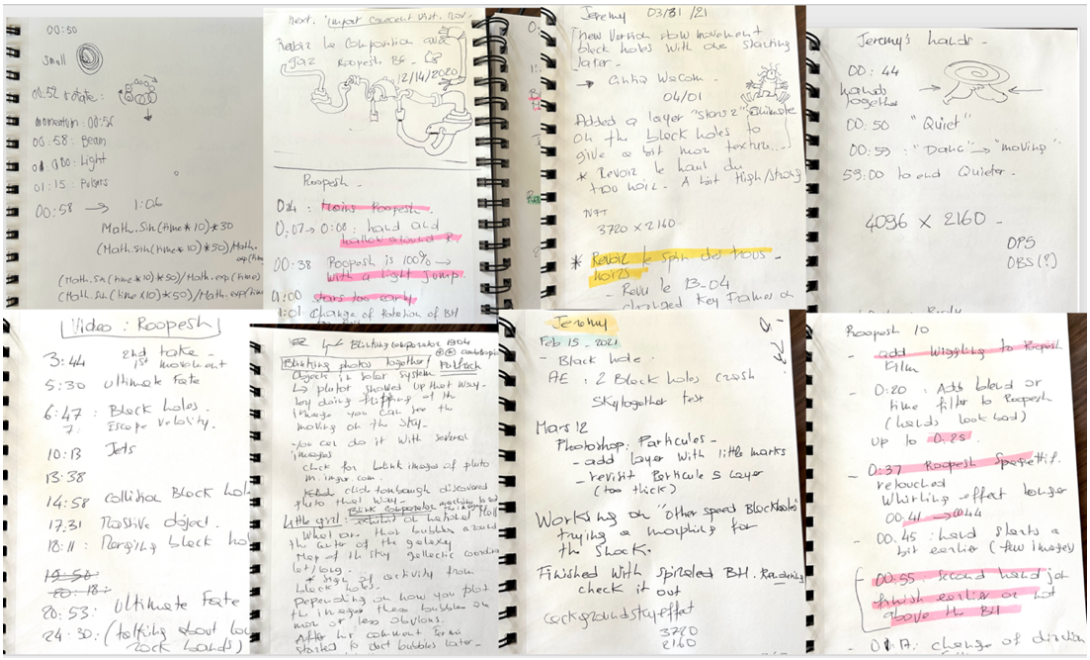


Figure 3.5: Production journal for The Movements of the Universe. Sketches and notes.

Having established the role of reflective documentation, the next section introduces the NASA scientists whose explanations and gestures provided the film's primary material.

3.4. Collaboration with NASA Scientists

Collaboration with seven NASA scientists informed the creative development of *The Movements of the Universe*. This section examines how scientists' explanations, metaphors and gesture patterns shaped specific animation decisions, including timing, motion paths, visual metaphors and narrative progression. Participant details appear in Appendix A.2.

3.4.1. Overview of Collaborators and Areas of Expertise

The NASA scientists involved in Strand 1 were selected for their complementary expertise in cosmology, compact objects, high-energy astrophysics, binary systems, dark matter and solar physics. Each brought specialist knowledge, explanatory habits and distinct gestural patterns that shaped how astronomical phenomena could be interpreted through animation.

Each collaborator was interviewed on camera and invited to gesture while explaining core ideas related to their field. These verbal and embodied accounts were later analysed and translated into animation motifs. Their contributions served three functions: grounding scientific plausibility, providing metaphors and spatial schemas through gesture and shaping the timing and rhythm of the film's explanations.

John C. Mather, Nobel Prize recipient in 2006 and JWST Senior Project Scientist, contributed to the treatment of cosmology and temporal scale. His description of the transition from inflation to gradual expansion guided the film's macro-structure and pacing. The dynamics of compact objects drew on Elizabeth Ferrara, whose work focuses on pulsars and extreme environments, as well as black hole specialists Roopesh Ojha and Jeremy Schnittman. Robin Corbet contributed expertise on binary systems, W. Dean Pesnell informed the treatment of solar variability and Regina Caputo clarified the evidential status of dark matter. Together, their explanations and gestures provided scientific grounding, metaphorical cues and pacing principles that shaped the construction of *The Movements of the Universe*.

3.4.2. Field Access and Filming Locations

Access to NASA facilities as an artist was an unusual opportunity, made possible through my participation in the Astro-animation class, which granted me the necessary credentials for on-site research. This access allowed me to conduct interviews, observe scientists in their professional environment and work in specialised facilities such as the green screen studio at NASA Goddard Space Flight Center.

Filming began in my apartment, where lighting issues, reflections, uneven exposure and limited environmental control created practical challenges (see Figure 3.6). The guitar visible in the frame formed part of Robin Corbet's explanation of gravitational waves, although this segment was later omitted from the final edit.



Figure 3.6: Dr Robin Corbet being interviewed in my apartment.

Seeking improved recording conditions, I moved to the NASA library, which offered a strong visual backdrop and also introduced audio disruption from ambient conversation and echo (see Figure 3.7).



Figure 3.7: Dr Roopesh Ojha and Dr Elizabeth Ferrara preparing for interviews in the NASA library.

Access to NASA's green screen studio significantly improved the recording conditions, providing professional lighting, sound isolation and technical support over several interview days. This improved the footage quality and expanded my understanding of production tools that supported the project's visual and conceptual development (see Figure 3.8).



Figure 3.8: Filming scientists Dr Jeremy Schnittman (left) and Dr John Mather using a green screen.

3.5. Animation Techniques and Creative Translation

After the interviews, I began compositing green-screen footage in Adobe After Effects, combining it with Adobe Animate, Photoshop and hand-drawn sequences. A representative example features Dr Regina Caputo. Filmed against a green screen, her image was converted to black and white, with only her hands and shirt retaining colour to highlight their expressive role. A starry sky replaced the background and an animated galaxy was inserted between her hands, creating the impression that she was interacting with the universe (Figure 3.9).

Animating the scientists' gestures proved especially productive. Using keyframes in After Effects, I mapped their hand movements and refined motion curves to ensure natural transitions. This contributed to the clarity and emotional resonance of their explanations (Figure 3.10).



Figure 3.9: Stages of integrating Dr Regina Caputo's green-screen footage: (1) original green-screen recording, (2) black-and-white conversion with hands/shirt in colour, (3) star-field background added, (4) animated galaxy composited between her hands.

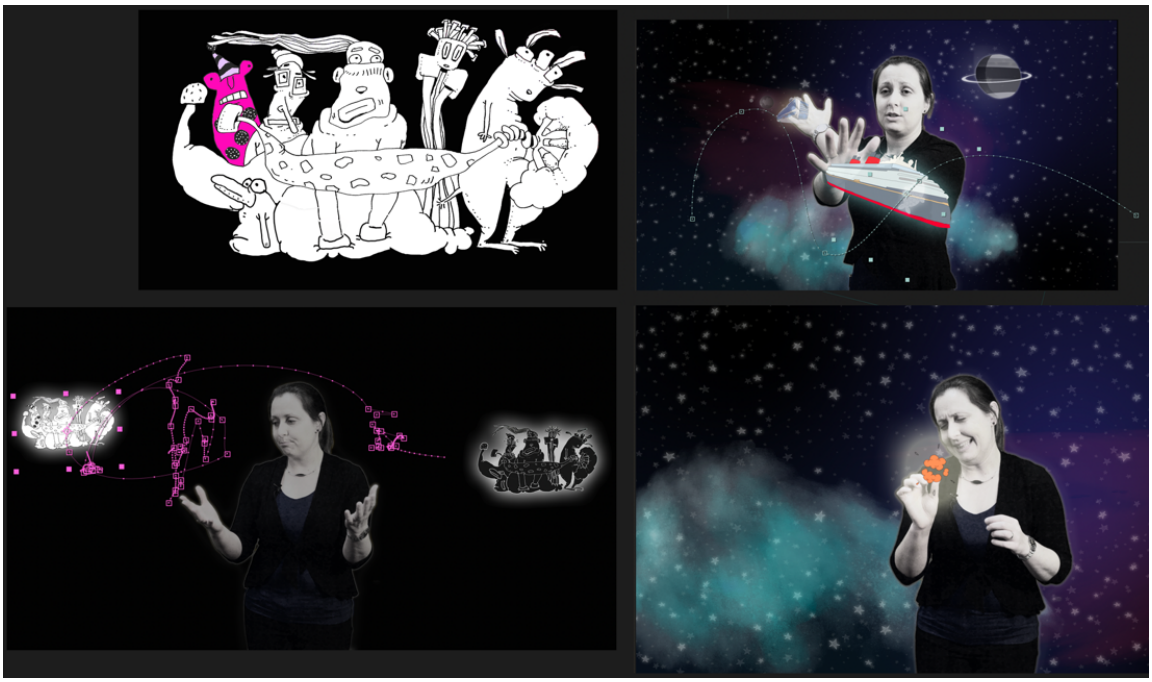


Figure 3.10: Workflow images of Dr Regina Caputo's explanations, incorporating hand-drawn animation and animation curves with keyframes in After Effects.

Crafting these sequences required careful attention to motion, colour, light and texture. These decisions shaped the film's visual form and supported the project's aim of combining affective engagement with scientific coherence. The next section introduces the completed film as the central creative output of Strand 1 and the basis for the follow-up interviews with scientists.

3.6. Presenting *The Movements of the Universe*

The Movements of the Universe opens with Nobel Laureate Dr John Mather, who introduces the origins of the cosmos and the earliest moments following the Big Bang. The film is structured as a progression across scale and processes, moving across cosmology, compact objects, solar activity and inferred phenomena such as dark matter. Gesture-informed animation shapes the unfolding of explanation on screen, with movement, pacing and visual rhythm supporting the communication of complex processes.

The film combines sequences derived from scientists' gestures with more freely animated passages in which astronomical concepts are explored through my own visual language. Some sections respond directly to hand movements recorded in the interviews, while others use abstract forms, particles, textures and playful transformations to evoke phenomena that cannot be directly observed. In representing the early universe, for example, I drew on forms reminiscent of children's toys or small animated objects. These allowed me to explore acceleration, cooling, interaction and separation through visual metaphor rather than literal depiction. The sequence became a personal and imaginative response to the early cosmos, shaped by visual memory and an intuitive sense of matter, motion and formation.

At times, the scientists appear on screen with their gestures integrated into the animated image; elsewhere, only the hands or their traces remain. This selective treatment allows gesture to function as a visual motif linking scientific explanation to metaphorical transformation. By isolating hands, movements and gestural fragments, the film emphasises the passage between concept and image. The scientist's hand becomes both evidence of explanation and a generative element within the animated world. This approach also alludes to early animation's visible hand and to Crafton's idea of the 'hand of the artist' (Crafton, 1979), while shifting attention from the animator's hand to the scientist's hand as a source of metaphor, explanation and visual transformation. Within the film, the hand operates as a mediating element through which observation, imagination and interpretation are brought into relation.

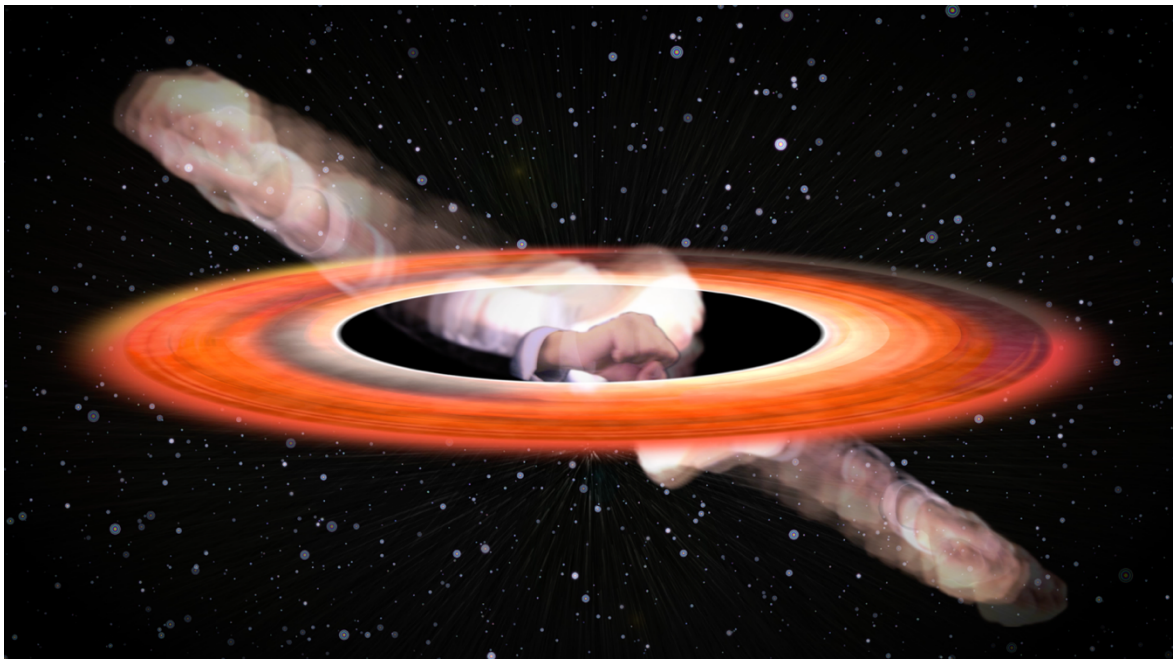


Figure 3.11: Gesture-informed animation in The Movements of the Universe. NASA astronomers' gestures are integrated with animated visualisations of cosmic phenomena.

The Movements of the Universe can be viewed at arcadiasphd.com or by scanning the QR code below.

Figure 3.12: QR code for The Movements of the Universe.

The completed film became the basis for follow-up interviews with the participating scientists, discussed in the next section.

3.7. Post-Production Interviews: Thematic Analysis of Scientist Gestures

Once *The Movements of the Universe* was completed, I conducted semi-structured follow-up interviews with the participating NASA scientists to gather feedback on the integration of gesture and animation. Of the seven collaborators, five were interviewed via Zoom between October 2024 and March 2025. One was unavailable and another declined due to workload. Each interview lasted between 20 and 60 minutes. These offered insight into how scientists perceived their gestures on screen and how they evaluated animation as a means of clarifying scientific ideas. An edited clip from these interviews is included in Volume 2 and can be accessed at arcadiasphd.com/research.

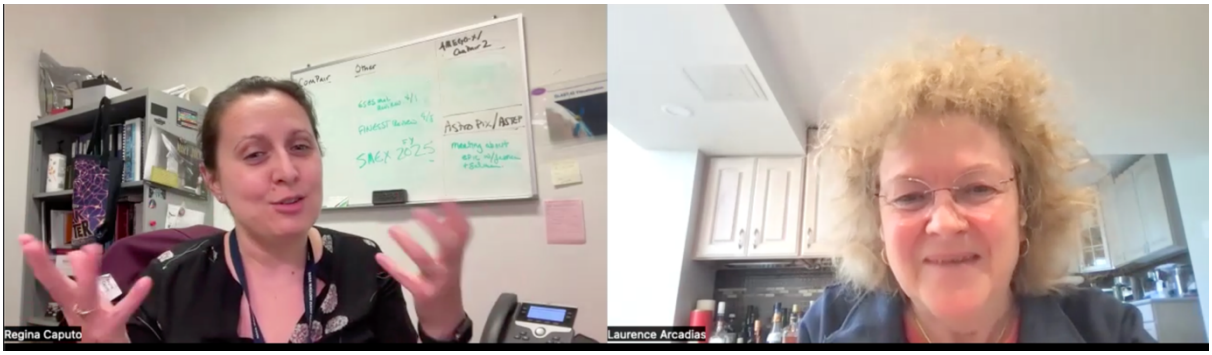


Figure 3.13: Zoom interview with Dr Regina Caputo during a semi-structured discussion.

3.7.1. Analytical Method: Reflexive Thematic Analysis

The interview transcripts and gesture-rich footage were examined using reflexive thematic analysis (Braun and Clarke, 2006). Coding focused on gesture, emotional tone, audience awareness and adaptation to the medium. MIRO was used to organise codes and themes, while reflexive memos documented interpretive decisions shaped by my dual role as animator and researcher.

Verbal metaphors and embodied gestures were examined in parallel to trace how analogy operated across speech and physical demonstration. The analysis distinguished between metaphors articulated verbally and those enacted visually or gesturally. Both were coded using the structural, ontological and orientational categories proposed by Lakoff and Johnson (2003), enabling cross-modal comparison between linguistic and embodied metaphor.

Thematic Dimension	Schnittman	Mather	Ojha	Corbet	Caputo	Summary Notes
Animation Integration	Intuitive & Deliberate (Dance-Inspired)	Some alignment, no conscious adaptation	Metaphoric & Deliberate	Structured demonstrations	Expressive alignment with emotion	Gestures support narrative alignment with animation across styles
Audience Engagement	Adapts gestures to audience	Rare use of gesture	Actively engages through gesture	Uses gestures for explanatory clarity	Builds emotional connection	Engagement levels vary; Ojha and Schnittman adjust, others rely on intuition
Learned vs. Intuitive	Media-trained yet intuitive	No formal training, stable style	Natural but consciously refined	Mostly spontaneous, refined by teaching	Mixed of intuitive & learned style	Most gestures are intuitive; learning arises through teaching or performance
Medium Adaptation	Adjusts gestures for audience	No adaptation across settings	Modulates gesture scale by setting	Does not change gestures by medium	Sees gesture as a tool for connection	Training and cultural background subtly shape gesture use
Emotional Functions	Communicates enthusiasm vividly	Uses gesture to express awe	Links enthusiasm to audience connection	Prioritises clarity over emotion	Highly expressive when passionate	Emotional expression enhances impact; varies by individual style
Gesture and Performance	Distinguishes gesture as explanatory	Contrasts with magician's misdirection	Sees strategic use in both scientists and magicians	Clarifies contrast to illusion	Not explicitly discussed	Scientists frame gesture as clarifying, not performative or deceptive

Table 3.1: Comparative Summary of Thematic Dimensions in NASA Scientists' Use of Hand Gestures.

Table 3.1 compares five NASA scientists across six thematic dimensions identified through reflexive thematic analysis. It highlights individual styles and shared patterns in the use of gesture for animation, audience engagement, emotional expression and science communication.

3.7.2. Visual Tools and Photo Composites

Table 3.1 provides a comparative overview of how each participant's gestures relate to the six thematic dimensions identified in the study. It highlights differences in gestural style, ranging from structured and deliberate to spontaneous and expressive, while also revealing shared assumptions about gesture as a resource for explanation, engagement and understanding. The composite photographic sequences that follow extend this discussion by showing gesture as embodied practice.

Dr Schnittman



Figure 3.14: Dr Schnittman demonstrating various gestures during his interview.

This composite in Figure 3.14 captures circular, expansive and metaphorical gestures that translate orbital motion and gravitational curvature into embodied form, reflecting his intuitive–deliberate hybrid style (see Section 3.7.3.1).

In interview responses, Dr Schnittman described gesture as a way to convey enthusiasm and support audience engagement:

"Showing my excitement through my hand gestures is a way to convey my interest in the subject. By expressing my enthusiasm, I can help the audience feel engaged and interested too."

Dr Corbet



Figure 3.15: Dr Corbet demonstrates the orbital motion of binary stars through hand gestures.

This image underlines his use of structured, repeatable movements, especially in classroom contexts.

Dr Corbet's gestures were primarily functional and grounded in years of teaching experience. His repeated demonstrations emphasised clarity, stability and instructional efficiency.

"*In the classroom, I do things like illustrating the Doppler effect by spinning around*."

Dr Caputo



Figure 3.16: Dr Caputo using expressive gestures to explain complex ideas.

Dr Caputo's gestures emerged organically and powerfully, amplifying the emotional tone of her explanations. She described expressiveness as integral to her communication style:

"*When I am excited, I become more and more expressive with my hands; I've always used my hands to express myself*."

Dr Ojha



Figure 3.17: Dr Ojha bringing abstract ideas to life through movement and metaphor.

Dr Ojha's gestures were intentional and shaped by teaching experience and performance influences. He often rehearsed gestures to support narrative clarity, as illustrated in his explanation of neutron stars:

"When explaining neutron stars, I demonstrate contraction and spinning by pulling my arms in like a figure skater."

Dr Mather



Figure 3.18: Dr Mather during a recorded interview session.

Dr Mather described himself as more verbally oriented, using few gestures in public communication:

"I mostly speak with words; I don't do hand gestures naturally."

While technical issues limited visual documentation, his interview responses still reflect a comparatively restrained physical style. Across participants, movement ranged from structured and metaphorical to demonstrative, expressive and reserved. These composites complement the thematic analysis by showing how scientists used distinct physical vocabularies to support explanation and engagement.

3.7.3. Thematic Findings

Consistent with Goldin-Meadow's (2003) account of gesture as a form of externalised thought, the scientists' reflections showed that gesture often conveyed aspects of reasoning not fully articulated in speech. Their responses also indicated how gesture shaped clarity, interpretation

and engagement in scientific explanation. Across participants, the analysis identified six thematic dimensions of gesture in science communication, as summarised in Table 3.1.

Each theme is presented with a guiding question, interpretive commentary and supporting quotations. Taken together, the themes show that gesture functioned as both a communicative aid and a resource for animation development.

3.7.3.1. Theme 1: Gesture and Animation as Mutually Reinforcing Modes of Explanation

Guiding Question: *How do your gestures interact with my animation in the film?*

Scientists consistently described gesture and animation as mutually reinforcing. Dr Schnittman and Dr Ojha, for example, used dynamic gestures and movement analogies that aligned closely with the animation's metaphorical transformations. Although Drs Mather and Corbet did not consciously adapt their gestures for the film, the animation nevertheless amplified their explanations by making implicit motion visible. Dr Caputo's expressive gestures, by contrast, heightened emotional resonance and connected abstract astrophysical concepts with affective experience. She noted that "*when I was talking about a galaxy and suddenly there was a galaxy swirling in*," the alignment between gesture and animation brought her explanation to life.

Dr Schnittman similarly described the result as a convergence between abstraction and lived experience: "*The real world interpreted with the animated world reminds me about the mathematical and the real world*."

These reflections suggest that the scientists experienced the final integration of gesture and animation as intuitive and organic. Gesture provided material for visual translation while also prompting new ways of thinking through scientific explanation.

3.7.3.2. Theme 2: Gesture as a Communicative Strategy for Audience Engagement

Guiding Question: *How do you use your hands when explaining scientific concepts***?**

Participants described differing levels of gestural awareness shaped by teaching experience, personality and communicative context. Dr Ojha reported rehearsing gestures to support narrative clarity, echoing Mayer's (2001) Multimedia Learning Theory, while others, most notably Dr Schnittman, favoured spontaneity, aligning with Merleau-Ponty's (2012) account of gesture as pre-reflective expression. Drs Mather and Caputo similarly relied on intuitive movement, suggesting that gestural style often develops implicitly through practice.
As Dr Schnittman explained,

> *"When I think too much about them, it feels awkward, I try to let them be natural."*

These accounts show that gestural style emerged through different communicative habits, but in each case it shaped how scientific ideas were framed for audiences. For the animation process, this meant attending not only to movement itself, but also to the communicative intention embedded within it.

3.7.3.3. Theme 3: Gesture as Mnemonic Support

Guiding Question: *Do gestures help people remember scientific ideas?*

Scientists frequently linked gestures to memory and recall. Dr Schnittman emphasised that gestures help concepts *stick*, aligning with Goldin-Meadow's (2003) view that gesture supports cognition by externalising thought and reinforcing learning. Others described recalling teachers whose dramatic gestures made explanations memorable, highlighting how movement can anchor abstract ideas in experience.
Ojha recalled,

> *"I remember teachers using dramatic gestures and those moments stayed in my memory."*

Corbet similarly explained,

"When I do physical demonstrations, it helps people remember."

Even when gestures were not consciously choreographed, they functioned as mnemonic supports, reinforcing the value of embodied explanation in scientific teaching. Within the animation process, these movements also provided cues for rhythm, emphasis and metaphorical framing.

3.7.3.4. Theme 4: Expressive Gestures and Affective Communication

Guiding Question: *Do gestures help express your excitement or connection to a concept?*

Expressive gestures emerged as an important means of conveying enthusiasm and affect. Drs Schnittman and Caputo used expansive movements to communicate excitement, while Dr Ojha linked physicality to emotional connection with the material. Drs Mather and Corbet emphasised clarity, although their responses still indicated an affective investment in the concepts under discussion.

As Mather put it,

"Here it shows my excitement about the grandeur of the expansion of the universe."

Caputo echoed this sentiment, noting,

"When I am excited, I become more and more expressive."

These reflections suggest that emotional transparency formed part of the communicative act itself. In the film, this dimension supported a mode of science communication in which feeling and explanation were not treated as separate.

3.7.3.5. Theme 5: Context-Responsive Science Communication Strategy

Guiding Question: *Do you change your gestures depending on the medium?*

Scientists described adapting their gestures according to audience and setting. Schnittman explained that he tends to 'over-animate' for children or large audiences, while Ojha adjusted the scale and precision of his gestures in smaller, more intimate contexts.

Ojha noted, "*I use larger gestures for big audiences, but smaller, precise movements in one-on-one interactions*," while Schnittman added, "*For children, I use simpler, less aggressive gestures. On a large stage, I have to over-anima*te."

These responses show that gesture functioned as a context-responsive communicative strategy shaped by audience, scale and mode of address. This sensitivity later became important for Toolkit development, where prompts and activities had to remain adaptable across different workshop settings.

3.7.3.6. Theme 6: Gestural Movements as Acts of Clarification

Guiding Question*: How do scientists' gestures differ from performers like magicians?*

Several scientists distinguished their gestures from performative practices such as magic or stage illusion. Unlike magicians, whose gestures often divert attention or obscure mechanism, the scientists described their own movements as acts of clarification, used to trace trajectories, indicate scale, or model force. I interpret this distinction as an ethic of epistemic sincerity: a commitment to making reasoning visible through gesture.

Corbet noted that "*magicians use hand gestures to mislead, while scientists use them to clarify.*" Schnittman echoed this sentiment humorously*: "There's nothing up my sleeve! My hands are here to help explain, not mislead*".

This framing aligns with Latour and Woolgar's (1979) account of scientific communication as a performance of credibility, in which gesture supports trust and intelligibility. Within the film, this distinction reinforced the use of animation as explanatory in intent, positioning movement as a conduit for understanding.

3.8. Thematic Synthesis: *The Movements of the Universe*

This section returns to *The Movements of the Universe* in order to synthesise how the thematic findings from Section 3.7.3 informed the film's visual development. It focuses on recurring elements including gesture, scale, rhythm, metaphor, sound and affect, showing how embodied explanation was translated into animated form. It also identifies the initial principles that later informed Toolkit development in Strand 2 and workshop adaptation in Strand 3.

3.8.1. From Gesture to Visual Form: Creating The Movements of the Universe

At the centre of this inquiry is the relationship between movement and meaning. Scientists' gestures functioned both as communicative acts and as prompts for visual development, informing metaphor, motion, rhythm and form. In this context, gesture became a mode of visual thinking.

In my reflexive creation of *The Movements of the Universe*, gesture, tone and presence guided the animation's visual and affective structure. Selected gestures were translated into parameters such as direction, speed, scale, opacity, layering, rhythm and transformation. A circular motion might suggest orbital movement; an expanding gesture might inform spatial growth; a compressive movement might become a cue for density, force, or collapse. This process was interpretive rather than literal, but it allowed embodied scientific explanation to enter the film's visual structure.

The animation remained open to metaphor and artistic intuition, while being checked through review with collaborators to reduce the risk of scientific misunderstanding. For example, Dr Caputo's hand placement suggested the compression of a galaxy between her palms, which I reinforced visually with a swirling galactic disk. Dr Ojha's mimed jets from a black hole inspired the use of transparent hand overlays to suggest temporality and motion. Dr Schnittman's gestural expansiveness evoked a Van Gogh-like aesthetic that informed the colour palette and background design.

These examples show how gesture operated as both source material and design method. The scientists' movements informed pacing, layering, scale and visual emphasis, shaping how concepts became visible through animation. See example in Figure 3.19.



Figure 3.19: Dr Jeremy Schnittman explaining black hole dynamics through expansive gesture.

Departing from the cool blues and blacks typically associated with astronomy, I adopted bold, coded colours shaped by emotional tone, visual cadence and, at times, the scientists' clothing. This chromatic layering created resonance between gesture and background. In Dr Pesnell's 'photon walk,' his fingers became a playful game-like character marching across his hand, a metaphor further amplified through sound design and animated overlays. See Figure 3.20.



Figure 3.20: Dr Pesnell demonstrating the photon random walk to the surface of the sun.

In Dr Ferrara's scene, I layered hand-drawn lines into a radiant stellar form that grew to envelop her body, transforming abstract explanation into a playful animated metaphor. A particularly tactile moment unfolds in the final sequence with Dr Mather, as the camera zooms from a medium shot into the texture of his shirt and finally to his eye. This progression draws on MacDougall's (2006) notion of *tactile space*, where the eye functions like touch, inviting intimate visual proximity. The scene mirrors Mather's closing reflection on 'no limits' and is further amplified by a sonic shift from his conversational tone to a distant, echoing reverberation, enhancing the affective scale of the moment.

Across these scenes, gesture, metaphor and visual rhythm guided the animation process. After sharing early drafts with some of the scientists, their feedback clarified aspects of the science and led me to refine movement, pacing and visual metaphors. This iterative exchange created a dialogue in which their embodied explanations and my creative responses continually informed one another.

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3.8.2. Gesture, Scale and Time

Extending Themes 1 and 5, this section examines how gesture informed the treatment of scale, texture and time in the animation. These dimensions were central to representing cosmic phenomena that exceed ordinary human perception. Bissonnette's (2014) discussion of scalar animation is useful here because it frames animation as a medium capable of moving across scales beyond bodily perception. This also aligns with Buchan's account of animation as a pervasive form capable of constructing worlds, temporal experience and perceptual relations (Buchan, 2013). In this study, animation allowed scale and time to be explored through pacing, duration, visual rhythm and transformation. By slowing down, extending, or compressing movement, the process offered a way of engaging with astrophysical time and making change perceptible.

Translating events such as gas bursts, ray emissions, or galactic motion required balancing scientific reference with artistic interpretation. I often began with accurate forms, then abstracted them through rhythm, painterly texture and motion to support a more intuitive understanding. This approach relied on a hybrid process in which hand-drawn textures were layered within Adobe After Effects to maintain a tactile visual quality. Complex scenes, such as swirling black holes, required careful integration of motion paths with expressive visual elements to achieve both dynamism and scientific plausibility.

Gesture, scale, texture and time functioned as interconnected elements within this process. Gestures often suggested force or dimension; scale shaped spatial relationships; texture introduced tactile abstraction; and time structured pacing and rhythm. As illustrated in Figure 3.21, these parameters interact within a hybrid animation workflow in which embodied cues and visual experimentation are synthesised into an interpretive visual language. This process produced an animated form grounded in scientific logic and shaped through creative intuition.

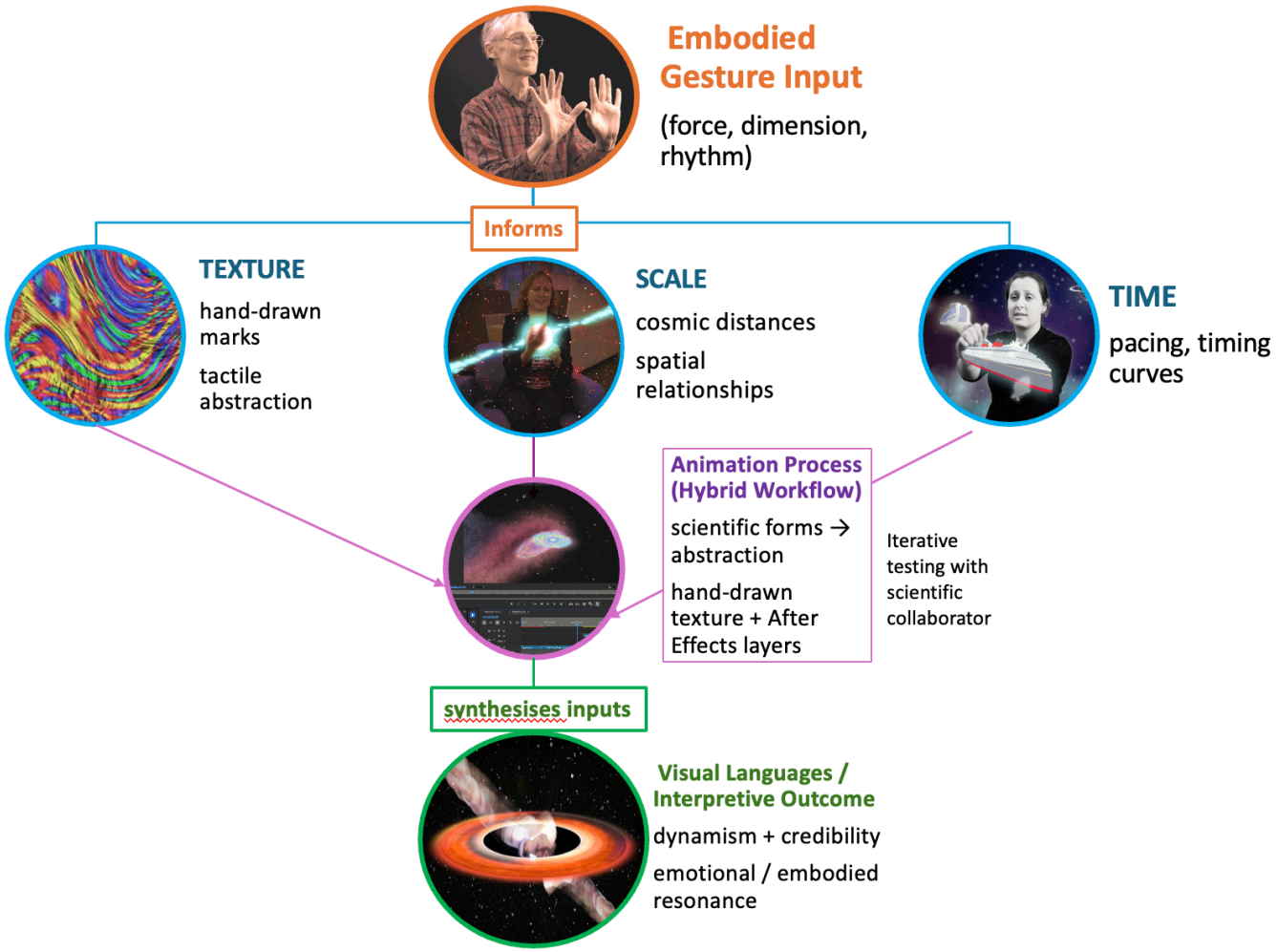


Figure 3.21: Visual Integration of Gesture, Texture, Scale and Time in Astro-animation Practice.

The diagram shows how scientists' embodied explanations informed animation parameters including texture, scale and time. These were synthesised through a hybrid workflow combining scientific reference with hand-drawn and digital processes, balancing scientific plausibility with expressive, tactile imagery

3.8.3. From Strand 1 to the Initial Toolkit

Strand 1 generated the initial principles, prompts and visual strategies from which the Astro-animation Toolkit began to emerge. Analysis of scientists' gestures, metaphors and embodied explanations identified several recurring elements that informed workshop design. These included gesture as a starting point for visual interpretation, metaphor as a means of making

abstract phenomena imaginable, pacing and rhythm as structuring devices for explanation and drawing-based experimentation as a bridge between scientific concept and animated form.

At this stage, these elements functioned as provisional Toolkit components. In Strand 2, they became the basis for more systematic refinement through expert feedback and workshop structuring. In Strand 3, they informed participatory activities through which students and community participants engaged astronomical ideas through drawing, movement, sequencing and discussion. Strand 1 therefore established not only the film's creative logic, but also the practical and conceptual foundations for the later Toolkit and its public application.

Reflective Note: Strand 1

At this stage, I did not yet understand the Toolkit as a formal output. What emerged through the film process was a set of recurring practices: observing gesture, identifying metaphor, testing movement and revising visual decisions based on scientific feedback. These practices later became the conceptual basis for Toolkit refinement in Strand 2 and participatory workshop design in Strand 3.

Strand 1 therefore established the creative and methodological foundation for the subsequent Toolkit development.

3.9. Summary of Chapter 3

Strand 1 traced the development of *The Movements of the Universe*, a practice-based animation project that examined how scientific gesture could inform the communication of complex astrophysical ideas. Through collaboration with NASA scientists, filmed interviews captured embodied explanations that became source material for animated sequences addressing black holes, gravitational waves, cosmic expansion and related phenomena. The chapter showed how scientists articulated thought through gesture and how these embodied cues shaped visual decisions in animation. Through iterative cycles of experimentation, reflective journaling and dialogue with scientific collaborators, the film

developed as a process of inquiry in which movement, timing, metaphor and spatial organisation structured meaning.

The analysis identified six thematic dimensions relating to explanation, audience engagement, memory, affect, medium adaptation and clarification. These findings did not remain confined to the film. They generated initial principles that informed the refinement of the Astro-animation Toolkit in Strand 2 and its later application in participatory workshop settings in Strand 3. Strand 1 therefore established the creative, analytical and methodological foundation for the wider thesis.

Chapter 4: Strand 2: Toolkit Development through Co-Creation with Experts

4.1. From Collaboration to Framework: Developing the Astro-animation Toolkit

Building on the gesture-informed principles established in Strand 1, Strand 2 examines how this process could be translated into a structured workshop format. It introduces the Astro-animation Toolkit as an emerging framework for participatory astronomy communication, grounded in analogue animation-making, scientific framing and reflective creative practice. Through the workshops discussed in this chapter, the Toolkit was tested as a practical method for supporting conceptual understanding, affective response and exploratory reasoning. Participant feedback and workshop observations identified the need for clearer instructions, stronger visual prompts, more explicit sequencing guidance and opportunities for reflection and sharing. These findings shaped the five-stage workshop sequence and the facilitative elements presented later in the chapter.

In this chapter, 'expert' refers to participants whose disciplinary knowledge, whether scientific, artistic, educational, or practice-based, informed the development of the Toolkit before its wider public implementation. Some of the early workshops discussed in Section 4.1.1 predated the doctoral project, but they provided foundational insight into how art and science could be integrated collaboratively. These initiatives shaped the Toolkit's initial structure and informed the more systematic development undertaken during Strand 2.

The workshops are presented as stages in the Toolkit's development. The BSA pilot identified the need for a portable and accessible animation format. The New York DOT Astronomy Conference highlighted the importance of clearer prompts, examples and sequencing explanations. The HEAD 21 workshop showed how narrative framing, metaphor and affective response could be supported in a specialist astronomy setting. The Transart/LJMU workshop extended the method into an artistic research context, where reflection, symbolism and interpretive freedom became especially visible. Together, these workshops informed the final Toolkit structure presented in Section 4.6.

4.1.1. Toolkit Prototyping: Early Development and Feedback

The first prototype of the Astro-animation workshop was piloted in May 2022 at the Baltimore School for the Arts (BSA), organised in collaboration with Dr Robin Corbet and supported by the Maryland Space Business Roundtable. This early workshop functioned as an early test case, revealing practical constraints and opportunities that later shaped the Astro-animation Toolkit.

At BSA, the workshop was planned collaboratively by BSA animation teachers, MICA students serving as research assistants and astronomer Dr Corbet. Planning focused on designing art–science activities for students aged 14 to 17 that could sustain engagement with astronomical concepts through making. Although it took place in a classroom, the format followed a more informal, after-school dynamic, encouraging experimentation, discussion and hands-on participation. The workshop was delivered in two sessions, each combining short scientific presentations with hands-on creative activities.

Three activity formats were tested. A large-scale collaborative colouring exercise enabled students to engage physically with projected astronomical imagery, supporting collective discussion and interpretation (Figure 4.1). Stop-motion animation activities invited participants to represent dynamic cosmic processes using drawings and physical materials (Figure 4.2). A third activity involved colouring and animating real images of comet 67P from the Rosetta mission, integrating scientific data with creative transformation (Figure 4.3).



Figure 4.1: BSA students engaging with a large-scale collaborative colouring exercise to explore astronomical imagery.



Figure 4.2: BSA students representing astronomical concepts through stop-motion.



Figure 4.3: BSA students with printed imagery from the Rosetta mission's observations of comet 67P.

Pre- and post-workshop surveys were conducted with 18 students using a five-point Likert scale. While the cohort was small, such datasets can offer valuable formative insight within practice-based, design-based research, where the aim is to identify patterns, usability challenges and directions for refinement. Moderate increases were observed across all categories, with the most pronounced growth in interest in animation and science-related careers (Figure 4.4). These findings functioned as early indicators of engagement, complementing observational and qualitative feedback gathered during the workshop.

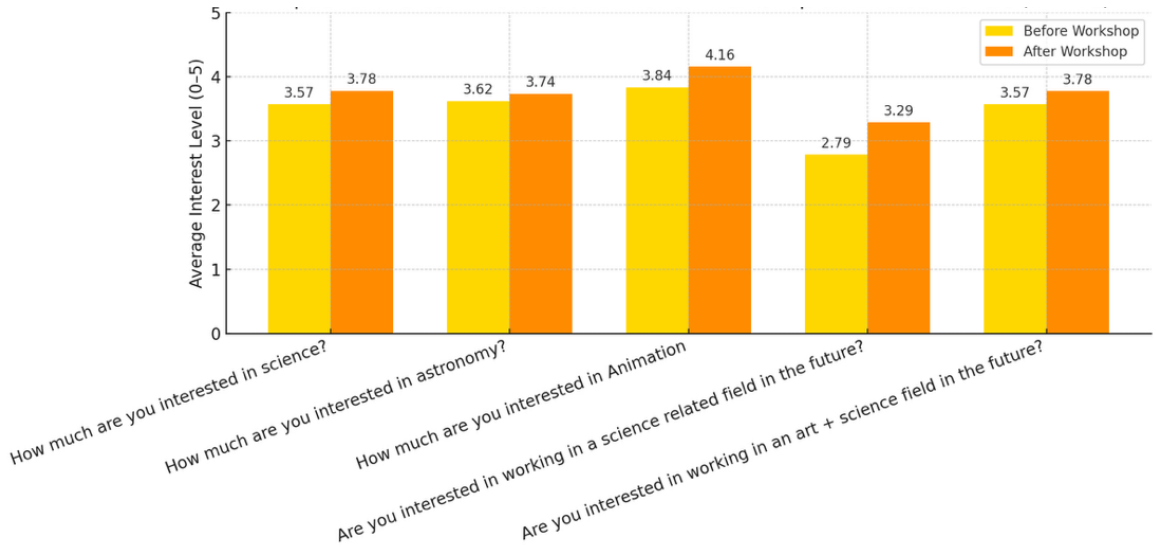


Figure 4.4: Impact of the initial BSA pilot Astro-animation workshop on student interest levels (n = 18).

These findings functioned as early indicators of engagement, complementing observational and qualitative feedback gathered during the workshop.

These early forms of feedback also informed decisions about workshop structure. The range of activities tested at BSA highlighted the need for a more transferable format. In this context, film-print animation refers to an analogue process in which participants draw, colour, or intervene directly onto printed film frames or image sequences that are later digitised and assembled into moving image form. It required minimal materials, accommodated participants with varied artistic experience and enabled direct engagement with scientific imagery. As a result, film-print animation became the core format of the Astro-animation Toolkit. Building on

these early insights, the approach was next tested within professional astronomy settings, beginning with its implementation at the New York DOT Astronomy Conference.

4.2. New York DOT Astronomy Conference (Scientists and Amateur Astronomers)

Group: Professional and amateur conference astronomers

Title of the workshop: Flying by Pluto

Held in October 2023, The New York DOT Astronomy Conference marked an important stage in refining the Astro-animation workshop concept. This two-day event brought together scientists, educators and astronomy enthusiasts in an *unconference*, a participant-driven format fostering collaboration and creative experimentation. Unlike traditional conferences with structured presentations, it allowed attendees *to* propose and lead their own sessions, providing an ideal setting to test Astro-animation as a participatory science communication tool (Kendrew et al., 2020).

During this event, an Astro-animation session titled Flying by Pluto was introduced. Ten participants animated NASA's *New Horizons* flyby of Pluto using four-frame image sheets derived from mission imagery (Figure 4.5). Although the group possessed scientific expertise, most had little or no experience with animation. This made the session a useful test of how clearly the workshop format could be introduced to non-animators.



Figure 4.5: Scientists from the Dot Astronomy conference attending the Astro-animation workshop.

Following a brief scientific introduction by Dr Robin Corbet, participants engaged in drawing and colouring sequences with minimal technical instruction. The resulting images were digitised, assembled into an animated sequence using Adobe Premiere and screened during the conference's closing session. The positive reception of the final film suggested that the workshop format could support meaningful creative engagement even among participants without prior animation experience.

At this stage, the Astro-animation Toolkit had not yet been articulated as a fully defined framework. Positioned between earlier public-facing workshops and the later consolidation of the Toolkit's structure, prompts and facilitation strategies, this session functioned as a formative implementation through which key needs and points of friction became visible. The participant-produced film from this workshop is included in Volume 2 as an example of the workshop's early format and creative outcomes.

4.2.1. Survey Insights: New York DOT Survey Findings

Survey responses (n = 5) were analysed descriptively to identify patterns in participant experience and suggestions for refinement. Although the sample was small, the data provided

early insight into how scientifically knowledgeable but artistically inexperienced participants engaged with the process. Qualitative comments and Likert-scale responses were coded thematically and visualised in a pie chart (Figure 4.6). The findings pointed to the need for clearer instructions, stronger visual examples and a more transparent explanation of how still images become an animated sequence. These refinements were later implemented and tested in expert workshops.

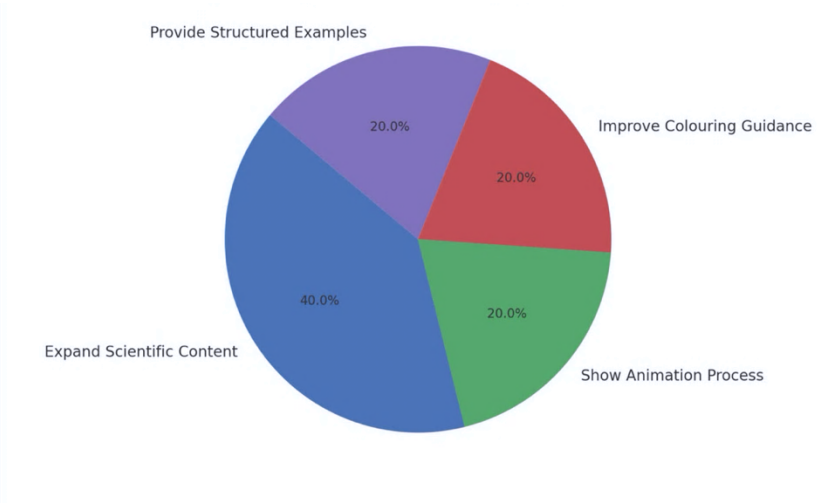


Figure 4.6: Participant Suggestions for Improvement, New York DOT Astronomy Conference (n = 5).

Figure 4.6 visualises participant suggestions from post-workshop surveys, thematically coded following Braun and Clarke's (2006) framework. Categories include Expand Scientific Content (40%), Improve Colouring Guidance (20%), Show Animation Process (20%) and Provide Structured Examples (20%). These findings informed later refinements to the Toolkit, particularly around instruction, visual examples and explanations of sequencing.

4.2.2. Qualitative Insights: Participant Feedback

Qualitative feedback reinforced and extended these findings. Participants responded positively to the creative process and to the inclusion of example animations, particularly student work: *"The MICA student videos are very cool and appealing"* (participant 2). At the same time,

several participants expressed curiosity about how individual drawings were transformed into a finished animation, indicating interest in the mechanics of sequencing and assembly: *"Showing how the animation gets made from all the photos would be interesting."* (Participant 3). In response, later iterations of the Toolkit incorporated clearer explanations of sequencing and optional demonstrations of image assembly to support both understanding and confidence.

Other participants described uncertainty during the colouring process, noting a fear of 'doing it wrong.' Requests for sample images and structured examples pointed to the need for clearer creative scaffolding, particularly for participants without artistic training. These insights informed refinements to facilitation strategies, including the introduction of visual prompts, optional examples and reassurance that interpretive variation was encouraged.

Together, feedback from the New York DOT workshop highlighted the importance of balancing openness with guidance. These refinements clarified instructional support, made the animation process more transparent and strengthened participants' creative confidence.

Toolkit Development Note: New York DOT Workshop

At this stage, the workshop format included three core elements: prepared film frames, a brief scientific introduction and participant animation-making through drawing and colouring. The New York DOT workshop showed that these elements were promising but required clearer prompts, stronger visual examples and a more explicit explanation of sequencing. These refinements informed the later development of the Astro-animation Toolkit.

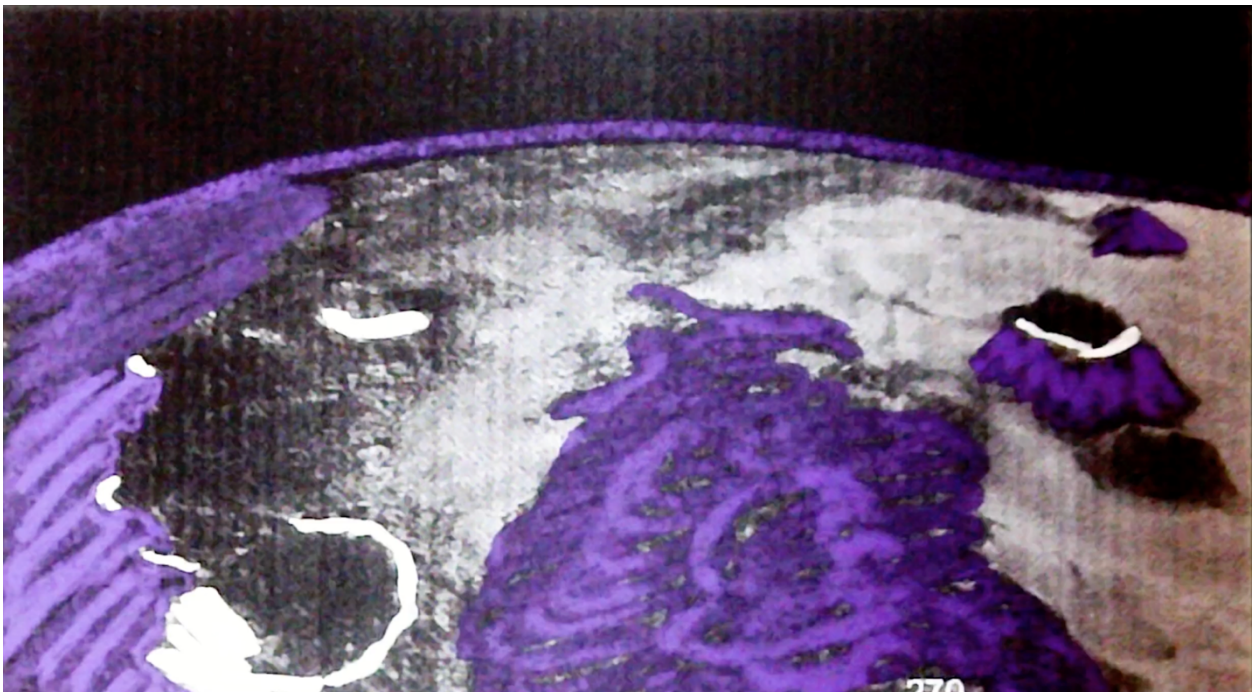


Figure 4.7: Still from Flying by Pluto, produced during the New York DOT Astronomy Conference workshop.

Figure 4.8: QR code linking to Flying by Pluto in Volume 2.

4.3. HEAD 21 Conference, Texas (Professional Astrophysicists)

Group: Conference scientists

Title of the workshop: The Eclipse



Figure 4.9: Scientists working on their animation segments

The HEAD 21 workshop, held in April 2024, provided a crucial opportunity to test the Astro-animation approach with scientific specialists. Taking place during the High Energy Astrophysics Division (HEAD) meeting in Texas, just before the total solar eclipse, the session drew approximately 30 astrophysicists. Scientists engaged readily in the animation process, treating it as an opportunity for playful experimentation and for exploring new modes of communication (see Figure 4.9). This workshop tested how the developing format supported metaphor, narrative and affective engagement within a specialist scientific context.

The session opened with a lightning talk by Dr Corbet, who situated the eclipse within cultural, historical and scientific contexts. Participants then received brief animation instructions from the Astro-animation Toolkit before working directly with printed frames from Nevil Maskelyne's 1900 eclipse film (Figure 4.10).

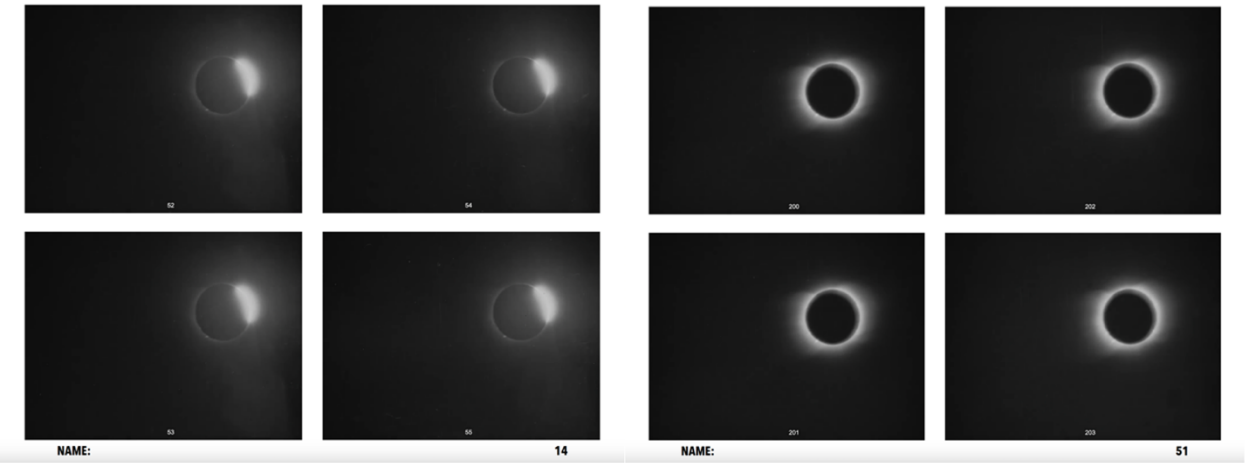


Figure 4.10: Prints from The 1900 Eclipse film by Nevil Maskelyne.

Art supplies, business cards and participant badges were also prepared for the session, helping to structure the workshop environment and support its practical delivery (Figure 4.11).



Figure 4.11: Art supplies, business cards and badges provided for the workshop.

With minimal prompting, scientists engaged in lively experimentation, producing drawings and short animated sequences that blended scientific insight with humour, metaphor and narrative invention. As part of the instructional component, the Principles of Animation

were briefly introduced through examples of patterns and simple motions, offering sufficient guidance for participants to begin their creative work (see Figure 4.12).

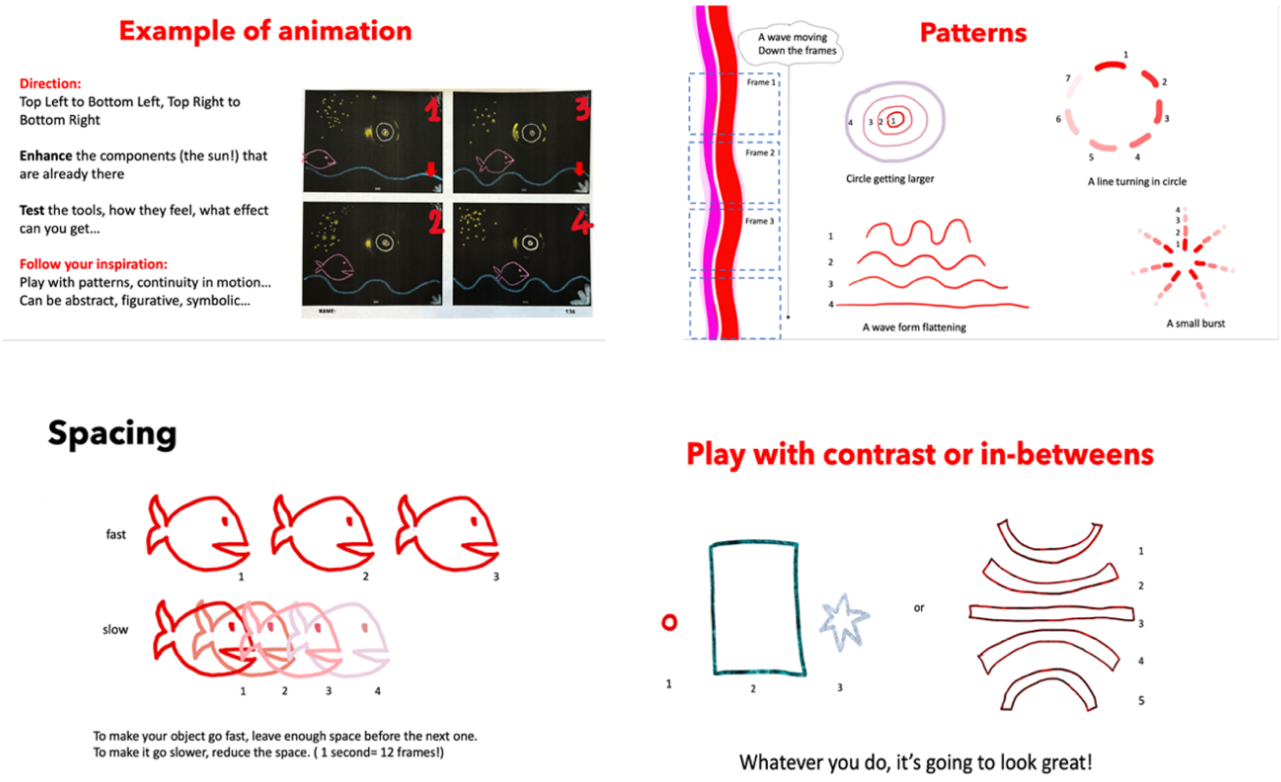


Figure 4.12: Animation instructions, slides from the Astro-animation Toolkit.

The completed drawings were photographed, sequenced in Adobe Premiere Pro and compiled into the film *The Eclipse*. The animation was accompanied by *The Sun Song*, performed by NASA's a cappella group, The Chromatics. Although the workshop itself centred on visual interpretation and analogue animation-making, the soundtrack contributed rhythm, emotional tone and cohesion across the collectively produced sequences. Informal responses from viewers during conference-break screenings suggested that the music deepened engagement with the final film by enhancing its affective register and reinforcing the sense of a shared creative outcome. In this context, sound functioned as a presentational layer that shaped how the animation was received.

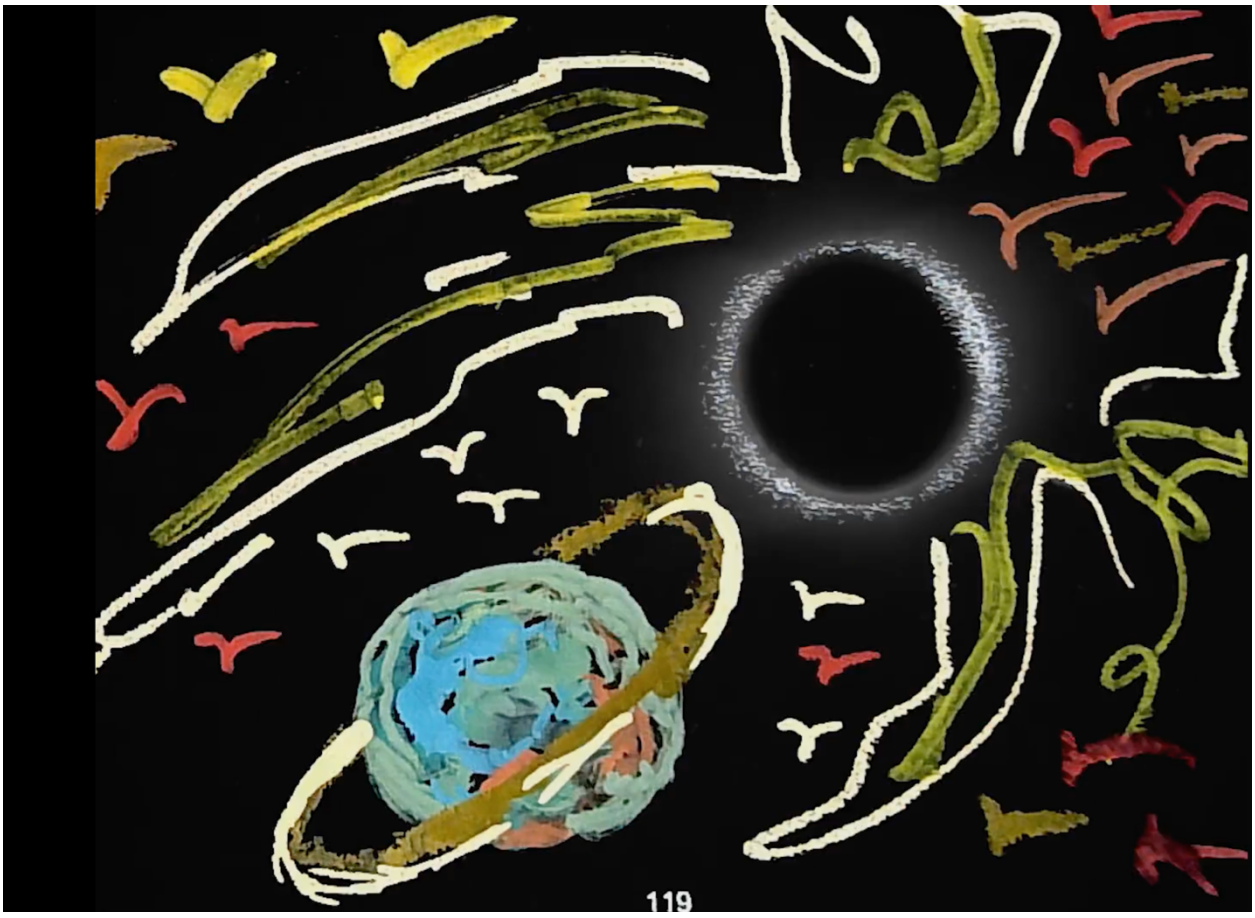


Figure 4.13: Still from The Eclipse, produced during Head 21 Conference workshop in Texas.

Figure 4.14: QR code linking to The Eclipse in Volume 2.

4.3.1. Quantitative Insights: Survey Findings

Nineteen participants completed post-workshop surveys, providing clear directional feedback on enjoyment, instructional clarity and perceived educational value. Enjoyment was rated highly (M = 4.6/5) and participants agreed that animation could support astronomy engagement for teenagers (M = 4.1/5). Instructional clarity also scored well, although several suggested minor refinements for those unfamiliar with animation. Figures 4.15 and 4.16 highlight new understandings in both animation (timing, rhythm, sequencing) and astronomy (motion, rhythm, eclipse dynamics).

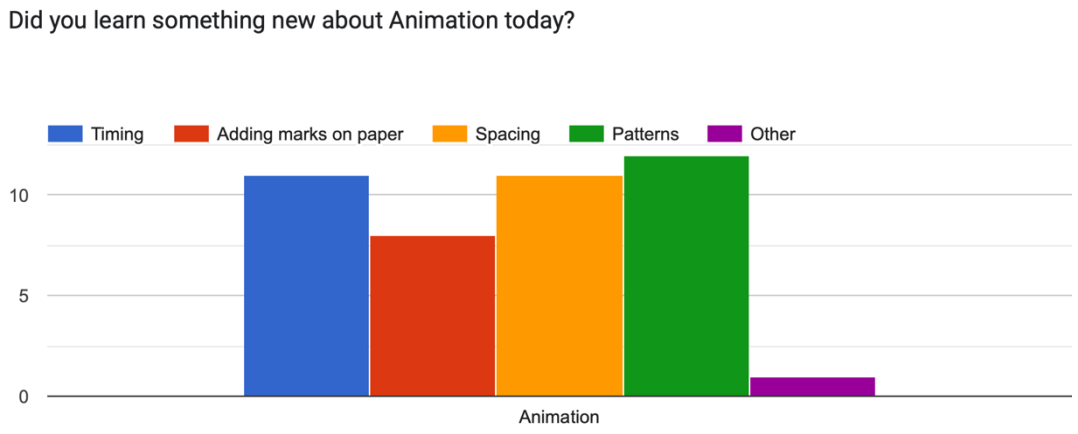


Figure 4.15: Participant self-reported learning outcomes from the HEAD 21 workshop (n = 19).

Figure 4.15 illustrates new understandings related to animation principles such as timing, rhythm and visual sequencing.

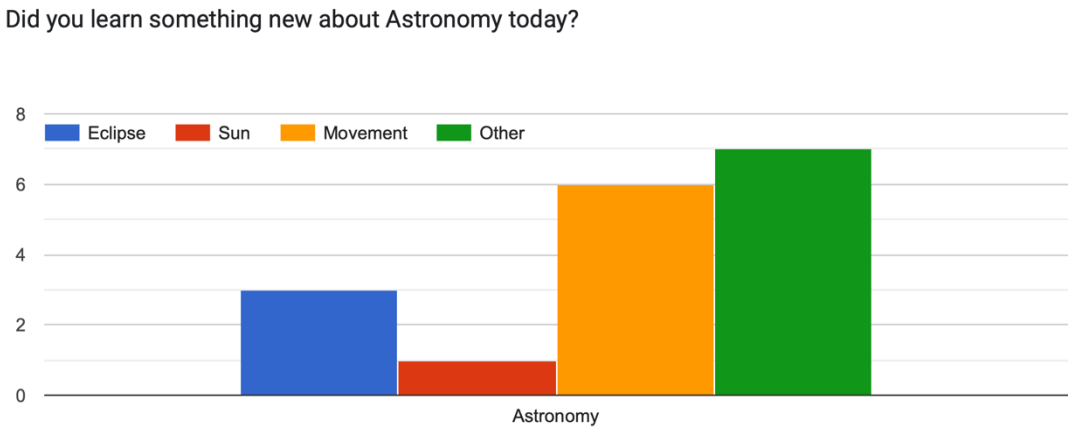


Figure 4.16: Self-reported astronomy learning outcomes from the HEAD 21 workshop (n = 19).

Figure 4.16 highlights how animation supported engagement with astronomical concepts, particularly movement and rhythmic patterns. Demographic data showed a predominantly early-career scientific cohort (ages 25–34), with most holding PhDs or master's degrees. The gender balance skewed male.

A Pearson correlation heatmap (Figure 4.17) revealed moderate positive relationships between enjoyment and instructional clarity ($r = 0.47$) and a stronger relationship between enjoyment and perceived educational value ($r = 0.58$). These findings suggest that, for scientific participants, emotional engagement appeared closely linked to perceived educational value, suggesting that affect and understanding reinforced one another in this context (Table 4.1).

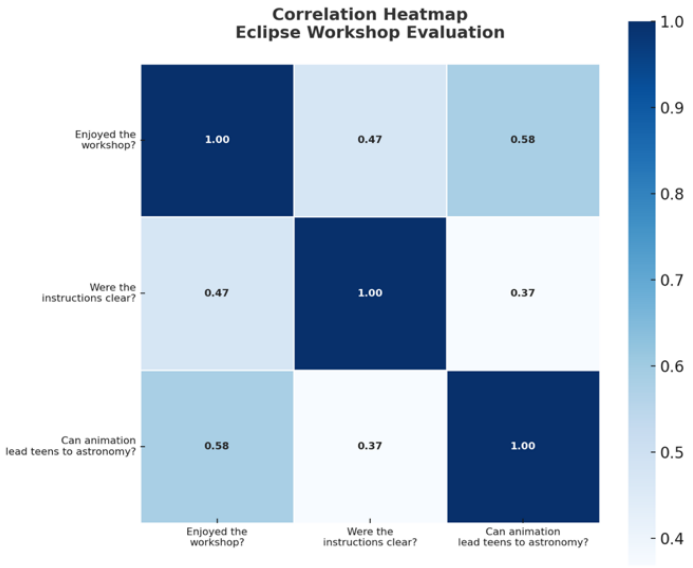


Figure 4.17: Heatmap showing relationships between participants' enjoyment of the workshop, perceptions of instructional clarity and beliefs about animation's educational value (n = 18). Darker colours indicate stronger positive correlations (r).

Variable Pair	Correlation (r)	Interpretation
Enjoyment ↔ Instructions Clear	0.47	Moderate positive relationship
Enjoyment ↔ Animation Leads to Astronomy	0.58	Stronger positive relationship
Instructions Clear ↔ Animation Leads to Astronomy	0.37	Weak positive relationship

Table 4.1: Correlation strengths between workshop variables (Pearson's r).

Note: Interpretations of correlation strength follow Cohen's (1988) conventions, where $r \approx .10$ indicates a weak effect, $r \approx .30$ a moderate effect and $r \geq .50$ a strong effect.

4.3.2. Qualitative Insights: Narrative Engagement

Participants frequently interpreted the eclipse through symbolic or emotional lenses, crafting spontaneous narratives that merged astronomical events with mythic or poetic themes. Recurring motifs included transformation, celestial relationships and cycles of disappearance and return. One participant described the eclipse as 'a love affair between the Sun and a being that emerges,' while another imagined an '*eclipse tulip*' that opens and closes with the moon's passage. Such metaphors exemplify how animation, even in simplified forms such as paper cut-outs and rotoscoping, can foster associative thinking and emotional resonance. Here, paper cut-outs involved altered paper-based elements arranged across sequences, while rotoscoping involved tracing and reworking existing film frames.

Others employed sensory and embodied language, describing the eclipse as something they could *feel* or *sense*. One remarked, "*The spaceship turns into an eye... it absorbs the identity of the Sun... it becomes ligh*t," conveying both physical and symbolic transformation. Another evoked sensory disruption and disorientation: "*The owls [were] going crazy and the towns in there being useless.*" These accounts resonate with Merleau-Ponty's (2012) theory of *embodied knowledge*, which holds that understanding is grounded in bodily perception and McNeill's (1992) concept of gesture as *thought in action*. In this context, drawing and storytelling became embodied modes of sense-making, inviting participants to engage with astrophysical ideas through intuition and affect.

Thematic analysis of interview data (Figure 4.18) supported these insights, revealing recurring engagement themes such as visual metaphor, embodied learning and curiosity-driven reflection.

Toolkit Development Note: HEAD 21 Workshop

The HEAD 21 workshop expanded the emerging Toolkit beyond the basic structure tested at New York DOT. It added a pre-selected historical film source, a contextual lightning talk by Dr Corbet, a brief animation explanation, consent buttons for photography and informal documentation through participant explanations recorded during the workshop. These additions clarified the need for the Toolkit to include scientific framing, animation instruction, consent and documentation procedures and opportunities for participants to explain the ideas behind their drawings.

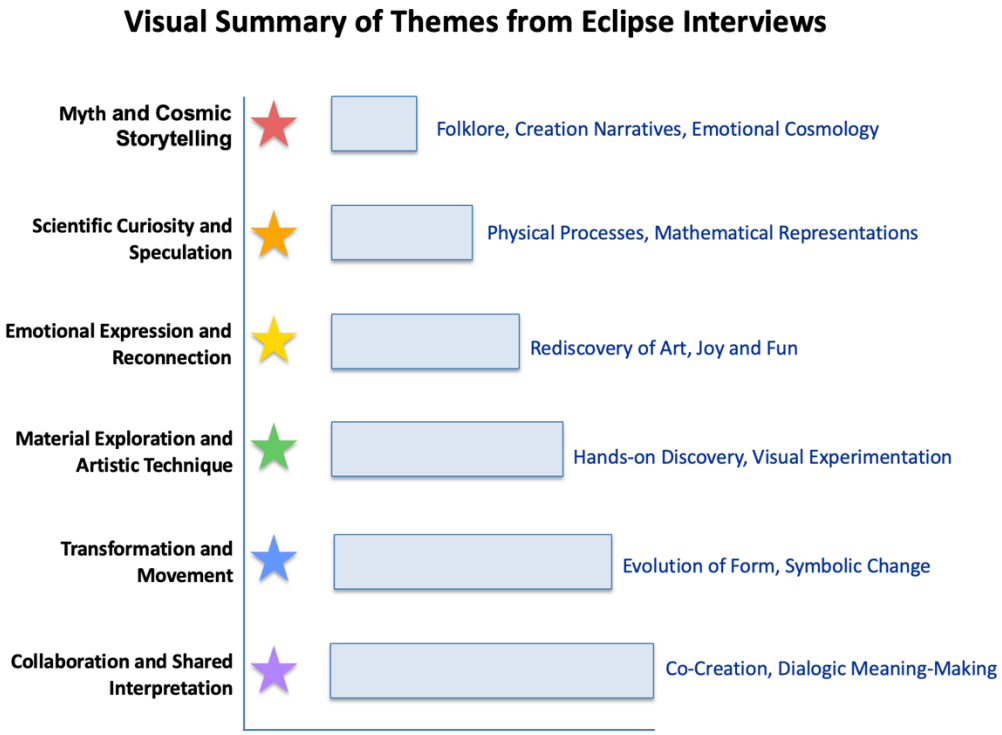


Figure 4.18: Overview of Eclipse interview reflections (n = 15).

Themes were identified through reflexive thematic analysis and visualised as major engagement dimensions (left) with associated subthemes (right). Colour-coded stars denote the six themes: red (Myth and Cosmic Storytelling), orange (Scientific Curiosity), yellow (Emotional Expression), green (Material Exploration), blue (Transformation and Movement) and purple (Collaboration and Shared Interpretation) (see Table A.7.1 in Appendix A).

The HEAD 21 workshop showed that specialist participants responded strongly to narrative, metaphorical and affective forms of engagement. Although participants shared a high level of scientific expertise, their creative responses foregrounded embodiment, storytelling, humour and emotional resonance. These insights informed the Toolkit's lightning talks, animation prompts and reflective discussion stages by clarifying the need to support imaginative interpretation while keeping participants connected to the astronomical material.

4.4. Transart/LJMU 2024

Group: Artists and art-researchers

Title of the workshop: Flying by Pluto

The Transart/LJMU session extended the testing of Astro-animation into an artistic research context, examining how the Astro-animation Toolkit supported interpretive, reflective and practice-based engagement with astronomical imagery. The workshop took place in July 2024 during the annual LJMU/Transart Art and Design PhD residency in Liverpool, with an additional remote session delivered to LJMU MA Art in Science/ MALSAD students. The residency provided a useful setting for testing the approach with participants whose primary orientation was artistic and interpretive rather than scientific.

Around 20 artists took part in the in-person Transart/LJMU workshop (see Figure 4.19) and approximately 8 MA Art in Science / MALSAD students from LJMU participated in the online session. In the in-person workshop, Dr Robin Corbet delivered a lightning talk before the animation component. The in-person participants followed simplified animation prompts, produced drawings, shared their work and provided both quantitative and qualitative responses after the event.

The MA Art in Science session was delivered online as an exploratory extension of the workshop. In this format, I delivered the presentation and animation instructions and students contributed digitally. The group did not complete formal surveys or interviews, so no quantitative or qualitative response data were collected from this session. However, their drawings were gathered and incorporated into the final workshop film, allowing the online session to contribute to the creative output while remaining outside the formal analysis.

Drawings from both the Baltimore and Liverpool sessions were compiled into a longer animated film, *Strange News from Pluto*, which featured the note: *"Astro-animation workshops from Baltimore, USA, to Liverpool, UK, using images of Pluto from NASA's New Horizons spacecraft."*



Figure 4.19: Transart students at the end of the Astro-animation workshop.

The film was set to *Kelly Watch the Stars* by AIR, which contributed to its atmosphere but also introduced limitations for festival submission because of music rights restrictions. It was screened on a large screen during the closing event of the Transart/LJMU summer session, where participants expressed enthusiasm for the integration of scientific data and creative storytelling.



Figure 4.20: Still from Strange News From Pluto, produced during LJMU/Transart Art and Design PhD residency in Liverpool

Figure 4.21: QR code linking to Strange News From Pluto in Volume 2.

4.4.1. Quantitative Insights: Transart/LJMU Survey Findings

Eleven participants completed post-workshop surveys. Although the sample size was small, the data provided useful formative insight into how the Astro-animation Toolkit functioned for artistic audiences. Of the respondents, 36.4% were mature adults aged 55–64; participants were predominantly White/Caucasian, highly educated and mostly women.

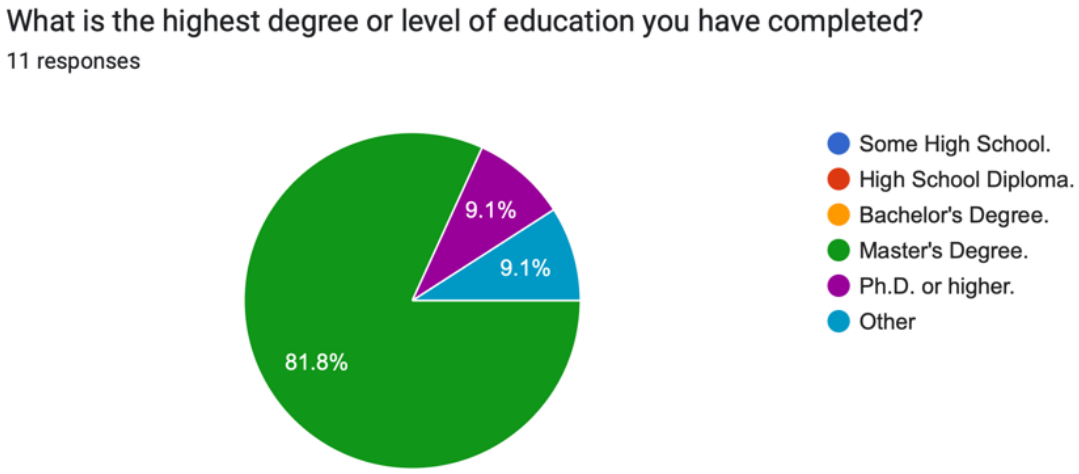


Figure 4.22: Educational Background of Workshop Participants – Transart/LJMU Workshop (n = 11).

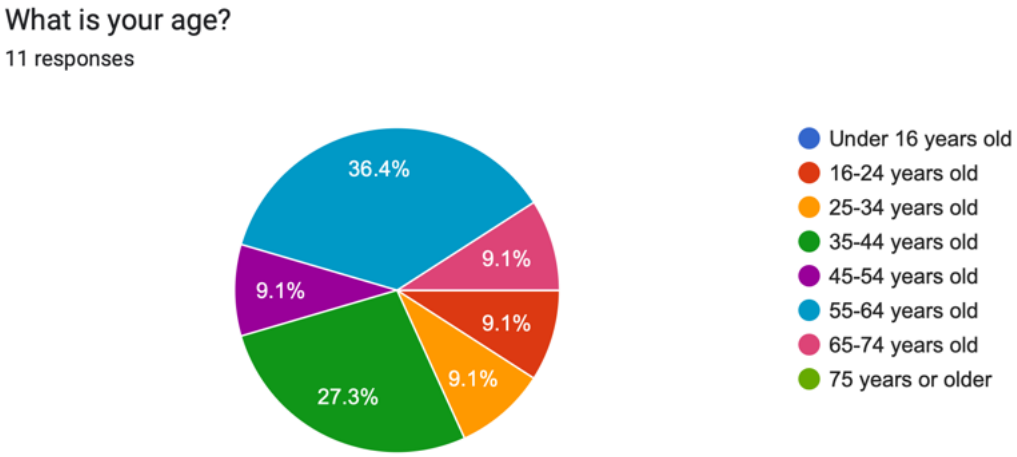


Figure 4.23: Participant Demographics from the Transart/LJMU Workshop (n = 11).

Participants praised the creative integration of art and astronomy, noting the workshop's interactive format and the hands-on experience of working with real Pluto imagery. Many also valued the freedom to interpret tasks personally, highlighting the contribution of diverse perspectives to science engagement. Suggestions for improvement centred on clearer instruction, with calls for demonstrations or visual aids to better support those unfamiliar with animation. Some participants also noted that earlier encouragement of collaboration could have deepened peer-to-peer exchange.

Quantitative feedback was broadly positive. A sentiment analysis of open-ended responses, used as a broad indicator of emotional tone, yielded an average score of +0.24 (on a –1 to +1 scale), indicating an overall positive tone. Nearly half (45.5%) strongly agreed that animation is effective for engaging teenagers with science and a further 27.3% agreed.

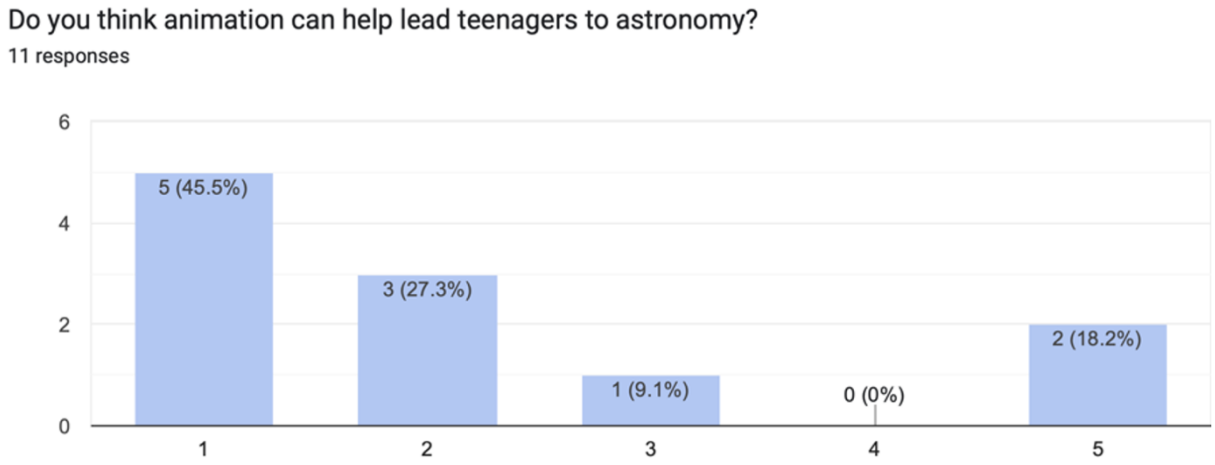


Figure 4.24: Perceptions of Animation's Educational Potential (n = 11).

A moderate positive correlation (r = .59) emerged between enjoyment and instructional clarity (Figure 4.25), indicating that clear facilitation played an important role in shaping the workshop experience. The weaker correlation between enjoyment and perceived educational value (r = .25) suggests that, in this setting, creative satisfaction and perceived educational impact operated as related but distinct aspects of participant experience.

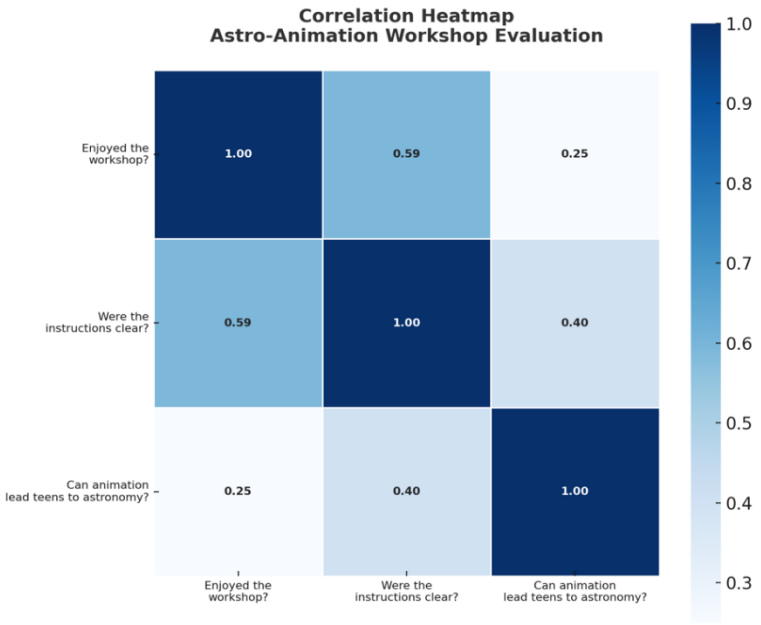


Figure 4.25: Correlation heatmap from the 'Flying by Pluto' Astro-animation Workshop (n = 11).

4.4.2. Qualitative Insights: Reflexive Themes from Interviews

Reflexive thematic analysis revealed nine intertwined themes, including creative inquiry, vulnerability, emotional resonance, embodied learning, curiosity and interdisciplinary synthesis. Participants often described uncertainty as part of the process, but this frequently shifted into experimentation and play. One remarked, "*I have no idea*," before quickly adding, "*We can play with it*" (A.8 LJMU/TransArt - P6, P19). Initial hesitation could also become confidence, as another participant reflected: "*At first it felt uncomfortable, but then it became fun*" (A.8 LJMU/TransArt - P12).

Emotional resonance was a recurring motif, as celestial bodies were imbued with symbolic meaning, "*Pluto has the heart on the side… so much love*" (A.8 LJMU/TransArt - P18), while inner–outer connections between self and cosmos invited moments of existential reflection: "*Space… it's beyond comprehension*" (A.8 LJMU/TransArt - P18). Participants also demonstrated embodied learning, using drawing and movement to grasp scale and motion: "*It gave me a visceral, embodied sense of the scale*" (P14). Curiosity and knowledge expansion were sparked by surprising facts, such as "*Pluto was smaller than the US*" (A.8 LJMU/TransArt - P17), while temporal and spatial scales emerged as recurring visual motifs, "*I was thinking of it as a spinning look*" (A.8 LJMU/TransArt - P6).

An interdisciplinary synthesis was also evident, as participants drew parallels between artistic and scientific thinking: "*Science and art both start with emotions*" (A.8 LJMU/TransArt - P19). Finally, memory and identity surfaced as reflective themes, with several participants recalling early experiences of drawing or animation and linking them to a renewed sense of self and creative belonging.

These interwoven themes reveal how Astro-animation fosters a reflexive dialogue between creativity, learning and emotional engagement, as summarised in the thematic map in Figure 4.26.



Figure 4.26: Reflexive thematic map of participant interviews (n = 19).

Themes were identified through reflexive thematic analysis and visualised as nine engagement dimensions (left) with associated subthemes (right). Colour-coded stars denote the nine thematic clusters: red (Creative Inquiry), orange (Courage and Vulnerability), yellow (Emotional Resonance), green (Inner–Outer Connection and Embodied Learning), blue (Curiosity and Discovery; Scale and Perspective), purple (Interdisciplinary Synthesis) and pink (Memory and Identity). The visual layout illustrates how these clusters form an interconnected reflexive

continuum in which creativity, learning and emotional engagement interact dynamically throughout the Liverpool Astro-animation workshop. See Appendix A.8 (Detailed Coding Table – Pluto Animation Workshop, TRANSART/LJMU Liverpool).

4.5. Comparative Insights Across Workshops

To contextualise the artist responses, correlation heatmaps from *The Eclipse* (HEAD 21, scientists) and *Flying by Pluto* (Transart/LJMU, artists) workshops were compared (Figure 4.27 a–b). In *The Eclipse* workshop (scientists), enjoyment correlated moderately with both clarity (r = 0.47) and perceptions of animation's educational potential (r = 0.58), suggesting that positive emotional engagement was strongly linked to perceived educational value. In contrast, the Transart workshop (artists) showed a stronger link between enjoyment and clarity (r = 0.59), but a weaker correlation between enjoyment and educational value (r = 0.25).

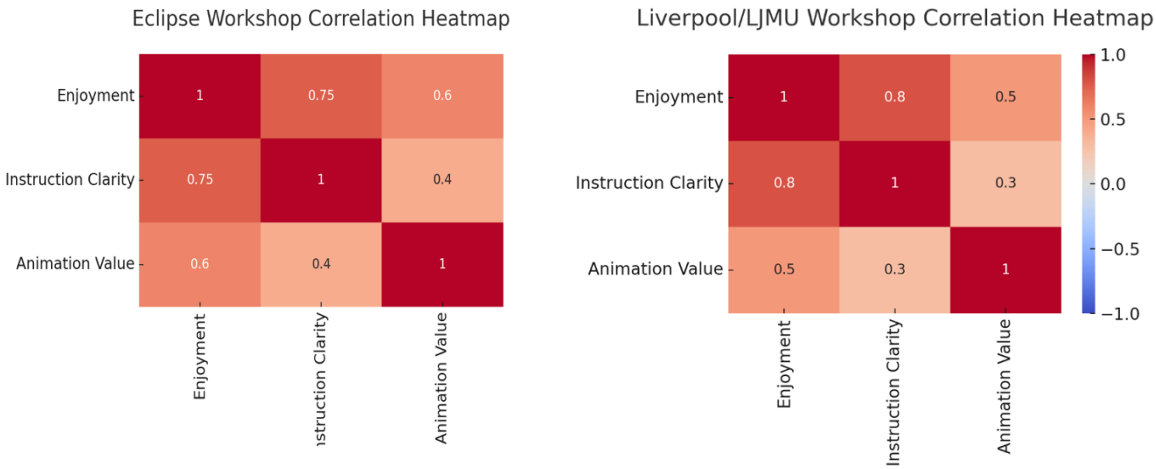


Figure 4.27 a-b: Correlation Heatmaps Comparing Participant Feedback Across the HEAD 21 and Transart/LJMU workshops.

Table 4.2 summarises the workshop contexts, participant insights and corresponding Toolkit refinements that emerged across the BSA pilot, the New York DOT Astronomy Conference, HEAD 21 and the Transart/LJMU sessions.

Workshop & Context	Key Insight from Participants	Toolkit Element Developed
BSA Pilot (High school students, Baltimore)	Wide variation in artistic experience required flexible formats.	Film-print animation adopted as the *core method* due to portability, adaptability and accessibility.
New York DOT Astronomy Conference (Scientists, Unconference)	Participants enjoyed creativity but requested clearer guidance (e.g., *"examples of coloring… to inspire the creativeness"*).	Structured instruction introduced, including step-by-step sheets and demonstration examples.
HEAD 21 Texas (scientists, eclipse-focused workshop)	Scientists responded positively to cultural framing and clear introductory talks; spontaneous reflections showed value of narrative engagement.	'Lightning Talks' embedded to provide concise scientific context; Principles of Animation tutorial refined and formalised in the Toolkit.
Transart/LJMU (Artists, UK residency + remote MA students)	Artists valued freedom to experiment; online session confirmed feasibility of remote delivery.	Toolkit made adaptable for interdisciplinary and online contexts, balancing structure with open-ended creativity.

Table 4.2: Summary of workshop contexts, participant insights and Toolkit refinements.

These findings show that each workshop context foregrounded different aspects of the Toolkit. In the HEAD 21 workshop, enjoyment was closely linked to perceived educational value. In the Transart/LJMU workshop, enjoyment was most strongly associated with instructional clarity. Together, these workshops indicate that the Toolkit required a stable sequence, clear guidance and room for participants to interpret astronomical imagery through their own visual and narrative choices. These findings inform the final Toolkit structure outlined in the next section. Figure 4.28 summarises how the Astro-animation Toolkit was refined through the Strand 2 workshops and situates this phase within the wider development of the project.

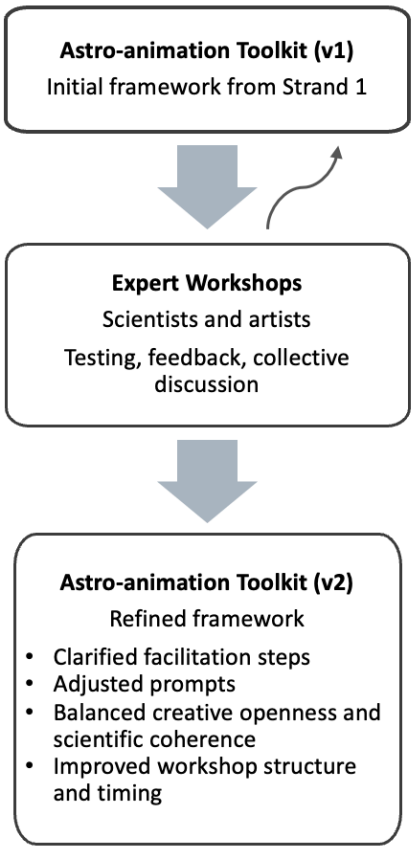


Figure 4.28: Refinement of the Astro-animation Toolkit through expert workshops (Strand 2).

Figure 4.28 illustrates how the initial Toolkit was refined through workshops with scientists and artists using iterative testing and structured feedback to clarify facilitation steps, adjust prompts and stabilise the workshop structure.

4.6. Presenting the Astro-Animation Toolkit

The final Astro-animation Toolkit operates on two connected levels. First, it provides a five-stage workshop sequence that guides facilitators through delivery: preparation, scientific grounding, animation-making, reflection and sharing. Second, it includes facilitative and evaluative elements that support the workshop across these stages, including lightning talks, animation instruction, participant surveys and live interviews. The sequence describes how the

workshop unfolds, while these elements explain how participants are supported, how reflection is encouraged and how participant experience may be documented.

As illustrated in Figure 4.29, this five-stage process guides participants from initial orientation through creative production and collective reflection. The structure emerged from repeated patterns across the Strand 2 workshops: participants needed scientific framing, accessible instruction, time for hands-on making, opportunities for reflection and a shared final presentation. The resulting process therefore reflects both facilitative intention and the practical lessons generated through expert testing in scientific, artistic and hybrid contexts.

The sequence begins with Preparation and Framing, which establishes the workshop context, materials and expectations. It then moves to Conceptual Grounding, where a short astronomy lightning talk provides participants with a shared point of departure. Collaborative Animation-Making forms the central activity, allowing participants to work with astronomical imagery through drawing, sequencing and visual metaphor. Reflection and Dialogue invites participants to articulate their interpretations and discuss their approach to the task. The sequence concludes with Assembly and Sharing, where individual contributions are compiled and presented as a collective animated outcome.



Figure 4.29: Five-stage workshop structure of the Astro-animation Toolkit.

The sequence guides facilitators through preparation, scientific grounding, animation-making, reflection and sharing.

Five-stage sequence	Main purpose	Supporting elements
Preparation and Framing	Sets up materials, aims, consent, and expectations	Workshop plan, printed frames, surveys
Conceptual Grounding	Introduces the astronomical topic	Lightning talk
Collaborative Animation-Making	Supports hands-on visual interpretation	Animation instruction, prompts, examples
Reflection and Dialogue	Encourages interpretation and discussion	Live interviews, group reflection
Assembly and Sharing	Presents the collective animated outcome	Digitisation, sequencing, screening

Table 4.3: Five-stage Astro-animation workshop sequence and supporting Toolkit elements.

The five-stage sequence describes the workshop's temporal structure, while the facilitative and evaluative elements describe the methods used to support participation and document participant experience within that structure.

4.6.1. Facilitative and Evaluative Functions of the Astro-animation Toolkit

Alongside the five-stage workshop sequence, the Toolkit identifies recurring facilitative and evaluative functions that support scientific framing, participation, reflection and documentation across the workshop stages. These functions are informed by Kolb's Experiential Learning Cycle (1984), which provides a framework for understanding how participants move between concrete experience, reflective observation, abstract conceptualisation and active experimentation during the workshop.

Kolb's experiential learning cycle	Astro-animation workshop process	Function within the Toolkit
Concrete Experience	Participants encounter astronomical imagery, scientific explanation and hands-on drawing tasks.	Establishes direct experience of working with scientific material through visual and material engagement.
Reflective Observation	Participants discuss choices, respond to prompts, complete surveys, or take part in live interviews.	Encourages participants to notice how they interpreted the material and what meanings emerged through making.
Abstract Conceptualisation	Participants connect their drawings, metaphors and sequences to astronomical ideas such as motion, scale, eclipse dynamics, or planetary movement.	Supports conceptual understanding by linking creative decisions to scientific interpretation.
Active Experimentation	Participants test ideas through drawing, sequencing, timing, transformation and revision.	Positions animation-making as an exploratory process through which participants learn by trying, adjusting and reworking visual ideas.

Table 4.4: Kolb's experiential learning cycle mapped onto the Astro-animation workshop process.

This mapping clarifies how the Astro-animation process activates different modes of experiential learning. Participants encounter scientific material, test ideas through drawing and sequencing, reflect on their choices and connect visual decisions back to astronomical concepts through practice. Within this learning structure, the Toolkit uses the following functions to guide, support and document participant experience:

1. **Preparation and Framing**. This phase gathers the practical and conceptual elements needed for the workshop, including the workshop aims, selected astronomical imagery, printed frames, materials, consent procedures, documentation plans and any optional evaluation tools. It establishes the conditions for participation and ensures that the workshop is ready to support both creative activity and reflection**.**
2. **Lightning Talks.** Short scientific presentations provide conceptual grounding and give participants a shared point of departure. They usually occur during the Conceptual Grounding stage, but their role extends across the workshop by anchoring creative interpretation in scientific context.

3. **Animation Instruction.** Step-by-step demonstrations introduce simple animation principles, such as sequence, timing, rhythm and transformation. These instructions lower the threshold for participation and prepare participants for the Animation-Making stage.
4. **Animation Making.** This is the central hands-on component of the workshop. Participants draw, colour, alter, or sequence astronomical imagery, translating scientific material into visual and temporal form through embodied and metaphorical exploration.
5. **Reflection, Documentation and Sharing.** Group discussion, informal feedback, live interviews, surveys, or other documentation tools may be used to capture participant experience, depending on the facilitator's aims, ethical requirements, available time and workshop setting. This phase makes visible the interpretive choices, emerging metaphors and affective responses that may not appear in the finished animation alone.

Together, these elements provide the Astro-animation Toolkit's support and documentation system. They help facilitators deliver the workshop, guide participants through animation-making and create opportunities for reflection and documentation. Their use can be adjusted according to facilitator aims, participant needs, available time and workshop setting.



Figure 4.30: Astro-animation Toolkit cover image, depicting participants using printed astronomical imagery as the basis for collaborative animation-making.

Figure 4.31: QR code linking to The Astro-animation Toolkit in Volume 2.

4.7. Strand 2 Synthesis

Strand 2 demonstrates how Astro-animation developed from a studio-based research practice into a participant-tested Toolkit for astronomy communication. Its contribution lies in showing how analogue animation-making can be organised into a repeatable workshop structure that supports scientific framing, creative interpretation, embodied engagement and reflective dialogue. Through expert and practice-based feedback, the study identified the facilitation conditions needed for Astro-animation to operate beyond a single film or individual creative

process. The workshops showed, first, that scientific framing and creative interpretation can be held together through a carefully structured process; second, that facilitation is central to participation; and third, that animation-making can support conceptual, embodied and affective engagement. These insights establish the Astro-animation Toolkit as a structured facilitation model linking scientific grounding, analogue animation-making, reflection and documentation.

Toolkit Development Note: Strand 2

Strand 2 transformed the provisional principles from Strand 1 into a structured workshop framework. Feedback from scientists, artists and art-researchers highlighted the need for clearer instructions, stronger visual prompts, concise scientific framing, opportunities for reflection and flexible adaptation across settings. These findings shaped the five-stage Astro-animation Toolkit: Preparation, Conceptual Grounding, Collaborative Animation-Making, Reflection and Dialogue and Assembly and Sharing.

4.8. Summary of Chapter 4

Strand 2 marks the methodological transition from the studio-based inquiry of Strand 1 to a structured and transferable workshop framework. These findings prepare the ground for Strand 3, in which the Astro-animation Toolkit is implemented in libraries, schools, festivals and other community-based learning environments.

Chapter 5: Strand 3: Testing the Astro-animation Toolkit in Community Learning Contexts

5.1. From Participation to Discovery: Engaging Communities through Astro-animation

Strand 3 builds on the expert-led development of the Astro-animation Toolkit undertaken in Strand 2. It examines how the Toolkit functions in public-facing informal learning environments, including libraries, cultural centres and extracurricular school programmes. The central aim of this strand is to assess whether the Astro-animation Toolkit can support engagement among participants without specialist backgrounds in astronomy or animation. The workshops use short scientific introductions and accessible animation prompts. Participants are invited to learn through drawing, sequencing, observing and discussion, with emphasis placed on participation, curiosity and exploratory making. The strand examines both cognitive engagement and affective experience.

This participatory approach aligns with research indicating that hands-on experiences can deepen emotional and conceptual engagement. Song and Bucy (2008) note that participation can shift audiences from passive viewers to contributors, increasing curiosity and emotional connection. This perspective informs the Astro-animation workshops, where accessible creative tools support personal connections to astronomical phenomena and position discovery as a shared activity. The following sections describe the workshop sites, participant groups and evaluation methods used in Strand 3.

5.2. First Workshop at the Enoch Pratt Library in Baltimore

Group: Families and children

Title of the workshop: *Flying by Pluto*

The Enoch Pratt Free Library family workshop, held in May 2024, was the first community-based test of the Astro-animation Toolkit. The two-hour session, titled *Flying by Pluto*, examined how the method functioned with mixed-age participants in an informal, drop-in setting. Participants engaged with NASA New Horizons imagery through drawing, colouring and simple animation-making.

Approximately 17 participants attended, including young adults, families and children. Nine adult participants completed the pre-workshop survey and seven completed the post-workshop survey. Children attending with parents or caregivers did not complete questionnaires, although observational notes recorded several children estimated to be between 6 and 10 years old. Drop-in attendance produced a mixed-age group that reflected the diversity of the local community. (See figure 5.1).



Figure 5.1: Participants at the Pratt Library workshop. Photo permission granted.

Lightning Talks on NASA's New Horizons mission to Pluto were delivered at the beginning and end of the workshop. MICA research assistants supported facilitation, scanning and participant guidance. The library scanner was used to digitise drawings during the session, allowing participant images to be incorporated into animated sequences. This workflow later informed the technical guidance included in the Astro-animation Toolkit. The facilitation process is illustrated in Figure 5.2.



Figure 5.2: MICA research assistant testing the Astro-animation workshop at the Pratt Library.

Prior to the workshop, the team tested the colouring stage of the activity to assess the clarity of the printed frames, the suitability of the materials and the timing of the drawing process. This helped refine the workshop instructions and supported consistency in facilitation (see Figure 5.2).

5.2.1. Quantitative Insights: Survey Findings from the Enoch Pratt Library Family Workshop

Nine adult participants completed the pre-workshop survey and seven completed the post-workshop survey. Respondents ranged in age from 16 to 54 years. The largest group was aged 25 to 34 (55.6%), followed by 16 to 24 (22.2%) and 45 to 54 (22.2%). Given the small number of completed surveys, findings are interpreted as formative and are read alongside interviews and observations as part of the mixed-methods analysis.

Figure 5.3 shows the percentage of participants reporting that they were 'very interested' or 'extremely interested' in animation, science and astronomy before and after the workshop. Interest in animation increased from 78% to 86% and interest in science increased slightly. Interest in astronomy declined from 67% to 57%. These shifts suggest stable or slightly increased interest in animation and science, while the decline in astronomy interest may reflect differences in prior knowledge, expectations, or limited time for astronomy-specific content.

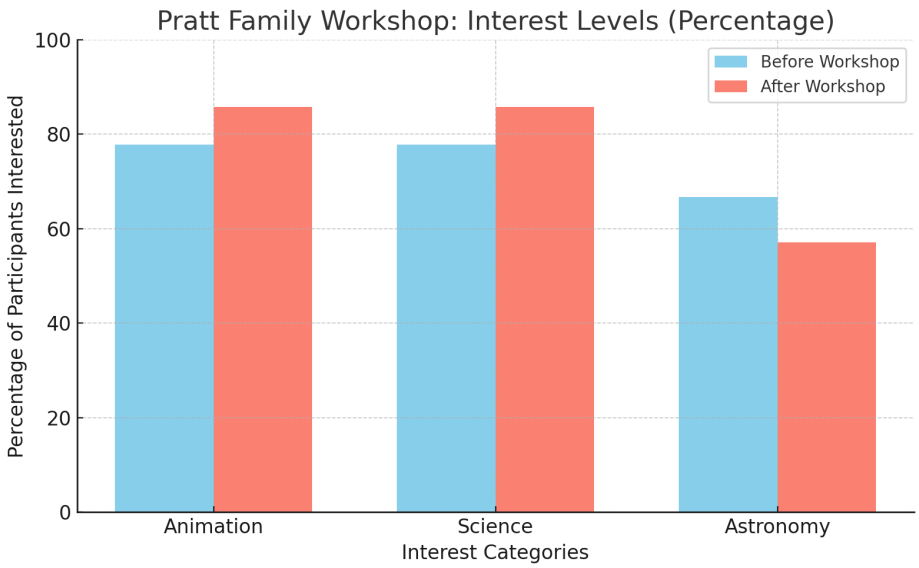


Figure 5.3: Percentage of Participants Expressing High Interest Before and After the Pratt Family Workshop (n = 9 pre-survey; n = 7 post-survey)

5.2.2. Qualitative Insights: Interviews and Observations

Interviews and observations indicated cognitive, emotional and creative engagement with the Astro-animation process. Participants described moments of conceptual learning, creative transformation and reflection on the relationship between art and science. One participant stated, "*I learned about Pluto. I always wondered why it wasn't a planet*," indicating engagement with astronomical classification. Another described creative development during the activity: "*I started with a fish but turned it into a spacecraft*," suggesting flexibility in metaphor and narrative. Several participants also described increased awareness of connections between art and science. One noted, "*Thinking about art and science as intimately*

connected… I think that's the future." These responses suggest that animation supported exploration and interpretation, including among participants who did not describe the activity as directly instructional.

Interview transcripts were analysed using reflexive thematic analysis (Braun and Clarke, 2006). Themes were derived inductively to capture affective, cognitive and creative dimensions of participant experience.

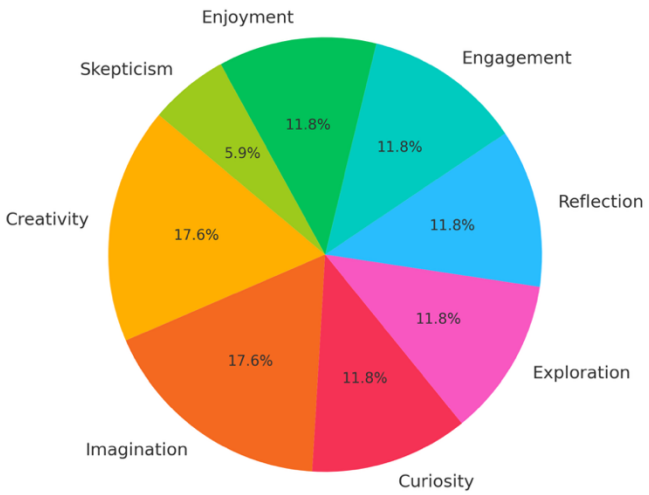


Figure 5.4: Emotional Engagement Wheel – Pratt Family Workshop (n = 8).

Figure 5.4 presents a visual summary of these themes, showing the relative distribution of affective responses across participant interviews. Creativity and Imagination were the most frequently articulated dimensions (17.6% each), followed by Curiosity, Exploration, Reflection, Engagement and Enjoyment (each at 11.8%). Skepticism appeared least frequently (5.9%). These patterns show that participants engaged with Astro-animation as a learning activity and an imaginative process.

In this analysis, participant responses were coded against six reflective prompts and synthesised in Table 5.1.

Theme	Participant Insight	Interpretive Summary
Conceptual Learning	"I learned about Pluto. I always wondered why it wasn't a planet."	Participants gained clarity on astronomical concepts, showing increased science literacy.
Emotional Engagement	"I started with a fish but turned it into a spacecraft."	Participants explored metaphor and identity via creative transformation.
Creative Transformation	"It looked so much like a video even though it was just photos."	Animation was experienced as a powerful creative tool that transformed static visuals.
Science–Art Integration	"'Before, I didn't think art had much to do with science, but now I see how they work together."	Workshop prompted reflection on interdisciplinary connections between science and art.
Science–Art Career Aspirations	"I'd love a job that mixes art and science!"	Animation sparked reflection on blended career trajectories that bridge art and science.
Barriers/Ambivalence	"I wish I could try something and see what it looks like and change it after."	Participants noted some friction between imagination and technical constraints.

Table 5.1: Thematic summary of Pratt Library family interview responses (n = 8).

The full interview transcripts and colour-coded thematic coding framework are provided in Appendix A.4, 'Pratt Library Family Interviews'.

5.2.3. Mixed-method Synthesis

The survey and interview findings provide complementary evidence of participant engagement. Survey findings showed stable interest levels, with small increases in animation and science and a decline in astronomy. Interview responses added examples of learning moments, creative interpretation and reflective statements about science and art. For example, "*I started with a fish but turned it into a spacecraft*" described imaginative transformation, while "*I'd love a job that mixes art and science!*" indicated openness to hybrid career thinking. Some participants valued the activity while describing its relevance in ways other than career interest.

Aspect	Survey Insight	Interview Insight	Interpretive Note
Interest Levels	Stable across animation and science; astronomy declined slightly	Participants expressed curiosity, joy and metaphorical creativity	Quantitative data shows baseline interest; qualitative data reveals richer engagement
Learning Impact	Minor reported change in understanding	Clear learning moments described (e.g., Pluto's reclassification)	Interviews highlight specific learning not captured in pre/post surveys
Role of Animation	Perceived as useful or interesting by most	Animation described as fun, identity-forming and expressive	Animation functioned as both cognitive and emotional learning tool
Career Connection	Slight openness to science or creative careers	"Thinking about Art and Science as intimately connected… I think that's the future".	Art–science integration surfaced as a viable career direction

Table 5.2: Mixed-method synthesis of Pratt Library family workshop findings.

The synthesis in Table 5.2 indicates that animation supported shared exploration of scientific ideas through creative interpretation. Survey findings captured general patterns of interest, while interview responses revealed emotional, conceptual and creative engagement in greater depth. The family workshop demonstrated the Toolkit's potential in a mixed-age, drop-in setting. The following Pratt Library session shifted the focus to teenagers, allowing the study to examine how the same activity functioned in a more informal youth context.

5.3. Teen Workshop at the Enoch Pratt Free Library

Group: Teens aged 13–18

Title of the workshop: *Flying by Pluto*

A second *Flying by Pluto* workshop was held at the Enoch Pratt Free Library in May 2024, one week after the family workshop. This session tested the Astro-animation Toolkit in a youth-focused, low-structure after-school setting. Between four and six teenagers participated, aged approximately 13 to 18. The session began with six participants, although two left shortly after the activity began. Research assistant observations and my own field notes indicated that engagement fluctuated during the session, partly because of the informal setting and limited

supervision within the library programme.

Evaluation was limited by fluctuating attendance and device access. Two surveys and two interviews were completed. Participant drawings were collected and incorporated into the *Flying by Pluto* animation loop.

5.3.1. Evaluation and Qualitative Insights: Teen Workshop

The teen-focused workshop generated a small but useful set of qualitative findings. Both survey respondents reported high interest in animation and astronomy. The two interviews provided more detailed insight into how participants used animation to connect astronomy with visual comprehension, emotional expression and personal identity. One participant used symbolic imagery to describe emotional fluctuation, drawing "*big hearts and small hearts with wavy lines*" and explaining, "*My heart goes from big to small sometimes and I can go from mean to nice*." This response suggests that the animation activity created space for metaphorical self-expression alongside engagement with astronomical imagery.

Participants also described animation as a tool for visual understanding. One stated, "*Yes, because I can visually see it, understand it*," while another noted, "*It showed me how everything works and how everything moves.*" These comments indicate that the visual and kinetic aspects of animation helped participants think about astronomical movement and spatial relationships. Knowledge development varied according to prior experience. One participant stated, "*I learned a couple of new facts about Pluto… but I also didn't really learn nothing because I know a lot of things about Pluto*." This response suggests that the workshop reinforced existing knowledge while also introducing additional information. Participants also reflected on the relationship between science and art. One stated, "*It made me see how fun it is to learn about planets.*" Another commented, "*It showed me different ways of art and different scientific movements and stuff.*" These responses indicate that the workshop supported informal reflection on how artistic and scientific processes can overlap. In terms of future aspirations, one participant expressed interest in pursuing art, while another indicated interest in biology. These responses suggest that Astro-animation resonated with participants through different personal interests.

The thematic patterns identified in the teen interviews are summarised in Table 5.3.

Theme	Participant insight	Interpretive summary
Visual Comprehension	"Yes, because I can visually see it, understand it."	Animation supported perceptual access to astronomical concepts.
Knowledge Reinforcement	"I learned a couple of new facts... but I also didn't really learn nothing…"	The workshop reinforced prior knowledge while introducing additional information.
Creative Engagement	"I enjoyed the fact that we get to be creative and express who we are."	Participants linked creative expression with engagement.
Science–Art Connection	"It showed me different ways of art and different scientific movements and stuff."	Participants reflected on connections between artistic and scientific processes.
Symbolic Expression	"My heart goes from big to small... I can go from mean to nice."	Animation supported metaphorical exploration of emotion and identity.

Table 5.3: Thematic summary of Pratt Library teen interview responses (n = 2).

The responses show how animation supported visual comprehension, knowledge reinforcement, creative engagement, science–art reflection and symbolic expression. See Appendix A.5 for the full thematic coding matrix.

The teen workshop highlighted the need for flexible facilitation in informal youth settings, particularly when attendance, supervision and device access are unpredictable. Balticon 58 provided a different public-facing context, where the Toolkit was tested with a single family group in a science-fiction convention setting.

5.4. Workshop at Balticon 58 - Family

Group: family group- (child approximately 10 years old with accompanying parents)

Title of the workshop: *Flying by Pluto*

As part of Balticon 58, I led an Astro-animation workshop for one family group, supported by a MICA research assistant. The session followed the same core protocol as the Pratt Library family workshop: Dr Corbet's Flying by Pluto Lightning Talk, animation instruction, hands-on drawing, interviews and participant surveys. The drawings were scanned and incorporated into the larger Pluto animation loop on Vimeo. The completed film was later

screened during a Balticon presentation in which Dr Corbet and I discussed the Astro-animation class and the wider research project.



Figure 5.5: Family group at the Balticon workshop. Photo permission granted.

5.4.1. Evaluation of the Balticon 58 Family workshop

The Balticon 58 workshop produced a small but focused set of responses from one family group. Participants remained engaged throughout the activity and used the drawing process to develop imaginative visual responses, including surreal landscapes and mythic elements. Interview responses indicated that all three participants learned new astronomy facts during the session. Some participants valued the creative process more strongly than its direct contribution to scientific understanding, suggesting that the workshop supported engagement through imagination, participation and shared making.

The session also provided an opportunity to connect the workshop activity with a public presentation about the Astro-animation class and the wider research project. The completed

animation loop was screened during this presentation, extending the workshop outcome beyond the immediate activity.

Following Balticon, the study returned to a school-based context at Baltimore School for the Arts, where the Toolkit could be tested with a larger group of teenagers in an animation classroom.

5.5. Workshop for teenagers at Baltimore School for the Arts

Group: High School students**.**

Title of the workshop: *Sunspot*

On 15 November 2024, an Astro-animation workshop was conducted at the Baltimore School for the Arts, a site previously visited during the early pilot phase of the Toolkit. Returning to BSA made it possible to test the more developed version of the Astro-animation Toolkit with secondary students in a familiar educational setting. Although the workshop took place in a school, its format was closer to an extracurricular or after-school session than to a formal classroom lesson, with emphasis placed on participation, drawing, discussion and creative experimentation.

The workshop was conducted with fourteen high school students aged approximately 14 to 15 who were enrolled in an animation class. The ninety-minute session focused on sunspots and used astronomical imagery as the basis for analogue animation-making. Students remained engaged throughout the session, contributing to an energetic classroom environment. At times, overlapping discussion made interview documentation more difficult, but the workshop showed sustained participation in the animation process.

All drawings were collected, scanned and compiled into a short film hosted on Vimeo. Titled *Sunspot*, this became the third film produced through the Astro-animation workshops, following *Flying by Pluto* and *The Eclipse*. Although formal post-workshop feedback could not be collected after the film's release, the teacher later reported that students valued seeing the completed animation and requested images for inclusion in the school journal. This indicates a

degree of collective ownership despite the absence of structured evaluation data. Student participation during the Sunspot workshop is shown in Figure 5.6.



Figure 5.6: BSA students animating Sunspot. Photo permission granted.

5.5.1. Evaluation Context and Survey Findings

Evaluation at BSA was shaped by institutional constraints. Staff requested the removal of demographic questions from the original questionnaire, which limited the scope of analysis while allowing the workshop to proceed. Pre- and post-workshop surveys were completed by fifteen students and findings are interpreted as formative.

Survey responses indicated modest shifts across several categories. Interest in astronomy increased by approximately 10 percent, while enthusiasm for animation as an educational tool declined by about 10 percent and science interest decreased by approximately 5 percent. Career interest in science or art–science pathways remained relatively stable at 15 to 20 percent. These patterns suggest varied responses to the interdisciplinary format. As shown in Figure 5.7, the workshop appeared to strengthen interest in astronomy for some students, while responses to animation and science were more mixed. Full survey data are reported in Appendix B.1.

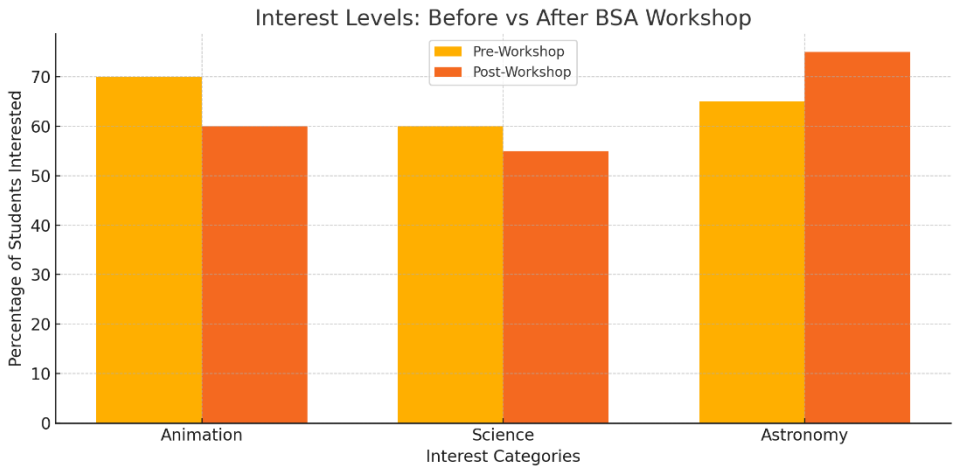


Figure 5.7: Interest Levels Before and After the BSA Workshop (n = 15).

5.5.2. Qualitative Insights: Interviews and Observations

Qualitative findings added detail to the survey results. Students most frequently recalled lessons grounded in visual storytelling, including Galileo's experiments, sunspots and solar scale, while more abstract concepts were less frequently remembered. Approximately 65 percent of students reported enjoying the workshop, particularly its narrative and visual components. One participant stated that "*the colours and movement made it feel alive*," suggesting that animation increased emotional engagement and made the material more vivid.

Interviews indicated that Astro-animation facilitated creative engagement with scientific material. One participant noted that *"art can help science in a way that people can understand better… visually*," highlighting animation's communicative function. Students also described

experimentation and individuality in their drawings, including *"I'm doing these little faces. I want to go with the flow*." Others referenced specific learning moments, such as "I learned about the sun, Galileo," linking visualisation with conceptual recall. Emotional responses were also noted in comments such as "*It looked so real, it made space feel big and alive*."

Long-term science career interest did not significantly shift, though the workshop supported creative expression and reflective engagement. Clearer articulation of art–science professional pathways may strengthen future iterations. Students' interpretations of terms like 'art' and 'science' may have shaped their responses. For some, science may be associated with formal instruction and abstraction, while art is associated with expression. The influence of disciplinary language on perception is discussed further in Chapter 6.

5.5.3. Reflexive Thematic Analysis for teenagers at Baltimore School for the Arts

Reflexive thematic analysis was conducted inductively. Survey data suggested reduced enthusiasm for animation and some ambiguity regarding art–science relationships. Interviews added varied perspectives on how students understood the relationship between animation, science and creative practice. Some participants entered the workshop already recognising art–science connections, while others identified this relationship during the session. Several students found the connection intuitive but difficult to articulate.

Visual elements were cited as supportive of understanding by several participants, although responses varied across the group. Career aspirations remained limited, reflecting both the artistic orientation of the school context and the need for clearer articulation of art–science professional pathways.

Several students described revised perceptions of the relationship between art and science. One participant stated, *"Before, I didn't think art had much to do with science, but now I see how they work together."* These responses indicate creative exploration, affective engagement and interdisciplinary awareness. Themes identified in BSA interviews are summarised in Table 5.4.

Theme	Participant Insight	Interpretive Summary
Conceptual Learning	"I learned about Galileo animation." "It helped me see how gravity kind of pulls on things."	Animation supported visual and sequential understanding of scientific forces.
Emotional Engagement	"How big the sun is, million earths can fit in, it's kind of crazy." "It looked so real, it made space feel big and alive."	Participants described sensory and affective responses to scale and motion.
Creative Experimentation	"I'm drawing a person going around the sun and catching stars." "I got to draw what I thought a black hole would look like."	Workshop enabled imaginative interpretation within scientific prompts.
Science–Art Integration	"I did not know that science and animation were so connected. I like that." "It's weird but cool to explain science with pictures and stories."	Students recognised intersections between artistic and scientific processes.
Career Imaginaries and Identity Formation	"A marine biologist but I am not good at science." "I liked it a lot, but I don't think this is a job people do?"	Awareness of art–science career pathways remained limited.

Table 5.4: Thematic summary of BSA student interview responses.

The themes indicate that BSA students responded to the workshop through conceptual learning, emotional engagement, creative experimentation, science–art integration and emerging reflections on career imaginaries.

5.5.4. Mixed-method Synthesis

Table 5.5 synthesises survey and interview findings across five themes: art–science connection, learning outcomes, engagement and interest, visual learning and science career interest.

Theme	Survey findings	Interview findings	Interpretive synthesis
Art–Science Connection	Six of fifteen students described animation as making science clearer or more understandable; four were unsure or disengaged.	Seven of fifteen participants mentioned the connection clearly or discovered it during the session.	Students recognised art–science connections in both direct and emerging ways.
Learning Outcomes	Eleven of fifteen students mentioned learning about GRBs, Galileo, sunspots, or scale.	Nine participants recalled GRBs, Galileo, sunspots, or scale.	Students recalled specific scientific topics across both response formats.
Engagement and Interest	Drawing, animation and slides were described as engaging by four to five participants; others expressed lower engagement.	Four participants described feeling engaged; others were ambivalent.	Responses show varied forms of engagement across the group.
Visual Learning Impact	Visuals were cited as helpful by four to five students, including comments such as “drawing part was fun” and “visual guides helped.”	Three students praised visuals explicitly; others did not mention them.	Visual learning supported understanding for some students, while responses varied across the group.
Science Career Interest	Three of fifteen expressed interest in science or art–science careers; at least one expressed disinterest.	Four participants showed openness to science or art-related careers, while a few expressed disinterest.	Awareness of art–science career pathways remained limited.

Table 5.5: Mixed-method synthesis of BSA survey and interview findings.

Survey data suggested reduced enthusiasm for animation and some ambiguity regarding art–science relationships. Interviews added varied perspectives on how students understood the relationship between animation, science and creative practice. Some participants entered the workshop already recognising art–science connections, while others identified this relationship during the session. Several students found the connection intuitive but difficult to articulate.

Visual elements were cited as supportive of understanding by several participants, although responses varied across the group. Career aspirations remained limited, reflecting both the

artistic orientation of the school context and the need for clearer articulation of art–science professional pathways.

Several students described revised perceptions of the relationship between art and science. One participant stated, "*Before, I didn't think art had much to do with science, but now I see how they work together*." These responses indicate creative exploration, affective engagement and interdisciplinary awareness. Themes identified in BSA interviews are summarised in Table 5.4.

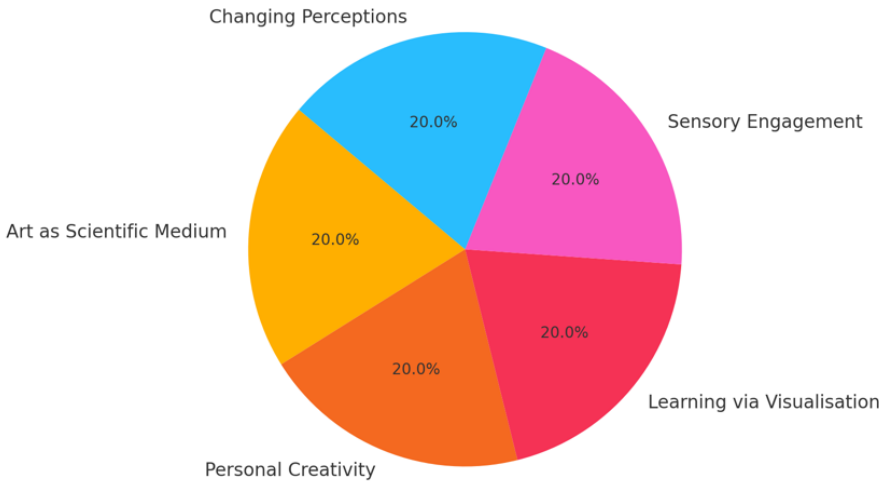


Figure 5.8: Distribution of Thematic Categories from BSA Interviews.

Changing perceptions, sensory engagement, learning through visualisation, personal creativity and art as scientific medium each accounted for 20 percent of coded responses. These themes indicate a balanced range of cognitive and affective engagement. Building on the BSA workshop, the Padova session extended the Sunspot project into an international university context and allowed the Toolkit to be examined with visually literate undergraduate participants.

5.6. Workshop at the University of Padova with undergraduate students - Italy

Group: College students. (undergraduates, approx. 19–24 years old)

Title of the workshop: *Sunspot*

On 21 November 2024, an Astro-animation workshop was delivered at Palazzo Liviano, University of Padova, as part of the international conference *Figuring the Invisible: Animation and Science Outreach in Contemporary Audio-Visual Culture*. I was invited to speak at the conference and also proposed and led this workshop for a group of undergraduate students who attended the event. The Padova workshop extended the testing of the Astro-animation Toolkit beyond the Baltimore-based library, school and festival contexts. It allowed the method to be examined with undergraduate students in an international conference setting, where participants brought different cultural references, disciplinary backgrounds and expectations of animation.

The workshop took place in a library room, with conference organisers providing recommended art supplies. It extended the *Sunspot* project previously conducted at Baltimore School for the Arts. Participants included twelve undergraduate students from the conference community, including Italian and international students. Most participants were film students, but they did not necessarily have formal training in animation. This made the workshop useful for examining how the Toolkit functioned with visually literate participants who were new to analogue animation-making. Student collaboration during the workshop is shown in Figures 5.9 and 5.10.



Figure 5.9: University of Padova students working on a Sunspot segment. Photo permission granted.

Surveys were not administered during this session. Instead, interviews were conducted to gather participant reflections. This decision followed earlier challenges with survey implementation at BSA, including time constraints and concerns regarding demographic questions. Interviews provided a feasible method for collecting qualitative feedback.

Student drawings were later combined with those from the BSA workshop to produce an extended version of the *Sunspot* animation. The soundtrack incorporated a licensed version of Rimsky-Korsakov's *Flight of the Bumblebee*, whose fast-paced tempo complemented the visual pacing of the animation.

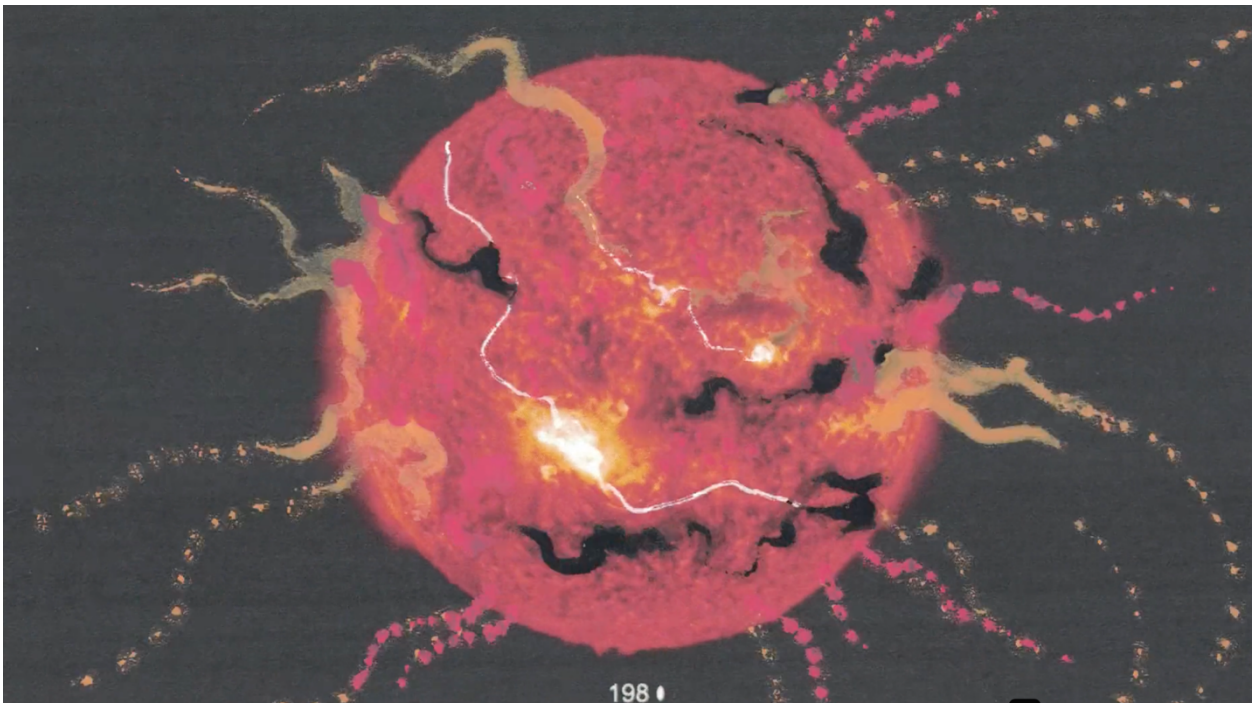


Figure 5.10: Still from Sunspot, produced during BSA and Padova workshops

Figure 5.11: QR code linking to Sunspot in Volume 2.

5.6.1. Evaluation of the University of Padova Workshop

The Padova workshop engaged twelve undergraduate students during the international conference *Figuring the Invisible: Animation and Science Outreach in Contemporary Audio-Visual Culture*. This setting allowed the Toolkit to be tested with participants already encountering animation and science outreach within a higher education environment. Interviews suggested that animation helped participants visualise abstract or otherwise invisible scientific phenomena while also allowing space for personal, cultural and emotional interpretation. One participant stated that *"without animation, we could not study or see the invisible,*" directly connecting the workshop experience to the conference theme, *Figuring the Invisible*.

Several participants described drawing as a way of processing information. One student explained, "*While I draw… it helps me to think, to process the information."* This suggests that the animation process supported reflective learning through action, allowing participants to work through ideas materially and visually. Another described the art–science combination as "*a really powerful mix*" because "*we learn also by doing*," reinforcing the role of active experimentation within the workshop.

The interviews also showed how participants used Astro-animation as a space for personal and cultural interpretation. One participant stated, "*I just want to go with the flow… I like creation and then destruction*," using the activity to explore transformation and imaginative movement. Another developed a mythological story connected to the Sun, explaining, "*It's not scientific, but I think that's okay*." This response suggests that cultural and mythological references became meaningful entry points into astronomical material, allowing students to connect scientific imagery with familiar symbolic frameworks.

Emotional and sensory engagement also emerged as important. One participant described the activity as calming, stating, "*It's calm, it's easy*. *Make me feel at peace*." Another connected the process to student well-being, explaining that academic work can be stressful and that the workshop "*make me feel better and make me feel happy*." These comments indicate that Astro-animation supported engagement not only through scientific understanding, but also through enjoyment, ease and imaginative participation.

Theme	Participant insight	Interpretive summary
Animation as a Tool for Visualising Science	"Without animation, we could not study or see the invisible."	Animation was understood as a way to make invisible or abstract scientific phenomena perceptible.
Learning Through Drawing and Process	"While I draw… it helps me to think, to process the information."	Drawing supported reflection and helped participants work through scientific ideas during the act of making.
Interdisciplinary Learning	"I think it's really a powerful mix. Because we learn also by doing."	Participants experienced the combination of art and science as an active, experiential learning process.
Creative Freedom and Personal Expression	"I just want to go with the flow… I like creation and then destruction."	Students used the workshop to explore personal imagery, transformation and imaginative interpretation.
Cultural and Mythological Interpretation	"I'm going to show a mythological story… It's not scientific, but I think that's okay."	Cultural stories and mythological references became entry points for interpreting astronomical material.
Emotional Well-being and Engagement	"It's calm, it's easy. Make me feel at peace."	The activity supported emotional ease, enjoyment and engagement within an academic setting.
Changing Perceptions of Animation and Science	"Before this presentation, I learned animation just about Disney… but now I also got that it was very useful for the science."	The workshop expanded participants' understanding of animation as a tool for science communication.

Table 5.6: Thematic summary of Padova student interview responses.

These themes indicate that participants engaged with Astro-animation through visualisation, reflection, cultural storytelling, emotional response and changing perceptions of art–science relationships. The responses suggest that animation functioned as both a conceptual and expressive practice. It helped students visualise phenomena that cannot be directly observed, while also allowing them to bring personal, cultural and imaginative references into their interpretation of astronomical material. The distribution of emotional themes in the Padova workshop is presented in Figure 5.12.

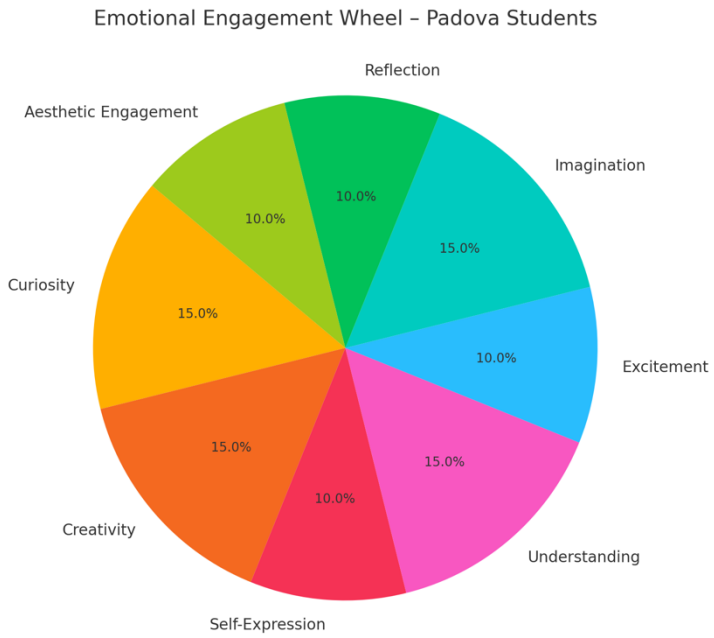


Figure 5.12: Emotional engagement wheel for the Padova student interviews (n = 10).

Prominent themes included curiosity, creativity, imagination, reflective engagement and emotional ease. While several Padova themes echoed findings from earlier workshops, including animation's capacity to visualise invisible phenomena, connect art and science, support personal expression and encourage affective engagement, the Padova workshop placed these themes in a specific context. Unlike the family, teen and community-based workshops, Padova involved university students attending an international conference on animation and science outreach. Participants therefore approached the activity with a more explicit awareness of the relationship between animation, scientific explanation and public communication.

The Padova workshop moved the Toolkit into an international higher education setting and demonstrated its adaptability to a conference-based format while retaining its core structure of scientific grounding, animation-making and reflection. Its strongest contribution was showing how undergraduate participants used animation to 'see the invisible,' while also connecting scientific imagery with personal, cultural and interpretive meaning.

Following Padova, the next implementation shifted from an international university setting to an informal public library context. The Montgomery County workshop examined how

the Toolkit functioned with teenagers in a flexible, drop-in environment shaped by spontaneous discussion and fluctuating attendance.

5.7. Workshop at the Library of Montgomery County with Teenagers

Group: Teenagers (9 attendees in total, 5 to 6 core participants contributing most consistently)

Title of the workshop: *Jupiter*

Following the Padova workshop, the next implementation took place on 14 May 2025 at Montgomery County Public Library as an Astro-animation workshop with teenagers. This shifted the Toolkit from an international higher education and conference context into an informal public library setting. The session followed an open, drop-in format, allowing the study to examine how Astro-animation operated with teenagers in a less structured environment. Although nine teenagers attended at some point, five to six participants remained most consistently involved in the activity, discussion and evaluation.

The library provided a room, screen, refreshments and promotion. Four teenagers initially attended. During Dr Corbet's lightning talk on Jupiter, five additional teens joined, bringing the total to nine. Staggered participation created challenges for structured pre- and post-survey data collection. Printed surveys were introduced to address earlier technical issues, but matching responses remained difficult.

Despite these constraints, the session generated substantial qualitative insight. Teens asked questions extending beyond Jupiter and engaged actively in discussion. Due to the library's media policy, video and photography were not permitted. The discussion was recorded using Microsoft Word's voice-capture function, producing a transcript of participant reflections. Several teens described animation as making science more accessible and engaging, particularly for peers who struggle with text-based learning. Some expressed interest in science, engineering and creative STEM communication, including questions about internships at NASA. Although formal data collection was limited, the workshop generated sustained curiosity and

discussion. It also highlighted the need for methodological flexibility in community-based settings, where open conversation may take precedence over structured evaluation.

5.7.1. Survey Findings from the Montgomery County Teen Workshop

To address earlier technical issues, surveys were administered in printed form and later digitised. Of the nine participants, seven completed pre-surveys and five completed post-surveys. Given the small number of completed surveys, findings are interpreted as formative and read alongside interviews and observations.

Post-survey ratings showed minor variation. Interest in animation remained at 100 per cent. Interest in science increased from 86 per cent to 100 per cent among respondents. Astronomy interest declined slightly from 86 per cent to 80 per cent. These shifts are therefore interpreted cautiously. Qualitative feedback emphasised involvement and curiosity. Pre- and post-workshop interest ratings are presented in Figure 5.13.

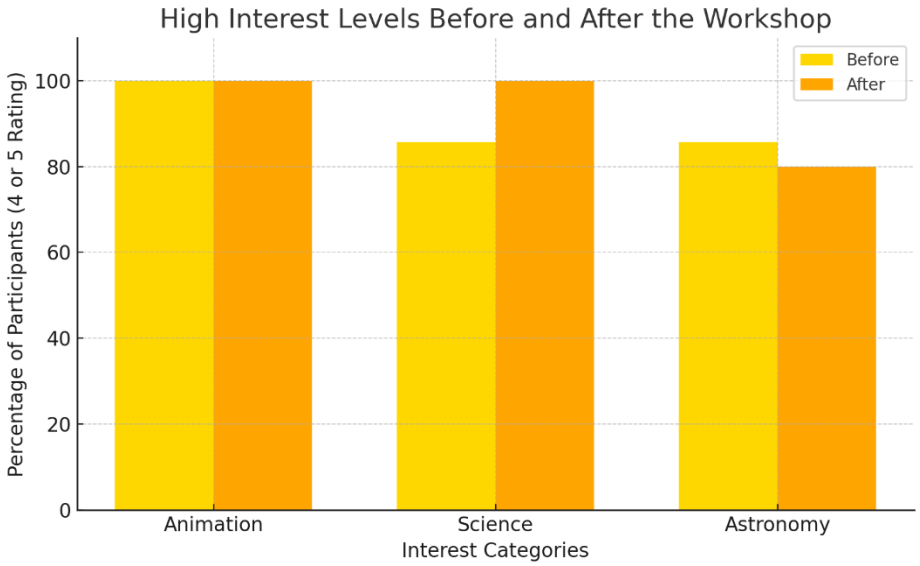


Figure 5.13: Percentage of Teen Participants Reporting High Interest (Ratings of 4 or 5) Before and After the Montgomery County Library Workshop (n = 7 pre-surveys; n = 5 post-surveys, out of 9 total participants).

5.7.2. Thematic Analysis of the Montgomery County Teen Group Discussion

Reflexive thematic analysis was conducted using Braun and Clarke's (2006) six-phase framework. Due to recording restrictions, transcription relied on real-time speech-to-text capture, which limited nuance and overlapping dialogue. These constraints are acknowledged in interpretation. Six teens contributed to the group discussion. As facilitator and interviewer, I adopted a reflexive stance, recognising the co-constructed nature of the dialogue.

Theme	Participant Insight	Interpretive Summary
Animation Sparks Scientific Engagement	'It's not the animation itself that teaches me the science, but because animation is involved, I'm more engaged."	Animation increased willingness to engage with scientific content.
Peer Play as a Catalyst for Learning	"I don't like shaming friends. I want him to join me. I think it would be beneficial for the animation community to gain people."	Social interaction supported participation.
Unscripted Curiosity	"Wait, gravity is still a thing in space. It just changes depending on your distance from a mass."	Teens extended discussion beyond scripted content.
Creative Aspirations	"I love creative writing. Maybe something with NASA and storytelling."	Participants linked science with narrative and creative futures.
Access and Equity in Science Engagement	(Paraphrased) Participants expressed surprise and excitement at speaking with a NASA scientist.	Direct engagement shaped perceptions of inclusion.

Table 5.7: Thematic summary of Montgomery County teen interview responses (n = 6).

Table 5.7 illustrates how participatory animation supported scientific engagement, peer learning and aspirational thinking in a public library teen workshop. The thematic structure of the Montgomery County teen interviews is synthesised in Figure 5.14.

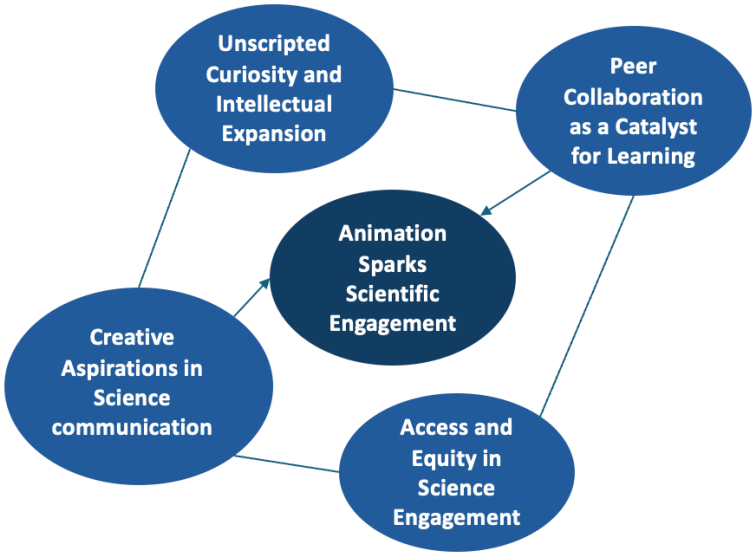


Figure 5.14: Thematic Map of Teen Interview Insights – Montgomery County Library Workshop.

Figure 5.14 synthesises five interrelated themes identified through reflexive thematic analysis, positioning Animation Sparks Scientific Engagement as a central organising construct. Surrounding themes represent social, cognitive and equity-oriented mechanisms through which participants articulated curiosity, collaboration, creative aspiration and access to science in a public library learning context.

The specific contribution of the Montgomery County workshop lies in showing how the Toolkit functioned in a flexible, drop-in teen environment. Unlike the more structured Padova workshop, this session was shaped by fluctuating attendance, conversational exchange and spontaneous questioning. Its value lies less in measurable pre- and post-survey change than in the evidence it provided of curiosity, peer learning and emerging awareness of interdisciplinary possibilities between art, science and communication. These findings are brought into dialogue with the wider Strand 3 data in the following cross-workshop synthesis.

5.8. Cross-Workshop Themes and Insights

Across Strand 3, several recurring patterns emerged from the workshops. Because workshop scale, participant numbers and data depth varied across sites, findings are interpreted proportionately. Larger and more systematically evaluated sessions, such as Pratt Library and BSA, provide stronger evidence, while smaller sessions, such as Balticon, offer more focused insight into process, engagement and adaptability. Across these contexts, animation supported engagement with astronomy through drawing, sequence, metaphor and shared interpretation.

A methodological tension emerged between surveys and interviews. Survey completion was often limited, particularly among teenagers, while interviews provided richer accounts of affective and conceptual engagement. Flexible and conversational methods appeared better suited to capturing outcomes in participatory creative contexts.

Interest in interdisciplinary possibilities was present across several workshops, but participants did not always recognise art–science practice as a professional pathway. This highlights the importance of visible hybrid role models and clearer examples of creative science communication careers. Variability in attendance also posed challenges across community settings. Drop-in formats complicated data collection but supported self-directed engagement, suggesting that openness and evaluation structure need to be balanced carefully in future Toolkit use.

Theme	Evidence across workshops	Insight	Toolkit implication
Scale and data depth	Participation and evaluation varied across sites, from one family group to larger workshop cohorts.	Findings should be interpreted proportionately, with greater weight given to larger or more systematic datasets.	Keep evaluation flexible and appropriate to each setting.
Personal interpretation	Participants used animation to connect astronomy with metaphor, emotion, humour, identity and narrative.	Animation made scientific ideas personally meaningful.	Use prompts that allow interpretation while staying connected to the astronomical theme.
Visual and embodied understanding	Participants described animation as helping them see movement, scale, transformation and sequence.	Drawing and sequencing supported visual, material and embodied reasoning.	Emphasise motion, transformation, scale and sequence in instruction.
Evaluation methods	Survey completion was limited in some settings, especially teen workshops, while interviews provided richer accounts.	Conversational and observational methods captured affective and cognitive engagement more effectively.	Combine simple surveys with interviews, observation, or reflection prompts.
Career awareness	Some participants valued art–science activity but did not recognise it as a professional pathway.	Hybrid career routes need to be made more visible.	Include examples of art–science roles and creative science communication careers.
Attendance variability	Drop-in and open-access settings led to fluctuating participation and uneven data collection.	Open access supported participation but complicated evaluation.	Allow partial participation and use simple documentation tools.
Curiosity and openness	Participants often reported enjoyment, surprise, curiosity, or openness, even when knowledge gains were modest.	Astro-animation encouraged openness to scientific ideas.	Evaluate affective engagement, curiosity and confidence alongside factual learning.

Table 5.8: Cross-workshop themes and implications for the Astro-animation Toolkit.

Toolkit Implementation Note: Strand 3

Strand 3 tested the Astro-animation Toolkit in community-based and informal learning settings. These workshops showed that the Toolkit needed to remain flexible enough to respond to different ages, levels of confidence, workshop durations, institutional requirements and consent procedures. The implementation phase confirmed the importance of clear prompts, differentiated support, participant choice and reflection methods that could be adapted to each setting.

5.9. Summary of Chapter 5

Strand 3 implemented and evaluated the Astro-animation Toolkit in libraries, schools, festivals and an international university context. A mixed-methods approach combined surveys, interviews and observation, prioritising depth and contextual interpretation over statistical generalisation. These workshops generated evidence of participant curiosity, creative engagement, visual learning and interdisciplinary reflection, while also revealing the practical challenges of evaluation in informal and participatory environments.

The contribution of Strand 3 lies in demonstrating that the Astro-animation Toolkit can support participatory science engagement through creative making. Its value is especially evident in how participants used drawing, sequence, metaphor and discussion to connect astronomical ideas with personal interpretation. The findings also show that flexible facilitation and proportionate evaluation methods are essential when working with diverse participants, fluctuating attendance and institutional constraints.

Taken together, the workshops show a clear progression across Strand 3, from family and community-based testing to teen engagement, a small public festival workshop, a school-based session, an international undergraduate context and a public library teen setting.

This progression demonstrates how the Astro-animation Toolkit was adapted across diverse participatory environments and how its findings were brought together through cross-workshop synthesis. This progression is represented in Figure 5.15.

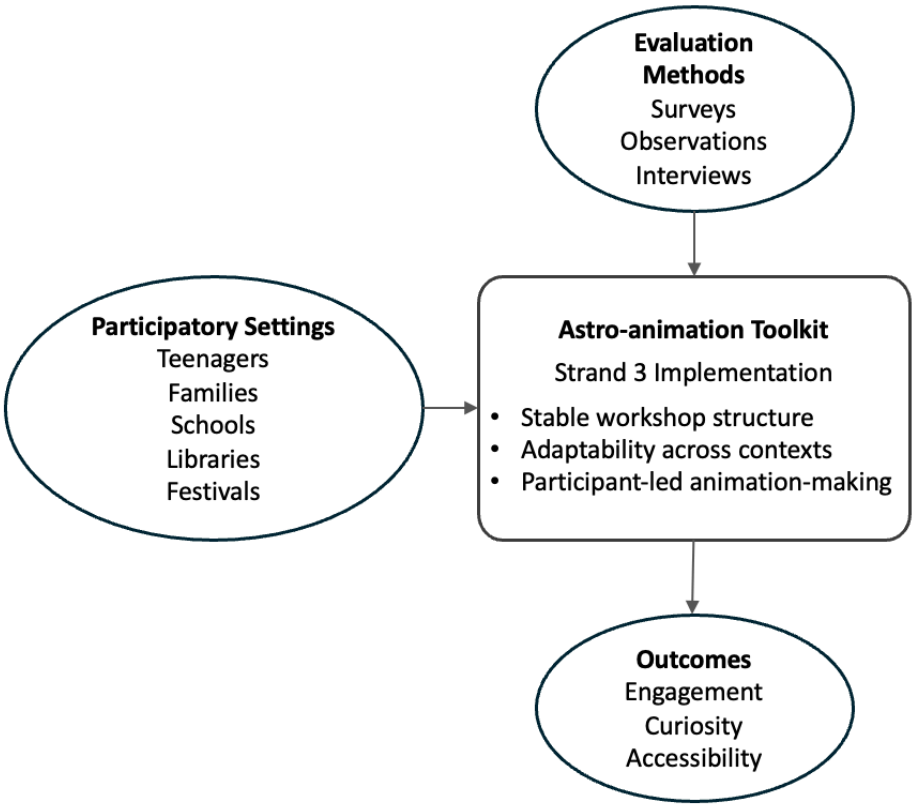


Figure 5.15: Implementation and evaluation of the Astro-animation Toolkit in participatory contexts.

Figure 5.15 summarises the Strand 3 workshop sequence and evaluation methods. It shows how the Toolkit moved across family, community, school, festival, university and public library contexts while retaining a stable workshop structure. Across these sites, surveys, observations and interviews were used to assess engagement in ways appropriate to each setting. The next chapter brings the three research strands together to discuss how Astro-animation contributes to embodied, creative and accessible approaches to astronomy communication.

Chapter 6: Discussion

6.1. Revisiting the Central Question and Aims

This chapter discusses the findings of the three research strands in relation to the central research question: How can participatory Astro-animation, drawing on gesture, metaphor and collaborative animation-making, engage teenagers and participants from underrepresented groups in astronomy communication? It also returns to the study's aims: to examine scientists' gestures as sources for animation practice; to develop and refine an Astro-animation Toolkit; and to evaluate how participatory animation-making supports inclusive engagement and meaning-making in community-based learning settings.

Guided by theories of embodied perception, multimedia learning, Science Capital and collaborative practice, this research positions Astro-animation as an experiential and participatory medium through which knowledge emerges through making. Across the three strands, the findings highlight animation's affordances for astronomy communication: motion, metamorphosis, scale and temporal change can be explored through sequential and metaphorical form, while participatory making allows these processes to be tested, interpreted and shared collaboratively.

What began as an open-ended exploration of scientists' gestures developed into a gesture-informed filmmaking process with NASA scientists, culminating in *The Movements of the Universe*. The subsequent development of the Toolkit translated these principles into adaptable workshop practices. Its implementation in community-based learning settings demonstrated how Astro-animation can support agency, imaginative engagement and participatory science communication, while also creating conditions in which access, confidence, recognition, prior exposure and belonging may be supported in informal astronomy learning.

This chapter is organised around three macro-themes that emerged across the study. The first, *Gesture and Metaphor as Embodied Reasoning*, examines how scientific ideas were externalised through movement and translated into animation. The second, *Participation,*

Agency and Collaborative Meaning-Making, considers how participants shaped the animation process through drawings, interpretations, questions and creative decisions. The third, *Representation, Accuracy and Animation as Inquiry*, examines how Astro-animation reframes scientific representation as a contextual, participatory and practice-based process.

6.2. Theme A: Gesture and Metaphor as Embodied Reasoning

The first macro-theme examines how Astro-animation begins with embodied reasoning. Across the study, gesture and metaphor provided the initial bridge between astronomical explanation and animation practice. Scientific ideas were approached as verbal, embodied, spatial and temporal forms that animation could interpret and transform.

This theme builds on the source review and methodological framework by connecting gesture studies, embodied perception, conceptual metaphor and practice-based research. McNeill's (1992) and Goldin-Meadow's (2003) work on gesture support the analysis of scientists' hand movements as part of thinking, while Merleau-Ponty's (2012) account of embodied perception helps frame understanding as grounded in bodily experience. Lakoff and Johnson's (1980/2003) theory of conceptual metaphor supports analysis of how abstract ideas are structured through embodied and visual associations. Astro-animation extends these frameworks by showing how gesture and metaphor can be translated into animation practice and adapted into participatory workshop methods.

This theme responds to the first aim of the study: to examine how scientists' gestures and metaphors could inform animation practice. In Strand 1, scientists' gestures provided empirical material for animation. In Strand 2, insights from gesture analysis informed the design of the Astro-animation Toolkit. In Strand 3, these principles were translated into participatory workshop practices through drawing, sequencing and animation-making. Together, these stages show how Astro-animation enabled astronomical concepts to be explored visually, materially and temporally.

6.2.1. Gesture as Embodied Scientific Reasoning

Strand 1 showed that gesture was central to the scientists' explanations. During the initial filmed interviews that informed the development of *The Movements of the Universe*, NASA scientists used gestures of varying scale and intensity to describe motion, force, rotation, expansion and spatial relationships. Some were explicit and expansive, while others were subtle or embedded within speech. In the animation process, I amplified and transformed these movements, treating them as starting points for visual interpretation. They did more than accompany speech. They helped organise scientific explanation by making spatial and temporal relations visible.

This finding aligns with McNeill's (1992) argument that gesture and speech form an integrated system of thought and communication and with Goldin-Meadow's (2003) account of gesture as a window into thinking. Within the interviews, gesture often revealed aspects of reasoning that were difficult to express verbally. Spiralling motions, expanding hand movements, circling gestures and directional sweeps made abstract astrophysical processes momentarily visible through the body.

For example, Dr Schnittman's spiralling gestures provided a way of thinking through orbital motion and gravitational interaction. Dr Corbet's instructional gestures supported clear explanation of sequence and movement. Dr Caputo's expansive and expressive gestures communicated both scientific structure and affective intensity. These examples show that the scientists used movement cognitively, spatially and emotionally, reasoning through the body while guiding the viewer's attention. In this sense, gesture became a form of embodied scientific reasoning, translating invisible or large-scale phenomena into human-scale movement. This was significant for Astro-animation because it provided a bridge between scientific explanation and animation practice.

6.2.2. Gesture–Animation Coupling and the Metaphor-to-Design Process

In this thesis, gesture-animation coupling describes the process through which scientists' gestures were translated into animated movement, timing, rhythm and visual metaphor. In *The Movements of the Universe*, gestures identified in the interviews became starting points for

animation. Their direction, speed, repetition, scale and rhythm informed decisions about composition, transformation and pacing.

This developed into the metaphor-to-design method used in the study. Verbal and gestural metaphors were identified, interpreted and tested through animation. Metaphors of spiralling, flowing, expanding, collapsing, stretching and orbiting, for example, became visual and temporal structures that shaped design decisions. Through iterative making, these metaphors could be extended, clarified, or revised.

Metaphor operated at several levels in Strand 1. Drawing on Lakoff and Johnson's (2003) account of conceptual metaphor, embodied or kinaesthetic metaphors emerged through bodily movement, as scientists enacted abstract concepts through gesture. Dr Ojha's demonstration of neutron stars, in which he pulled his arms inward like a figure skater, translated contraction and spin into embodied form. Ontological metaphors appeared when invisible processes such as gravity, expansion, or photon movement were given visual form. In Dr Caputo's sequence, the compression of a galaxy between her hands became a swirling animated disk, making an abstract process perceptible. Conceptual metaphors shaped broader design decisions by organising how astronomical processes unfolded across time. Dr Schnittman's expansive circular gestures, for example, informed the treatment of orbital motion and gravitational curvature, shaping pacing, movement and visual rhythm within the sequence. Metaphor therefore operated across gesture, image and temporal structure, linking embodied explanation to animation practice (Lakoff and Johnson, 2003; McNeill, 1992; Goldin-Meadow, 2003). These metaphorical layers allowed Astro-animation to move across scientific explanation, embodied interpretation and visual experimentation.

This coupling also positioned animation as a mode of inquiry. By animating a gesture or metaphor, I tested how movement might carry meaning, where it clarified a concept and where it introduced ambiguity. Animation therefore became a reflective process in which gesture, metaphor and scientific explanation were repeatedly adjusted in relation to one another. The metaphor-to-design process also informed the later Toolkit. Insights from Strand 1 shaped the workshop emphasis on movement, transformation and visual interpretation. Participants were encouraged to consider how astronomical phenomena move, change, expand, rotate, or

interact. In this way, gesture-animation coupling became transferable, moving from studio-based collaboration with scientists into participatory workshop practice.

6.2.3. Drawing, Sequencing and Embodied Learning

In Strands 2 and 3, embodied reasoning moved from scientists' gestures into participants' animation-making. Drawing and frame-by-frame transformation allowed participants to explore astronomical ideas through physical and visual action. Motion was generated through drawing, sequencing and visual change.

This distinction is central to the study's contribution. Many forms of science communication rely on audiences viewing expert-produced images or animations. Astro-animation asks participants to construct movement themselves. Through drawing on printed frames, altering sequences and imagining transitions, they engaged with astronomy through hand, eye and body. Scientific ideas became more tangible as sequences were drawn, adjusted and tested.

Workshop data indicated that this process supported understanding. Participants described how working with sequential images helped them see movement, scale and transformation more clearly. In the BSA Sunspot workshop, one participant stated, "*The animations prior made me more interested because I understood it more*," while another noted that "*Having a visual guide and being able to draw on it helped me understand science more*." These responses suggest that animation-making supported conceptual understanding by slowing down motion and making change available for inspection. Experiential learning also emerged through uncertainty and experimentation. Participants often began by asking what they were supposed to draw or whether they were doing it correctly. As the activity developed, many became more willing to test ideas, add marks, extend movement, or introduce imaginative elements. This pattern aligns with experiential learning, as understanding developed through doing, reflection, adjustment and further action.

Animation-making therefore functioned as a method of inquiry within the workshop. It also became a method of sense-making through which participants used visual marks to test how an astronomical idea might move, transform, or become visible. Astro-animation thus

supported embodied learning by connecting perception, action, imagination and scientific interpretation.

6.2.4. Synthesis of Theme A

Theme A shows that gesture and metaphor provide a methodological bridge between astronomical explanation and animation practice. Across the study, they enabled scientific ideas to move between speech, body, image and animated sequence. This finding is central to the thesis because it positions Astro-animation as a practice through which scientific concepts can be explored materially, temporally and collaboratively. Theme B extends this argument by examining how these embodied processes became participatory through shared meaning-making.

6.3. Theme B: Participation, Agency and Collaborative Meaning-Making

The second macro-theme examines how Astro-animation supported participants' creative agency. In this context, creative agency refers to participants' ability to shape the animation process through drawings, interpretations, questions and creative decisions. Across the three strands, this appeared in how participants shaped movement, metaphor, colour, rhythm and visual emphasis. Engagement therefore involved contributing to how the scientific idea was interpreted through animation.

This theme responds directly to the study's aim of evaluating how participatory animation-making can support inclusive engagement and meaning-making in astronomy communication. It also connects to the wider research question by showing how different participant groups, including teenagers, families, university students, artists and scientists, engaged with astronomy through shared creative practice. The findings suggest that Astro-animation created a setting in which scientific ideas could be explored socially, emotionally and imaginatively. Theme B also revisits Science Capital by considering how access, confidence, recognition and prior exposure shaped opportunities to engage with astronomy through creative making.

6.3.1. Shared Authorship and Collaborative Making

Shared authorship emerged across the study as a key feature of Astro-animation. In this context, shared authorship refers to a collaborative process in which participants' drawings, gestures, interpretations and decisions shaped the animation's visual and conceptual development. Responsibility for facilitation, editing and final assembly remained with the animator-researcher, while meaning emerged through multiple contributions.

In Strand 1, shared authorship was visible in the collaboration with NASA scientists. Their gestures and verbal metaphors shaped the animation process itself. Scientists' movements informed visual rhythm, spatial composition, pacing and metaphorical transformation in *The Movements of the Universe*. Reflecting on this process, Dr Caputo observed that "*when I was talking about a galaxy and suddenly there was a galaxy swirling in*," describing a moment in which her explanation was carried into the animation. Their contributions therefore became part of the film's structure, while the completed work also allowed them to encounter their own communicative gestures from a different perspective.

In Strands 2 and 3, shared authorship became more explicitly participatory. Workshop participants contributed drawings and visual interpretations that were later assembled into collective animated sequences. These contributions often extended beyond literal illustration. In *The Eclipse* workshop, one participant described the activity as collaborative, noting, "*It's a collaboration piece… he's taking this last frame and rolling with it*." This comment shows that participants understood their drawings not as isolated contributions, but as part of a shared sequence shaped across multiple hands. Even when they began by following instructions, they were actively interpreting and extending the material. Astro-animation therefore redistributed authorship by allowing scientific meaning to develop through collaborative making.

This collaborative structure is important because it distinguishes Astro-animation from expert-led forms of science communication in which audiences primarily watch or receive information. In Astro-animation, participants become co-interpreters of the scientific idea. Their contributions may be partial, improvised, or uneven, but they remain integral to the production of meaning within the workshop.

6.3.2. Agency, Identity and Personal Interpretation

In the workshops, creative agency was closely connected to identity and personal interpretation. Through drawing and sequencing, participants could alter images, represent movement or transformation and connect astronomical material to their own visual language.

This was particularly significant in workshops with teenagers. Several participants used animation to connect astronomy with narrative, emotion, or personal interests. In some cases, they introduced expressive symbols, humour, or imagined characters into astronomical imagery. In the Pratt teen workshop, for example, one participant added hearts "*to symbolize my heart going from small to big*", using the sequence to register a personal and affective response. Such additions created points of entry through which participants could relate to the astronomical material. The scientific image became something they could handle, transform and interpret.

Agency therefore emerged through the act of making. Participants could decide how to visualise motion, emphasise change and connect astronomical phenomena to their own forms of expression. This is particularly significant for underrepresented or less confident participants, who may have had limited prior access to astronomy communication or may not initially see themselves as belonging within scientific spaces. In Science Capital terms, the workshops created opportunities for recognition, confidence-building and participation through visual and material action. Astro-animation offered a form of participation that did not depend on prior expertise, technical vocabulary, or confidence in formal science learning. Participation could begin through making, altering and interpreting images.

Identity is understood here as something expressed through participants' choices, comments and creative responses. In the Pratt teen workshop, one participant remarked, "*We get to be creative and express who we are*", directly linking the activity to self-expression. In the Pratt Library workshop, another participant reflected, "*I feel like in doing this I'm also in this world that I'm creating… it's helped me to have more of a connection with it*", suggesting that animation-making supported both personal investment and imaginative identification with the material. When participants introduced humour, emotional motifs, or narrative elements, they

positioned themselves in relation to the scientific content and made astronomy meaningful through their own interests, imagination and visual language.

6.3.3. Emotion, Affect and Investment in the Process

Emotion and affect were closely connected to participation. Across the workshops, participants described animation as fun, exciting, surprising, accessible, or motivating. In the Montgomery County Library workshop, one teenager described animation as an affective motivator, explaining that "*because animation is involved, I'm more engaged and more ready to learn*" (TW-P6, Appendix A.10). The same participant also suggested that animation could introduce science to younger audiences because "*animation is so fun… it could really teach people our age or even younger to enjoy science*" (TW-P6, Appendix A.10). These comments show how creative participation supported motivation and encouraged greater openness to scientific material.

Similar patterns appeared in other workshop settings. In the HEAD 21 Eclipse workshop, a conference participant described orbital interaction metaphorically as "*a love affair… it creates life*" (ECL-P2, Appendix A.10), linking celestial motion with emotional and imaginative interpretation. In the Padova workshop, undergraduate participants described drawing and animation as ways of processing and connecting with scientific material. One participant stated that drawing "*helps me to think, to process the information*" (PAD-P2, Appendix A.10), while another described "*doing animation on something that is real and alive*" as 'very special' (PAD-P8, Appendix A.10).

These responses indicate that affect shaped engagement with astronomy. Curiosity, enjoyment, surprise and emotional investment helped sustain attention and encouraged participants to explore unfamiliar ideas through drawing, sequencing and collaborative making. This aligns with the thesis's wider theoretical framing of learning as perceptual, experiential and imaginative. It draws on Merleau-Ponty's (2012) account of embodied perception, gesture studies by McNeill (1992) and Goldin-Meadow (2003) and research on awe and emotional salience in science engagement (Keltner and Haidt, 2003).

Affective engagement also appeared through anticipation and pride. Participants often wanted to see how their drawings would look once assembled into the completed animation.

This expectation created a sense of investment in the process. The final animation became a shared object that reflected individual contributions while also belonging to the group. This pattern supports the broader aim of Astro-animation: to enable participants to explore, question and interpret scientific ideas through drawing, sequencing and collaborative making.

These findings also resonate with the learning frameworks introduced in Chapter 2, particularly Kolb's (1984) emphasis on experiential learning and the role of coordinated visual, verbal and active engagement in multimedia learning (Mayer, 2005; Mayer and Moreno, 2002).

6.3.4. Interdisciplinary Reframing of Art and Science

The workshops also prompted participants to reconsider the relationship between art and science. Across several settings, the pairing of animation and astronomy was described as unexpected, but useful for thinking about scientific ideas through movement, storytelling and visual interpretation. This reframed science as a field open to creativity and suggested that artistic skills could contribute meaningfully to scientific communication.

This interdisciplinary reframing was particularly visible among teenagers and university participants. Teenagers often responded to the unexpected compatibility of animation and astronomy, while Padova participants reflected more explicitly on how animation could help process, visualise and communicate scientific ideas. One participant described drawing as a way '*to think, to process the information*,' while another stated that animation made it possible to '*see the invisible*' (Appendix A.9).

This reframing also appeared in the scientist collaborations. Scientists involved in Strand 1 and the HEAD 21 workshop recognised that animation could make aspects of their explanations more visible, dynamic, or emotionally resonant. Their responses suggest that Astro-animation created opportunities for scientists to see how their explanations could be translated visually, animated and reinterpreted through movement.

The art-science relationship in Astro-animation is therefore reciprocal, with scientific concepts, embodied gestures, visual metaphors and participant interpretations shaping one another. Gesture becomes animation and participants extend it through drawing and

interpretation. This supports the thesis's wider argument that Astro-animation operates as collaborative inquiry.

6.3.5. Synthesis of Theme B

Theme B shows that participation in Astro-animation involved agency, interpretation, emotional investment and shared authorship. Participants shaped the work through drawings, questions, interpretations, visual choices and emotional responses. Across the workshops, scientific ideas became open to personal and collective interpretation, allowing participants to connect astronomy with imagination, narrative, humour, feeling and visual expression.

Building on Theme A, this theme shows what happens when embodied reasoning becomes shared practice. Theme C considers how this participatory process reframes questions of representation, accuracy and creative exploration.

6.4. Theme C: Representation, Accuracy and Animation as Inquiry

The third macro-theme examines how Astro-animation reframes questions of representation and accuracy through movement, metaphor and creative interpretation. This theme responds to the study's wider aim of developing a practice-based approach to astronomy communication. It also addresses how creative practice can remain scientifically responsible while allowing space for interpretive participation. In this research, accuracy was approached as a contextual design consideration shaped by purpose, audience, setting and mode of participation.

6.4.1. Scientific Accuracy as Contextual Design

A recurring issue throughout the research was the relationship between scientific accuracy and creative interpretation. Astronomy communication often involves phenomena that exceed direct human perception, including gravitational interaction, solar activity, orbital movement, cosmic distance and transformation over time. These phenomena require visual mediation. In

this study, accuracy was therefore approached as a contextual design consideration shaped by purpose, audience, setting, facilitation and fidelity to scientific source material.

This discussion builds on the continuum of scientific accuracy and public engagement introduced in Chapter 1 and visualised in the pyramid/continuum model (Figure 1.14). That model frames representation as a contextual design choice rather than a simple division between accurate and inaccurate forms. Within this framework, Astro-animation occupies a scientifically inspired position: it remains grounded in scientific source material, expert input and reflective discussion, while using metaphor, movement, imagination and participatory making to support engagement.

Across the three strands, scientific accuracy operated through different forms of grounding. In Strand 1, scientists' gestures and explanations anchored the work in domain reasoning, while animation supported visual and temporal interpretation through metaphor, rhythm, timing and sensory judgement. In *The Movements of the Universe*, animation decisions were informed by scientific explanation, visual metaphor, iterative reflection and feedback from collaborating scientists. In Strands 2 and 3, scientific grounding was provided through lightning talks, NASA imagery, facilitator explanation and group discussion. Within that structure, participants interpreted movement, transformation and scale through their own visual language.

This approach frames accuracy as a matter of informed judgement. A participant's drawing could be scientifically meaningful when it showed engagement with motion, force, rotation, scale, gravity, heat, expansion, or transformation, even when the image was imaginative or symbolic. Scientific meaning therefore emerged through the relationship between explanation, image, movement and interpretation.

6.4.2. Making and Viewing as Connected Processes

A central finding of the research is that animation-making produced sustained engagement with astronomical ideas. Participants worked with astronomy through frame-by-frame animation-making, using drawing, sequencing and visual adjustment to explore motion, transformation, scale and visibility.

In Theme C, this matters because it reframes representation as a process. Participants' drawings became part of a sequence through which scientific ideas could be tested and interpreted. This shows how scientific grounding and interpretive engagement operated together in Astro-animation.

The completed films also played an important role. They allowed participants to see their individual drawings transformed into collective movement. The process from drawing and sequencing to scanning, assembling and viewing helped participants recognise their contributions as part of a shared interpretation of the astronomical material.

6.4.3. Animation as Practice-Based Inquiry

Across the thesis, animation functioned as a mode of inquiry. It was used to investigate how scientists' gestures and metaphors could be translated into visual form, to inform the design of an adaptable Toolkit and to support participatory exploration of astronomy with public audiences. This positions animation as both method and outcome. The animations produced during the research are creative works, but they also record processes of thinking, collaboration and interpretation. Decisions about timing, rhythm, transformation and visual emphasis formed part of the analytical process, while workshop participants used marks, symbols and sequences to test how astronomical ideas might move or change.

From my perspective as animator-researcher, this process revealed that animation can be a way of thinking through scientific ideas rather than simply illustrating them. In Strand 1, translating scientists' gestures into animation showed that gesture could operate as a bridge between explanation and design. Dr Ojha's contraction gesture suggested compression and spin; Dr Schnittman's expansive circular movements informed rhythm and gravitational curvature; and Dr Caputo's hand positions prompted the visualisation of galactic compression. By animating these gestures, I tested how motion, pacing and transformation might clarify a concept or introduce ambiguity. Animation therefore became a site in which scientific meaning was explored through making.

This enquiry extended into Toolkit development and workshop practice. In Strand 2, cycles of testing and revision showed that animation-making could scaffold engagement as well

as explanation. In Strand 3, participants' drawings demonstrated that animation afforded a way of slowing motion down, breaking change into visible stages and making abstract processes available for interpretation through marks, sequencing and metaphor. Astro-animation therefore afforded a participatory mode of science communication in which astronomical ideas could be explored through movement, transformation and collaborative visual thinking.

6.4.4. Positioning Astro-animation within Astronomy Communication

Astro-animation contributes to astronomy communication by offering a practice-based model centred on embodied making, shared interpretation and creative authorship. Across the three strands, scientific explanation, gesture, metaphor, drawing and animation became linked through practice.

This positioning connects Astro-animation to wider art-science practices that foreground dialogue, process and mutual influence, including long-term collaborative models such as Arts at CERN (2024). As discussed in Chapter 1, these models establish important precedents for sustained artist-scientist exchange, but they do not address the specific gap examined in this thesis: how collaborative animation-making can be used as a structured facilitation model for engaging public audiences with astronomy.

Astro-animation's specific contribution lies in embedding gesture-informed animation within workshop contexts where scientists' explanations, the animator-researcher's interpretation and participants' drawings, questions and creative decisions collectively shape the final work. In this sense, Astro-animation offers a framework for astronomy communication in which scientific ideas are explored through embodied, creative and collaborative interpretation.

6.4.5. Synthesis of Theme C

Theme C shows that scientific representation within Astro-animation depends on context, purpose, facilitation and reflective judgement. Accuracy remained important throughout the research, but it was not treated as a fixed opposition to imagination. Scientific grounding was maintained through source material, expert input, facilitator explanation and discussion, while

participants were given space to explore movement, transformation, scale and affect through creative interpretation. The next section considers the practical implications of this argument.

6.5. Implications

Across the three strands, Astro-animation demonstrated how gesture-informed animation and participatory making can support visual interpretation, collaborative inquiry and access to astronomical ideas. The following subsections outline how the research informs animation practice, supports science communicators and offers a structured approach for workshops with teenagers, families and public audiences.

6.5.1. Implications for Animation Practice

The findings highlight animation's role as both a creative medium and a research method. In Strand 1, NASA scientists' gestures showed how physical movement can externalise thought. Through animation, these kinaesthetic explanations became exploratory sequences that informed visual interpretation. This extends gesture theory into creative practice by showing how gesture-informed animation can function as a method for thinking through scientific ideas.

Across the workshops, participants also described drawing and sequential experimentation as supporting sense-making. A participant in the Pratt Library Family Workshop reflected that seeing Pluto images 'one after the other' helped them understand both the movement of the planet and the frame-by-frame structure of animation (Appendix A.4). This response illustrates how attention to small differences between frames can support perceptual awareness and sequential reasoning.

For animation practice, this suggests that the animator's role can extend beyond producing finished visual explanations. In Astro-animation, animation becomes a structured environment for inquiry, where movement, timing, metaphor and transformation are used to interpret scientific ideas. This has implications for animators working in science communication, education and public engagement, as it positions animation as a process of investigation as well as a final outcome.

6.5.2. Implications for Toolkit Design and Facilitation

The Astro-animation Toolkit offers a modular framework for animators, scientists and educators. Its core structure consists of a short scientific lightning talk, animation instruction, collaborative animation-making and reflection. In this research project, participant surveys and interviews were also used as evaluation methods, but these are not required for every future use of the Toolkit. In non-research settings, reflection may instead take the form of group discussion, participant sharing, informal feedback, or facilitator observation.

This distinction matters because the Toolkit functions both as a research instrument and as a practical facilitation model. Within the PhD, surveys and interviews supported data collection and evaluation. In future educational or public engagement contexts, reflective discussion can function as an experiential learning tool.

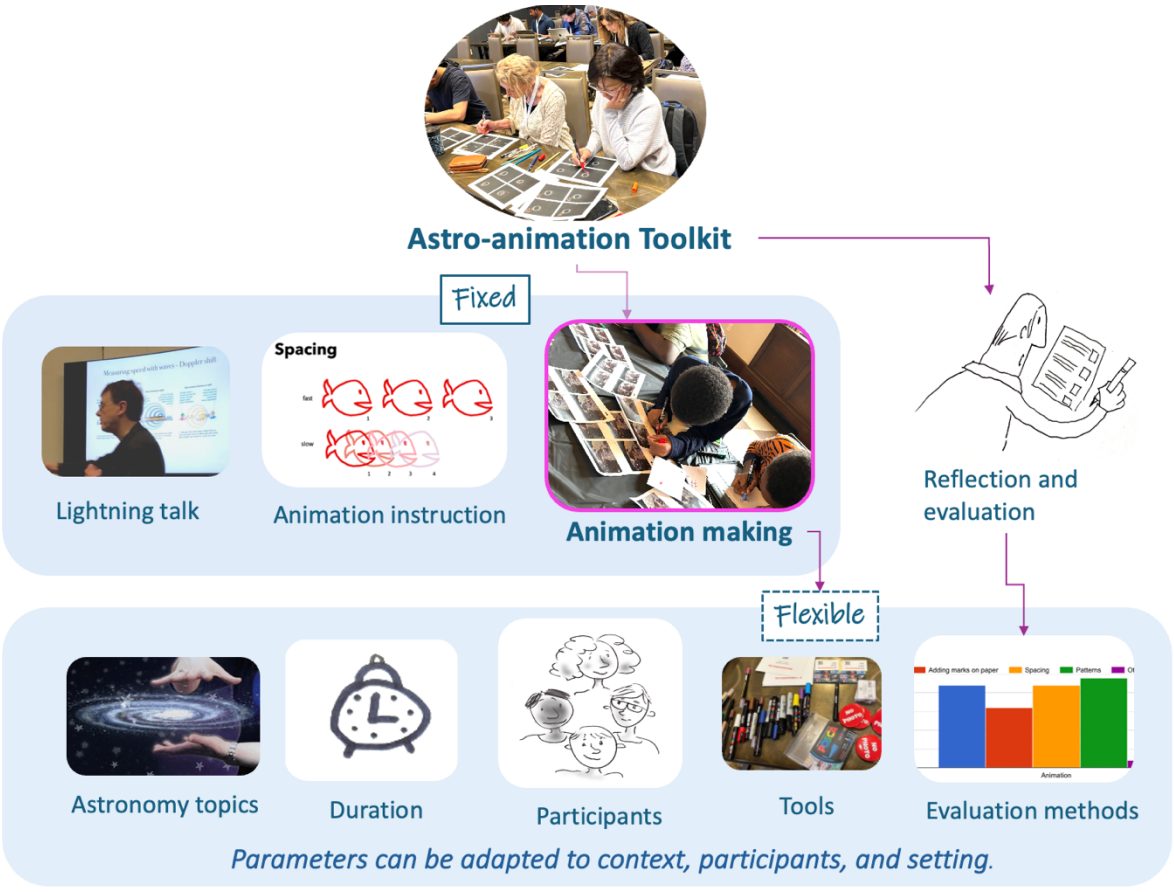


Figure 6.1: Overview of the Astro-animation Toolkit structure.

The fixed core process consists of an astronomy lightning talk, animation instruction, collaborative animation-making and reflection. Contextual elements, including topic, duration, participant group, tools, facilitation structure and evaluation or reflection methods, can be adapted according to setting.

6.5.3. Implications for Astronomy Communicators

For astronomers and science communicators, Astro-animation offers a practical model for turning explanation into shared visual exploration. The findings indicate that animation can support clarity, emotional engagement and interpretation when scientific ideas are explored through gesture, metaphor, drawing and sequencing.

Across workshops, participants described animation as helping scientific ideas become perceptible through visual and material action. A BSA student noted that "*seeing a visual source… helps understand different scientific terms and seeing the sun orbits around*" (BSA-P5, Appendix A.10). Teens at the Pratt Library similarly commented that animation allowed them to "*visually see it, understand it*" (PT-P10, Appendix A.10) and to grasp "*how everything works and moves*" (PT-P11, Appendix A.10). These reflections suggest that animation supported conceptual processing by making motion and transformation experientially accessible.

For astronomers, educators, outreach professionals and other science communicators, this finding highlights the value of designing activities around movement, transformation and visual interpretation. Animation-making can be used as an active method through which participants explore scientific concepts, while finished animations can become shared outcomes of that process. Short talks, demonstrations and image sequences provide scientific grounding, while drawing and sequencing allow participants to test how a concept might move, change, or become visible.

Metaphor is especially important in this process. Although participants did not explicitly categorise their metaphors, their responses and drawings can be understood through kinaesthetic, ontological and conceptual metaphor. Kinaesthetic metaphors appeared when participants used bodily movement, gesture, or drawn motion to imagine astronomical processes. Ontological metaphors appeared when abstract phenomena such as force, heat,

gravity, or solar activity were given visible form through characters, particles, flows, explosions, or expressive marks. Conceptual metaphors shaped broader interpretations, such as orbit as relationship, solar activity as energy, or transformation as growth, destruction and renewal. These categories help show how animation-making allows scientific ideas to be translated into forms that can be seen, felt, revised and discussed.

Scientists participating in the HEAD 21 Eclipse workshop also emphasised animation's narrative and affective dimensions. One described orbital motion metaphorically as "*a love affair… it creates life*" (ECL-P2, Appendix A.10), while another observed that "*the spaceship turns into an eye… it absorbs the identity of the Sun*" (ECL-P2, Appendix A.10). These examples show how metaphor and emotional framing can support conceptual exploration in astronomy communication. They also suggest that scientists can benefit from seeing how participants reinterpret scientific ideas through visual and temporal form.

The practical implication is that Astro-animation can support a shift from explanation towards facilitated inquiry. Designed for paired facilitation, typically an astronomer and an animator or media practitioner, the Toolkit offers a transferable format for libraries, museums, schools, festivals and astronomy events. In this context, animation operates as a collaborative method through which scientific ideas are explored, interpreted and shared.

6.5.4. Implications for Outreach Initiatives with Underrepresented Communities

The study offers specific insights for outreach initiatives seeking to engage young people and underrepresented groups in astronomy. Workshops at the Pratt Library, Montgomery Library and the Baltimore School for the Arts indicate that animation can lower barriers to participation by offering multiple entry points: visual, tactile, narrative and social.

Participants frequently described animation as approachable and engaging. One teen emphasised its motivational role: "*animation is so fun… it could really teach people our age or even younger to enjoy science*" (TW-P6, Appendix A.10). A BSA participant reflected on the value of combining artistic and scientific approaches: "*It's fun to have a class that provides both space and art… I've always liked animation and science and they are connected in my mind*" (BSA-P3,

Appendix A.10). These responses suggest that animation helped frame astronomy as accessible, creative and open to interpretation.

As discussed in the Introduction, arts education reporting identifies continuing inequities in access, participation and provision across districts and disciplines, including uneven access to media arts and other arts opportunities (*Arts Education in Maryland Schools*, 2024). Science communication and outreach literature also identifies barriers to participation, including limited access to science spaces, unfamiliar technical language and narrow perceptions of who science is for (Archer et al., 2015). As introduced in the Introduction and Methodology, Science Capital frames these barriers in terms of access, confidence, recognition, prior exposure and belonging. In the workshops, this framework guided activities that offered low-threshold entry points, visible creative contribution, collaborative making and opportunities for participants to connect astronomy to their own interests and visual language.

Astro-animation responds to these barriers by inviting participants to explore scientific ideas through visual, material and collaborative activity. Prior scientific knowledge or academic confidence is not required as a starting point. Participants can begin by making, experimenting and interpreting the material in their own way. This mode of participation also supported identity exploration. In several workshops, participants introduced symbolic or expressive elements into their animations, including faces, emotional motifs, humour, or personality traits, reframing cosmic phenomena in personally meaningful ways (Appendix C.1). Through drawing and animation, participants positioned their own interpretations within scientific narratives.

The findings also underscore the importance of facilitation. Participants often required differentiated support, clearer prompts, or additional scaffolding. These observations informed refinements to the Toolkit, including step-by-step instruction sheets and structured demonstrations. The Montgomery Library STEAM Festival workshop, which included younger children and a neurodiverse participant, further demonstrated that the Toolkit's image-based and hands-on format can adapt to varied ages, abilities and linguistic backgrounds.

Scalability also requires qualification. The approach is transferable across contexts, but it depends on facilitation quality, preparation and time for collaborative development. A skilled animator helps shape the final animation, while scientific input keeps the workshop connected

to accurate astronomical ideas. Where direct access to scientists is not possible, prepared scientific materials can provide foundational content. Funding influences the number and duration of workshops, but the basic model can remain viable with modest resources when facilitation is carefully planned. Overall, participatory animation can support inclusive outreach by giving participants creative, social and personal ways to explore scientific ideas. This process can build confidence and make astronomy feel more connected to everyday experience.

6.5.5. Reflection on the Workshops and Future Development of the Toolkit

During the workshop phase, I learned that the core sequence of scientific introduction, animation instruction, collaborative making and reflection could remain consistent, while its delivery needed to be adapted to different settings. Scientific talks and imagery provided conceptual grounding, while simple animation techniques offered an accessible starting point. Participants' ages, prior interest and confidence shaped the level of explanation, prompting and practical support required. Venue and available time shaped what could be completed, while consent arrangements affected documentation and evaluation. The Toolkit therefore provides a flexible framework whose core principles can support different forms of delivery.

The contrast between Strands 2 and 3 was particularly important. In Strand 2, the method was developed with scientists, whose contributions shaped its scientific content and structure, and was subsequently refined through feedback from artists on its wording, prompts, demonstrations and workflow. The public and youth workshops involved audiences with more varied relationships to astronomy and animation. They showed how the method operated outside its initial expert context and raised questions about recruitment, evaluation, co-design and independent delivery. The following sections reflect on these experiences and consider future use of the accuracy–engagement continuum, delivery by new facilitator teams and adaptation to other scientific disciplines.

6.5.5.1. Challenges Encountered and Lessons from Participant Engagement

I initially expected recruitment, consent and evaluation to follow a broadly consistent process across venues. In practice, these procedures were shaped by each institution and its patterns of attendance. At the Enoch Pratt Library, many families arrived without registering in advance,

and obtaining consent for minors during a busy public workshop proved difficult. At the Baltimore School for the Arts, concerns about surveys and external content required additional discussion with staff, while some students were redirected to other academic responsibilities during the sessions. These circumstances interrupted participation and resulted in incomplete demographic and engagement data.

I also expected pre- and post-workshop surveys to provide a clear account of changes in interest and understanding. Completion rates varied, particularly in youth and drop-in settings. At Montgomery County Public Library, nine teenagers participated during the workshop, while seven completed the pre-survey and five completed the post-survey. Because individual pre- and post-workshop responses could not be matched, I could not determine whether participants' answers had changed. The percentages therefore describe two small sets of responses rather than evidence of change resulting from the workshop. The Baltimore School for the Arts surveys also produced mixed findings: interest in astronomy was slightly higher in the post-workshop responses, while responses about interest in science and the educational value of animation were less positive. These results showed that enjoyment, scientific interest and approval of animation as a learning method should not be treated as interchangeable outcomes.

Interviews, observations and discussions about participants' drawings provided richer evidence of engagement (see Appendices A.4 and A.10). At Pratt, PL-P1 explained, "I learned about Pluto. I always wondered why it wasn't a planet," while a participant in the family workshop described an imaginative transformation: "I started with a fish but turned it into a spacecraft." These responses revealed conceptual curiosity and creative interpretation that were difficult to capture through short surveys. They also helped me recognise that personal imagery could provide an entry point into astronomy when participants had opportunities to explain their choices.

These experiences changed how I understand workshop evaluation. Scheduled school workshops, library programmes and festival drop-ins may require different evaluation processes. Recruitment, consent, documentation and evaluation procedures should be agreed with host organisations before delivery. Matched pre- and post-workshop surveys may be

appropriate for groups with consistent attendance, while observation, short interviews and participant reflection may be more suitable for drop-in settings. Facilitators could also provide opportunities for participants to explain what their animation represents, how it relates to the astronomical source and how their creative decisions developed. These approaches would allow future users or researchers to select evaluation methods appropriate to participants' ages, attendance patterns, available time and institutional requirements.

6.5.5.2. Co-design with Target Communities

The workshops supported shared authorship within a format that I had already designed. Participants shaped the animations through their drawings, metaphors and choices about movement and transformation. The astronomical topic, workshop duration, animation materials, evaluation methods and how the completed work would be shared were decided in advance. Their participation therefore shaped the resulting animations but did not extend to co-designing the workshop itself. This distinction became more important as the project moved from expert testing to teenagers and public audiences. The scientists and artists in Strand 2 could readily enter a structure organised around astronomy and animation; a teenager who is indifferent to both may reasonably question why the topic, materials and evaluative questions have already been chosen for them.

Co-design literature provides a more precise way to address this limitation. Druin (2002) distinguishes children's roles as users, testers, informants and design partners, demonstrating that 'participation' can describe very different degrees of influence. Durall et al. (2021) connect co-design in informal science learning to accessibility, personal relevance, social learning, learner autonomy and identity-building, while emphasising that design principles must be adapted to context rather than treated as a universal checklist. Calabrese Barton, Kim and Tan (2020) go further with the concept of 'rightful presence': youth should not be invited into science spaces as temporary guests or recipients of authorised knowledge, but should be able to expose and transform the practices that position them at the margins. These perspectives suggest that future co-design could involve intended participants in selecting topics and prompts, shaping workshop activities and deciding how their contributions are reflected on and shared.

Co-design would bring together animation, scientific and participant expertise. I would continue to shape the practical workshop design and animation methods, while scientists would support its scientific grounding. Teenagers and other intended participants could influence the topic, prompts, examples, modes of collaboration and forms of reflection. Making these roles explicit would clarify how decisions and responsibilities are shared.

One possible model would involve a small, paid youth advisory group recruited through a partner organisation. Recruitment could include organisations working with communities underrepresented in astronomy, while recognising that one advisory group could not represent the experiences of all teenagers or communities. Members could discuss their interests, previous encounters with space imagery, preferred media, access needs and the factors shaping whether an astronomy activity felt relevant and accessible to them. They could compare alternative topics, scientific explanations, image sequences and animation techniques. Their role could include revising prompts, considering whether activities should be individual or collaborative and identifying forms of reflection that do not resemble school assessment. The same group could then review a pilot and discuss which recommendations had been adopted, modified or declined.

The Strand 3 findings reported in Appendix A.10 identify points at which participant input might have influenced the research design. The mixed BSA survey responses indicate that the terms ‘art’ and ‘science’ may not have been understood consistently; co-design could have tested this wording before data collection. At Pratt, a teenage participant used changing hearts to express a personal idea, while a participant in the family workshop transformed a fish into a spacecraft, as recorded in Appendix A.4. These examples helped me recognise personal imagery and visual transformation as possible entry points into astronomy. Montgomery County teenagers’ questions about NASA internships also showed that career examples might have been selected with them. Co-design could therefore shape both the workshop content and its relevance to intended participants.

Co-design should not be treated as automatically equitable. Gallacher and Gallagher (2008) caution that participatory methods can still reproduce adult authority. Clear decision-making roles would therefore be essential. Participants should understand what they can

influence, how their contributions will be used and which decisions remain with the researcher, facilitators and scientific experts. Their time should be recognised, consent should be accessible and disagreement or withdrawal should remain possible. Scientific experts would identify potentially misleading representations, while facilitators would oversee safeguarding and practical delivery. This approach would bring scientific, creative and lived expertise together within a clear and accountable structure.

6.5.5.3. Using the Accuracy–Engagement Continuum in Evaluation

In retrospect, having completed the workshops, I recognise that the accuracy–engagement continuum introduced in Figure 1.14 could have played a more active role in evaluating the workshops. It provided a framework for considering scientific accuracy, accessibility and creative interpretation, but it was not systematically applied to participants' animations or reflections. In future evaluations, it could be used to assess how participants' animations remain connected to astronomical sources while allowing space for creative and personal responses. The continuum would support reflection on the relationship between accuracy and engagement, rather than being used to rank animations or test participants' knowledge.

The participant responses reported in Appendix A.10 show why this would be useful. In Padova, one participant developed a mythological solar story and stated, "It's not scientific, but I think that's okay." During the Eclipse workshop, a scientist used metaphors of love and identity to interpret the encounter between celestial bodies. At BSA, one participant explained that the visual material helped with "different scientific terms and seeing the sun orbits around." At Montgomery, a teenager observed, "It's not the animation itself that teaches me the science, but because animation is involved, I'm more engaged and more ready to learn." These examples show how scientific interpretation, metaphor and personal engagement operated across different workshop settings.

The Padova participant clearly distinguished their mythological story from a scientific account. The BSA participant's brief comment that the visual material helped with 'seeing the sun orbits around' was not followed by further discussion, so it does not show precisely how they understood the movement. This difference demonstrates the value of including participants' explanations when using the continuum. A short conversation could record what

they intended and how their response related to the astronomical source, while keeping the emphasis on reflection and engagement rather than testing their knowledge.

Participants' explanations also revealed what had sparked curiosity or wonder, why particular metaphors had been chosen and how they were developing a personal connection with astronomy. Reflection could therefore document whether the activity offered a meaningful entry point into the subject and encouraged participants to feel that astronomy could also be for them. It could also enable facilitators to recognise when a creative interpretation remained connected to the astronomical prompt and when additional context might be useful.

Facilitators could use the continuum through three brief moments of reflection. Before making, participants could identify an aspect of the astronomical prompt that interests them, such as movement, scale, colour or transformation. During making, the facilitator could ask what a particular movement or image represents. After making, participants could explain what inspired their animation, why they made particular visual choices and how their work relates to the original source. These conversations would help the facilitator consider the relationship between scientific connection and creative engagement without assigning a score to the animation.

This approach reflects what I learned from Strand 3. The surveys produced small, incomplete and sometimes mixed patterns, while interviews and observations provided richer accounts of curiosity, confidence and creative ownership. In a public workshop, the continuum could guide an informal conversation rather than a formal evaluation. Where research evaluation is required, participant reflections and facilitator notes could record how the astronomical prompt, metaphor and personal meaning connect. Used in this way, the continuum could help facilitators recognise different forms of engagement while keeping imaginative participation connected to astronomy. The following sections consider how this approach might support independent facilitators and how it would need to be adapted for use in other scientific disciplines.

6.5.5.4. Improving the Toolkit for Independent Facilitators

A further limitation is that I developed and led the workshops in collaboration with a science expert. My knowledge of animation, the research history and the intended balance between

guidance and openness allowed me to make adaptations that were not always stated in the Toolkit. The positive relationship between clarity and enjoyment at Transart/LJMU and the need for clearer demonstrations at White Oak suggest that this practical knowledge forms part of the method. The Toolkit clearly specifies two facilitators: an astronomer or appropriate science expert and an animator or time-based media expert, with one acting as Lead Facilitator. However, the present study does not establish how a pair with no previous involvement in the research would interpret and apply this guidance.

A future study could examine how a science expert and an animator or time-based media practitioner, neither previously involved in the project, use the Toolkit without direct coaching. Their planning, reflections and participant feedback could reveal whether the division of roles is clear, what knowledge the method assumes and how the pair balances scientific grounding with creative interpretation.

This testing would help distinguish the fixed core from the Toolkit's adaptable elements. Paired facilitation, scientific grounding, a visible animation demonstration, participant making, reflection, assembly and sharing would remain central. Topic, duration, materials, group size, level of collaboration and evaluation method could vary according to the setting. The science facilitator would identify the essential concept, select appropriate source material and clarify potentially misleading interpretations. The animation facilitator would demonstrate movement and sequencing, support participants' visual decisions and lead or coordinate the assembly of the final film. Both would contribute to reflection, enabling scientific and creative perspectives to remain in dialogue.

The Toolkit already provides guidance on facilitator roles, timings, consent, preparation and technical processes. The consent and data-collection challenges encountered at Pratt and BSA also showed the importance of distinguishing consent to attend a workshop from consent to participate in research. If a future facilitation team used the Toolkit to collect research data, it would need approval from the relevant research ethics body and appropriate procedures for participant information, consent, withdrawal, data storage, anonymity and the use of creative work. These requirements would vary according to the institution, discipline and participant group.

Independent testing could determine whether this guidance is sufficiently clear when used by a new facilitation team. It might also indicate whether supplementary support would be useful, such as a shared planning checklist, annotated examples situated along the accuracy–engagement continuum, differentiated prompts or low-technology alternatives. Future users or researchers could examine whether any of these supplementary resources would benefit new facilitation teams alongside the guidance already provided in the Toolkit.

6.5.5.5. Transferability to Other Scientific Disciplines

The Eclipse, Pluto, Sunspot and Jupiter workshops applied Astro-animation to different astronomical topics, participant groups and institutional settings. Each workshop required adjustments to the scientific material, timing and participant support while retaining the basic sequence of introduction, animation-making, reflection and sharing. These workshops showed that the method could be adapted within astronomy and led me to consider which elements might transfer to other sciences.

Drawing, gesture and animation-making may be particularly relevant to dynamic, invisible or difficult-to-observe processes. Research into participant-generated animation has shown how creating and discussing animated sequences can support engagement with scientific ideas (Hoban and Nielsen, 2014; Hoban, Nielsen and Shepherd, 2015). Moore's Loop (2016), discussed in Section 1.2.2, also demonstrates how drawing and animation can contribute to representing microscopic biological processes.

Adapting the method to another discipline would involve more than replacing astronomical imagery with different subject matter. Each field has its own forms of evidence, terminology, visual conventions and ethical responsibilities. A microbiology workshop might explore cellular movement or infection at a microscopic scale, while climate science might involve long-term change, complex causal relationships and scientific uncertainty. The prompts, source materials and explanations would therefore need to respond to the particular discipline.

The accuracy–engagement continuum discussed in Section 6.5.5.3 would also need to be adapted to each field. A metaphor that provides an accessible and imaginative response to planetary motion may have different implications when applied to illness, medical treatment or climate risk. The science facilitator would identify which aspects need to remain scientifically

accurate and where simplification could become misleading. The animator or time-based media facilitator would help participants translate these ideas through movement, sequence and transformation while maintaining space for interpretation.

Adapting the method would also require collaboration with specialists from the relevant field to ensure that its content and source materials are appropriate. Consultation or co-design with intended participants could help shape the language, topics and workshop format so that the activity is understandable, relevant and accessible. The core participatory sequence could remain, while the scientific content, materials, prompts and criteria for accuracy would be adapted.

These considerations support a cautious claim of transferability. The paired facilitation and participatory process could remain, but the scientific content, criteria for accuracy and name of the adapted method would reflect the new field. As this research tested the method only within astronomy, its application elsewhere remains for future practitioners and researchers to investigate.

Overall, applying Astro-animation requires practical decisions about scientific explanation, facilitation, timing, participant support and evaluation. The contribution of this research therefore includes the Toolkit and the practical understanding gained through designing, testing and adapting the method across the workshops. The cycles of practice and reflection through which this understanding emerged are consistent with Schön's (1983) account of reflective practice and Candy and Edmonds' (2018) discussion of practice-based research.

6.5.6. External Reception and Public Impact of Astro-animation Films

Beyond the workshop contexts, several Astro-animation films received recognition in film and science communication festivals. *The Eclipse*, created during the astronomer-led workshop at the HEAD meeting of the American Astronomical Society, was selected for the Annecy International Animation Film Festival (2025), received Best Science Fact Film at the San Francisco Science Fiction Short Film and TV Awards (2025) and received the Audience Award at the Iron Mule Festival (2024). *The Movements of the Universe* was selected for screening at the AmDocs Film Festival in Palm Springs (2026). Other works, including *Strange News from Pluto*

and *Sunspot*, were screened at the British Science Festival 2025 and at library and community events. Documentation of these screenings and awards is included in Volume 2.

Presented as part of the 2025 Sabbatical Exhibition at the Maryland Institute College of Art (MICA), the Astro-animation installation brought together films, workshop documentation, participant drawings and supporting materials from the project. Held from 22 August to 14 September 2025, the exhibition offered a gallery-based view of the research process, tracing how scientific ideas moved across gesture, drawing, animation and public engagement.

These screenings and exhibitions show that Astro-animation circulated beyond the research settings in which it was produced. The films and installation reached artistic, educational and science communication audiences, extending the impact of the practice into public contexts. Their reception suggests that gesture-informed and collaborative animation can operate both as a research outcome and as a public-facing form of astronomy communication. This external circulation should, however, be understood alongside the practical and institutional limitations that shaped the research process.

6.6. Limitations

Recruitment through institutions serving communities described as underrepresented remained a significant limitation. I initially assumed that public institutions would provide relatively direct access to intended participants. In practice, libraries, schools and cultural organisations mediated that access through their own definitions, programming priorities and outreach structures. Workshop recruitment and delivery were therefore shaped by institutional conditions as well as by the aims of the research.

As discussed in Section 6.5.5.1, consent, scheduling and evaluation requirements at Enoch Pratt Library and the Baltimore School for the Arts affected participation and the continuity of data collection. These experiences showed that access in community-based research is negotiated through organisational structures and competing priorities. Early discussion with partner organisations about research aims, consent, scheduling and evaluation would help future projects establish processes appropriate to each setting.

Science Capital informed the rationale for focusing on access, confidence, recognition, prior exposure and belonging, but it was not used as a formal measurement tool. This means that the study did not attempt to quantify participants' Science Capital before and after the workshops. Instead, the framework supported the design and interpretation of the workshops, particularly in relation to how participants encountered astronomy through creative, social and visual forms of engagement.

These constraints are documented in Chapter 5, particularly Sections 5.3, 5.5 and 5.7. They reflect broader challenges associated with interdisciplinary research in community-based learning settings, where consent procedures, institutional culture and scheduling pressures shape research conditions. Future projects would benefit from proportionate ethical protocols and flexible data-collection strategies. These may include clear explanations of data use, flexible consent mechanisms, concise surveys, exit reflections, verbal assent where appropriate and small-group debriefs.

Beyond the formal data phases, an additional workshop provided a final opportunity to test the Toolkit's usability in a public setting. Held on 18 October 2025 at the White Oak Branch of Montgomery County Public Libraries during the Montgomery STEAM Festival, the ninety-minute session included thirteen participants aged approximately 7 to 16, along with a librarian and a support assistant who also participated. The group was younger on average than the intended teenage focus. Following the basic Toolkit protocol, the session began with a brief astronomy lightning talk on Jupiter led by Dr Corbet. Participants then created animations using printed image sequences derived from Hubble Space Telescope imagery (NASA Jet Propulsion Laboratory, 2017). Although this workshop was not included as formal analytical data, it offered further practical insight into the Toolkit's adaptability and suggested that animation could motivate participation across a wider age range.

The White Oak workshop highlighted both the adaptability and limits of the Toolkit. Several participants initially expressed uncertainty about what to draw or whether they were proceeding correctly. As the session progressed, engagement increased: some participants became absorbed in the animation process, while others required clearer prompts and demonstrations. The drawings were later compiled into *Jumpin' Jupiter* (2025). This workshop

illustrated the Toolkit's potential adaptability in a multi-age public setting, while also indicating the need for differentiated scaffolding and clear facilitation.

These limitations clarify the institutional, ethical and contextual conditions within which Astro-animation operates. They also suggest that the Toolkit may be transferable across settings, although successful implementation depends on facilitation, preparation, consent procedures and the specific conditions of each host institution.

6.7. Contribution to Knowledge

This thesis contributes to knowledge by developing, analysing and applying Astro-animation as a practice-based approach to astronomy communication. These contributions can be understood across three domains: conceptual, methodological and practical. Together, they show how animation can operate as a collaborative mode of inquiry in science communication contexts.

They emerged through the iterative development of Astro-animation across the three research strands: from gesture-informed studio exploration, to expert refinement, to public implementation. Across this process, the research retained its core principles of gesture, metaphor, movement and collaborative making, while adapting facilitation strategies to different audiences and settings.

6.7.1. Conceptual Contribution

The central conceptual contribution is the articulation of Astro-animation as an embodied and participatory process within astronomy communication. The thesis establishes gesture as a connecting mechanism across the three strands. In Strand 1, scientists' gestures were analysed as empirical material. In Strand 2, insights from gesture analysis informed the structure of the Astro-animation Toolkit. In Strand 3, gesture-informed principles appeared through drawing and collaborative animation-making. This continuity shows how scientific ideas can move between speech, body, image and animated sequence.

The thesis also clarifies the role of metaphor within animation practice. Metaphor operates across kinaesthetic, ontological and conceptual levels, shaping visual transformation, temporal sequencing and collective reasoning. Through iterative animation-making, metaphoric structures are extended, tested and revised.

A further conceptual contribution is the positioning of metamorphosis as an organising principle within Astro-animation. Transformation occurs within the animated imagery and across the wider collaborative process, as ideas move between explanation, gesture, drawing, sequencing and shared interpretation. Astro-animation therefore integrates analytical, embodied, affective and imaginative modes of knowing within a structured creative process.

6.7.2. Methodological Contribution

Methodologically, the thesis demonstrates how animation practice can operate as inquiry within a mixed-methods, practice-based research design. The study developed a gesture-informed animation approach in which scientists' gestures and verbal metaphors served as starting points for visual interpretation. Gesture was treated as investigable material, while movement, timing, rhythm and transformation formed part of the analytical process.

The research also integrates animation practice with qualitative methods, including interviews, thematic analysis, reflective journaling, participant feedback and workshop observation. Across the three strands, animation-making functioned as a method of investigation, analysis and engagement. Knowledge developed through cycles of making, observation, adjustment and reflection. This methodological contribution shows how creative practice can generate analytical insight while remaining compatible with systematic qualitative research.

6.7.3. Practical Contribution

The practical contribution is the development of the Astro-animation Toolkit, an adaptable structure for facilitating participatory astronomy workshops through animation. The Toolkit translates the research findings into a workshop model built around scientific grounding, animation instruction, collaborative animation-making and reflection. It can be adapted

through topic, duration, participant group, materials, facilitation structure and evaluation or reflection methods. Refined through expert workshops, the Toolkit was implemented in settings involving teenagers, families, university students and mixed public audiences. These applications demonstrate how animation can support participation and conceptual sense-making through visual, tactile, narrative and social entry points.

The research also identifies conditions that support effective implementation, including facilitation expertise, scientific input, preparation time, differentiated scaffolding and structured reflection. Scalability is therefore defined as transferability across contexts. The framework maintains conceptual coherence while allowing adaptation to the needs, resources and constraints of each setting.

6.8. Future Research

Future research could extend Astro-animation in several directions. One area concerns the function of sound within Astro-animation practice. In the workshop films, sound was added primarily in post-production through selected soundtracks that supported rhythm, pacing and emotional tone. In The Movements of the Universe, by contrast, sound assumed a more substantial creative role. The film was developed in collaboration with a sound designer familiar with the project and with my wider animation practice, allowing sonic metaphors to reinforce movement, scale, transition and affect. These choices shaped the temporal and emotional experience of the film. However, sound was not systematically examined within the research design. Further research could investigate how rhythm, texture, silence, voice and music contribute to embodied understanding, emotional response and collaborative inquiry in animation-based astronomy communication.

A second area concerns the use of the Astro-animation Toolkit by other professionals. In this PhD, the Toolkit was developed, facilitated and evaluated by the animator-researcher in collaboration with scientists, educators and partner institutions. Future research could examine how the Toolkit functions when used by other animators, teachers, science communicators, librarians, museum educators, or outreach professionals. This would help assess its

transferability, identify what training or guidance facilitators need and clarify which elements of the Toolkit must remain fixed and which can be adapted.

Further research could also include longitudinal studies of participant engagement, comparative studies across cultural and institutional settings and collaborations with planetariums, science centres, libraries, schools and digital platforms. These developments could extend the participatory framework of Astro-animation while remaining attentive to the institutional and social conditions that shape public science engagement.

These findings show that applying Astro-animation requires balancing scientific grounding, creative openness, facilitation and the requirements of each setting. They also raise questions about how this balance would be interpreted by professionals outside the project. This would test whether its core principles and facilitator roles are communicated clearly enough to support responsible adaptation without my direct involvement.

6.9. Conclusion

Across the three macro-themes, this chapter has shown how Astro-animation develops through three connected movements: gesture and metaphor provide an embodied basis for interpretation; participatory animation-making gives participants agency in shaping scientific meaning; and scientific grounding supports creative interpretation while maintaining connection to astronomical concepts. This thesis has developed Astro-animation as a practice-based approach to astronomy communication, showing how gesture, metaphor, collaborative animation-making and participatory engagement can support embodied and creative forms of science communication. The research demonstrates that animation can function as a mode of inquiry as well as a communication form. Through gesture-informed filmmaking, expert refinement and community-based workshops, Astro-animation created conditions in which astronomical concepts could be externalised, tested, revised and reinterpreted through making. These processes were central to how participants made sense of dynamic and conceptually distant astronomical phenomena.

The thesis also reframes the relationship between scientific accuracy and public engagement. Astro-animation is scientifically grounded through source material, expert input,

facilitation and reflection, while allowing space for metaphor, imagination and interpretive participation. Its value lies in creating conditions in which astronomical ideas can be explored, shared, questioned and developed through collective making. Ultimately, this thesis argues that Astro-animation offers a flexible framework for astronomy communication. It integrates gesture and metaphor as forms of knowledge-making, positions animation as an investigative tool and opens astronomy communication to the lived experiences, cultural perspectives and creative possibilities of diverse participants. Its contribution lies in shifting astronomy communication from presentation towards participation, inviting scientists, artists, students and public audiences to work through astronomical ideas together.

In returning to the eclipse described in the Introduction, the thesis closes where it began: with the question of how astronomical phenomena are perceived, interpreted and made meaningful. Astro-animation emerged from this problem as a way of extending that moment, enabling cosmic processes to be explored through gesture, metaphor, drawing and animation-making. Across the three strands, participants moved beyond viewing the universe as a distant spectacle and engaged with it as a process that could be interpreted, inhabited and reimagined through collective practice.

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