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EDITORIAL

On making things visible. Including ourselves

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Abstract: This editorial introduces a special issue on animation in science communication, situating the contributions within broader debates on mediation, representation, and knowledge production. It highlights three interconnected themes: the instrumental use of animation to translate complex scientific phenomena; the ethical tensions between accuracy, engagement, and transparency; and the collaborative, interdisciplinary practices that underpin contemporary visualisation. The issue also reflects on the epistemological limits of visual representation and the implications of current publishing models. Together, the contributions position animation not only as a communicative tool, but as an epistemic practice operating between science and society.

Keywords: animation; science communication; visualization; interdisciplinarity; epistemology

1. Twelve numbers and the thirteenth, at last

As the readers who follow us perhaps know, *Mutual Images* journal was established in 2016 by the Mutual Images Research Association (MIRA), a scholarly, non-profit, and independent organisation committed to the study of the ever-changing cultural relations between Europe and Asia; and, more broadly, between specific national and regional contexts across these two vast cultural areas. The journal's field of interest has always been wide and deliberately porous: it encompasses visual media, popular culture, animation, comics, cinema, television, media studies, cultural history, and the analysis of mutual stereotypes and representations. What has remained constant across twelve numbers is the conviction that the meeting of cultures — often asymmetrical, always complex — produces images that deserve sustained scholarly attention.

Looking back at those twelve issues is an exercise that combines satisfaction and humility in equal measure. Satisfaction, because the journal has grown in scope, visibility, and authorial diversity: scholars from Australia, China, France, Germany, Italy, Japan, Singapore, Spain, the United Kingdom, the United States, and many other countries have published here, and the range of disciplines and methodologies represented in our pages has expanded in ways we could not have anticipated at the outset. Humility, because we are acutely aware of the limitations that come with being a small, independent, non-funded journal run by a handful of dedicated people in their own time, without institutional support and without the resources that larger publications take for granted.

Those limitations bring us to something we owe our readers, contributors, and the wider scholarly community: a frank acknowledgement of the delays that have affected this number, and an apology for them. The submission deadline for no. 13 was generously set for mid-November 2025. The papers arrived, were reviewed through our standard double-blind peer-review process, were revised by their authors, and were cleared for publication. What then intervened was a combination of factors internal to our editorial process: a period of structural reorganisation affecting the journal's workflow, a redesign of our metadata standards, and, most significantly, an ongoing effort to re-index all previously published articles across a range of academic catalogues and bibliographic databases with a view to broadening the journal's visibility and accessibility from late 2026 onwards. This re-indexing work, which is a condition for our inclusion in several important scholarly directories and citation indices, has been as time-consuming as anticipated, and it has occupied much of the editorial team's capacity during the months when this number should have been finalised and published.

We are aware that delays in academic publishing are never merely administrative matters: they may affect the career progression of the scholars who have entrusted their work to us, the timeliness of research contributions, and the credibility of a journal that asks its authors to invest their time and expertise. We take these concerns seriously, and we commit to a more regular publication rhythm going forward. To all contributors who waited longer than they should have: we are genuinely grateful for your patience, and we hope that the quality of this issue goes some way toward justifying it.

2. Animation, science, and the "challenge of the invisible"

The articles gathered in this issue derive, for the most part, from papers presented at the international conference "Figuring the Invisible: The Role of Animation in the Communication of Scientific Knowledge" held on 15-16 December 2023 at the Lucerne University of Applied Sciences and Arts (HSLU). The conference was organised by Marco Bellano and Jlanit Schumacher, under the auspices of the Marie Skłodowska-Curie Global Research Project *Ficta SciO* (European Commission Horizon framework), whose central aim is to identify and raise awareness about the audiovisual conventions and communication tactics of animation in multimedia science outreach. The scientific committee included Marco Bellano himself with Tina Ohnmacht and Jürgen Haas.

A comprehensive introduction to this special number — situating the articles within the intellectual framework of the *Ficta SciO* project and the broader field of science communication and animation studies — has been prepared by the guest editor, Marco Bellano, and appears separately in these pages. What follows here is not a substitute for that introduction, but a complementary and more personal reading.

2.1. Animation as instrument and expression

One of the most striking features of this collection is the consistently instrumental orientation of its contributions. Animation here is not, in the main, treated as an autonomous expressive medium — the object of aesthetic or historical inquiry in its own right — but as a tool: a means to communicate science, to change behaviour, to dismantle stigma, to render perceptible what would otherwise remain hidden from view. This is not a criticism. The instrumental uses of animation constitute a rich and socially consequential domain of practice, and they are, as the *FICTA SciO* project recognises, underrepresented in animation scholarship relative to their cultural significance. But it is worth naming this orientation explicitly, because it shapes what the contributions ask of animation and what they find in it.

Across the papers, animation is mobilised "to make the invisible visible" in at least three registers. In health communication, it serves to translate medical data — the nutritional content of a meal, the immune response to a virus — into emotionally legible experiences that can motivate real-world behavioural change. In science outreach, it gives sensory form to phenomena that lie beyond direct human perception: the behaviour of black holes, subatomic particles, the biochemical architecture of a coral polyp. And in what we might call critical or reflexive communication, it raises questions about the nature of images themselves: about what it means to "see" something, and about the conditions under which we can claim that this or that visual representation is "truthful".

This last register is perhaps the most philosophically ambitious, and it is developed most forcefully in the contribution that sits, deliberately, at the close of the issue: a wide-ranging argument about computation, machine learning, and the epistemic crisis of the generated image. Where most of the other papers treat animation as a solution to the problem of invisibility — a way of making the unseen accessible — this final piece reframes the production of images itself as a problem, asking what happens to the evidentiary and communicative function of the visual when any image can be fabricated and distributed at speed. The tension between these two orientations — animation as illumination, animation (and image generation altogether) as potential deception — is not resolved in this issue, nor should it be. It is one of the defining tensions of our present moment, and it would be intellectually dishonest to paper over it.

2.2. Ethics of representation. Accuracy, engagement, honesty

A second thread running through virtually all the contributions is the ethical dimension of science visualisation: the question of how to balance accuracy with accessibility, scientific rigour with emotional engagement, fidelity to data with the demands of storytelling and aesthetic pleasure. This is not a new problem — it is, in some sense, as old as scientific illustration itself — but it appears in these pages with a freshness and urgency that reflects the expanded possibilities of contemporary media.

Several authors wrestle explicitly with the risks of oversimplification and misrepresentation. The dangers of using visual language in ways that exceed what the underlying data actually supports — a standard atom diagram that encodes a fundamentally misleading picture of atomic structure, a solar system representation that sacrifices scale to aesthetics — are discussed with a practical rigour that will be useful to anyone working in science communication. Alongside these risks, the same contributions identify a powerful countermeasure: transparency. A proposed framework distinguishing between original data, accurate simulation, designed communication, and artistic interpretation offers a vocabulary for being explicit about the epistemic status of visual content: a vocabulary which, in an age of generative artificial intelligence and pervasive image fabrication, is more necessary than ever, as hinted at a few paragraphs earlier, in § 2.1.

At the same time, other contributions in this issue demonstrate that the pursuit of emotional engagement and narrative satisfaction is not inherently in tension with scientific integrity. A stylised, deliberately non-photorealistic VR environment can communicate nutritional information more effectively than a clinical data display; an animated short film can honour both the scientific intentions of its NASA collaborators and the expressive ambitions of its student animators; a mixed-technique documentary can anthropomorphise a researcher as the microscopic organism she studies without betraying the complexity of her work. The ethics of visual science communication, these papers suggest, is less a matter of choosing between accuracy and engagement than of finding forms — and maintaining a reflexive honesty about the choices made — that serve both.

2.3. Making the inscrutable visually comprehensible

There is a further dimension of this problem that the contributions in this issue touch on, and that deserves naming directly. Much of what animation and computer graphics have done for science communication has involved making the invisible not merely visible, but clean — legible, bounded, coloured, and scaled for a human eye that was never designed to perceive what it is being shown. The atoms in a chemistry textbook have neat orbits and clear borders; the planets of the solar system appear, in almost every illustration ever produced, at scales and distances that bear no relation to reality; the nebulae photographed by space telescopes glow with colours that are, in large part, the product of false-colour imaging and processing choices made by human operators.

This is understandable, and often necessary. A nucleus drawn to its true scale relative to its electron cloud would be invisible on any page. A solar system drawn to correct proportions would require most of its planets to be represented as specks too small to see. The aesthetic decisions embedded in scientific visualisation are not incidental: they are the condition of possibility for any visual communication of science at all. But they carry epistemological costs that are rarely made explicit, and that accumulate over time into a collective visual imagination of nature that may be, in fundamental ways, misleading.

The question becomes sharper when we move from the microscopic to the astronomical. The black hole at the narrative centre of the film *Interstellar* (by Christopher Nolan, 2014) — visualised by a team that included the physicist Kip Thorne, working from general-relativistic equations to produce what were, at the time, some of the most scientifically grounded dynamic images of a rotating black hole ever rendered — is a case worth pausing on. The images are extraordinary, and the physics behind them is serious. But are they comprehensible to a non-specialist audience in the way that matters most: not as spectacle, but as understanding? The spacecraft orbiting the event horizon is depicted at a scale legible to human perception; the black hole itself appears as a sphere, which is the correct topological intuition for a hole in three-dimensional space, but also an analogy that may smuggle in wrong assumptions about what a singularity actually is. The question is not whether the images are accurate — they are, within their assumptions — but whether the frame of accuracy is itself communicable to those who do not already understand the physics behind all that.

This tension — between the image that is scientifically defensible and the image that is epistemically transparent to its audience — runs beneath the surface of several contributions in this issue. It also points toward a question that the field of science visualisation has not fully resolved: whether the goal of animated and illustrated science communication is to give audiences a correct impression of what things are, or a useful one, and whether these two goals can, in practice, always be pursued together. The cleaned-up, high-contrast, spectrally enhanced images that dominate science outreach — the crystalline atomic models, the vividly coloured cellular structures, the sharp-edged astronomical objects — are pedagogically powerful precisely because they are not what those things look like. The universe, at most scales accessible to scientific instruments, is noisy, ambiguous, and resistant to the kind of visual resolution that makes for a compelling educational image for us small, in so many ways at once mighty and limited, human beings. One might ask whether there is not also a place, in science communication, for images that preserve some of that noise that may let audiences encounter the genuine difficulty of *seeing*, rather than the reassuring clarity of having been shown.

2.4. Collaboration, interdisciplinarity, and the co-production of knowledge

A third shared characteristic of the contributions in this issue is their emphasis on collaboration: not as an incidental feature of the projects described, but as a methodological and even an epistemological value. Virtually every paper discusses, in varying degrees of detail, the processes by which scientists, animators, educators, medical professionals, students, children, and community members have worked together to produce forms of visual communication that none of them could have achieved alone.

What is notable is how consistently the contributors describe this collaboration as transformative: not merely additive, not a matter of scientists providing content while animators provide form, but a process in which the encounter between different ways of knowing produces something new. Scientists discover that their hand gestures, captured on film and translated into animation, convey dimensions of their understanding that their equations and graphs do not reach. Animators find that the discipline of scientific accuracy, far from cuffing their creativity, provides narrative and aesthetic constraints that can be generative. Children, given confocal microscopes and drawing paper, produce characters and worlds that illuminate the scientific phenomena they have just observed in ways that neither the scientists nor the animators had anticipated.

These are not isolated anecdotes, but structurally recurring features of the interdisciplinary practice described across the issue, and they point toward a model of science communication — and, more broadly, of knowledge production — in which the boundaries between expert and audience, between researcher and public, are productively blurred.

2.5. A note on geographic and cultural distribution

A candid editorial note is warranted here. The contributions to this number are geographically and culturally concentrated in ways that are worth acknowledging. The authorial voices represented in this issue come predominantly from Europe and North America — from Australia, Austria, Italy, and the United States. The most notable exception is the contribution from Singapore, itself a multilingual and multicultural city-state whose relationship to the categories of "Western" and "Eastern" is complex and not reducible to simple binaries; and even there, the research team is predominantly of Western institutional formation. The views from outside the Global North — and specifically those from East, South, and Southeast Asia — are largely absent from this collection.

This is a limitation that the guest editor and the editorial team are probably aware of, and it is one that reflects broader structural asymmetries in the fields from which these papers emerge. Animation studies, as a discipline, has made significant strides in recent years toward diversifying its geographic and cultural perspectives. For example, the two volumes edited by Tze-yue G. Hu and Masao Yokota, *Japanese Animation: East Asian Perspectives* and *Animating the Spirited* (both published by the University Press of Mississippi, in 2013 and 2020 respectively), among others, have done important work in foregrounding Asian perspectives on animation history, industry, and aesthetics that had been marginalised by the field's predominantly North Atlantic orientation. The study of science communication and science visualisation has been somewhat slower to undertake this kind of critical self-examination, though the urgency of doing so is recognised.

For *Mutual Images* journal, this asymmetry is more than a bibliographic observation. The journal's founding mission — to facilitate genuine intellectual exchange between European and Asian perspectives on cultural phenomena, visual media, and creative industries — makes the relative absence of Asian scholarly voices from a special issue published under its auspices a matter of some concern. The *FICTA SciO* project, which provided the conference from which this issue originated, is a European-funded initiative, and the conference itself took place in an Italian university: these institutional conditions go some way toward explaining the demographic of the contributions, but they do not make the imbalance less significant. We note it here not as self-criticism for its own sake, but as an invitation — to future contributors, to future guest editors, and to the research communities whose work we hope to host — to help us make this journal's pages more faithfully reflect the cross-cultural dialogue it was created to promote.

3. Independent, free, ethical

There is a conversation happening in the world of academic publishing that deserves to be named directly. Over the past decade, an increasing number of scholarly journals have adopted the "article processing charge" (APC) model: a system in which authors — or, more typically, their institutions or funders — pay substantial fees, often running to several hundreds or even thousand euros or dollars per article, to have their work published in open access. The fees vary, but they are rarely modest: major publishers charge anywhere from one thousand five hundred to over eleven thousand euros per article, and even some ostensibly mission-driven open-access publishers have adopted tariffs that effectively price out scholars from less affluent institutions or from countries without robust research funding systems.

The logic of this model is presented, almost universally, in the language of openness and democratisation: by shifting the cost from the reader to the author, it removes paywalls and makes scholarship freely available to anyone with an internet connection. This is a genuine good, and we do not dispute it. What we do dispute is the extent to which this model has, in practice, transferred significant financial power to commercial publishers, created new forms of inequity between well-funded and under-resourced researchers, and introduced perverse incentives: since a journal that charges per article has, structurally, a financial interest in accepting as many articles as possible, which is not an arrangement that naturally favours rigour and selectivity.

Mutual Images Journal charges nothing. Not to readers, and not to authors. We operate on the principle that scholarly knowledge should circulate freely, without financial gatekeeping of any kind; and we operate on it not because we have found a comfortable way to make it costless, but because we believe the principle matters enough to absorb the costs ourselves. The journal's editorial, technical, and administrative work is carried out by members of the Mutual Images Research Association on a voluntary basis, in time taken from teaching, research, and personal life. Our platform costs are borne by the Association directly. Our peer reviewers, like peer reviewers everywhere, give their expertise without remuneration. We mention none of this to solicit sympathy, but to be transparent about what independent, non-profit academic publishing actually involves.

We are not under the illusion that this model is scalable to all contexts, or that it is without cost — as the delays discussed in the first section of this editorial attest, there are things a journal without a budget simply cannot do as quickly or as smoothly as one with institutional support. But we believe there is something important in maintaining the existence of scholarly spaces that are not governed by market logic, that do not treat the production and dissemination of knowledge as a transaction, and that insist, perhaps stubbornly, that it is possible to publish rigorous, peer-reviewed, open-access scholarship without charging anyone for the privilege.

In a publishing landscape that has become, in many areas and contexts, so blatantly mercenary — and in which the pressure to publish in high-fee journals is felt especially acutely by early-career researchers and by scholars from the Global South, who are doubly disadvantaged by a system that rewards wealth as much as quality — we think this insistence has a modest but genuine ethical value.

We thank all the contributors to *Mutual Images Journal* no. 13, the reviewers who gave their time and expertise generously and anonymously, the guest editor, talented fellow scholar, and good friend Marco Bellano for the intellectual energy and scholarly care he brought to this number, and the readers — wherever they are reading, and in whatever circumstances — who continue to find something of value in these pages.

 The present Introduction, and the editorial work for this guest-edited issue, were carried out in the context of the Marie Skłodowska-Curie Global Action "Figuring the Invisible: Conventions and Tactics in Animation for Science Outreach" (FICTA SciO), funded by the European Union. Views and opinions expressed are however those of the author only and do not necessarily reflect those of the European Union or the European Education and Culture Executive Agency (EACEA). Neither the European Union nor EACEA can be held responsible for them.

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ORIGINAL ARTICLE

Animation as a visual bridge between science and society

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Abstract: Scientific knowledge has always depended on images, especially when it addresses phenomena that escape direct sensory perception. This introduction sketches the privileged yet problematic role of animation in figuring the "invisible" within contemporary science communication, pointing out some connected epistemological and ethical questions. In fact, the increasing visual coherence, realism, and interactivity of animated models can obscure the constructed nature of scientific models, encouraging audiences to read them as direct depictions rather than as mediated arguments. The present special issue of Mutual Images Journal is related to the Marie Skłodowska-Curie project FICTA SciO – Figuring the Invisible (2023–2025), which investigated conventions and tactics of animation for science outreach while advocating transparency as a core communicative value. The introduction outlines the conceptual stakes of the project and presents the seven contributions as complementary inquiries into how animation shapes scientific understanding, visibility, and public trust within contemporary visual culture.

Keywords: scientific animation; invisibility; science communication; visual epistemology; useful animation; modelling and simulation; immersive media; animated documentary

1. Science, animation, and the "invisible": a necessary dilemma

From early anatomical drawings to contemporary data-driven simulations, visualisation has always been a constitutive element of scientific epistemic practices. This longstanding entente between images and science acquired a thought-provoking pre-eminence when scientific inquiry addresses entities and processes that cannot be accessed through direct sensory perception, as in the case of objects that are too small, too distant, too fast, too slow, or too abstract to be seen, heard, or otherwise experienced without technological mediation. In such cases, visualisation does not merely illustrate knowledge; it actively participates in creating a scientific paradigm.

In this context, animation has a key role. Unlike photography or live-action recording, animation does not need to foreground optical indexicality. As such, it is a privileged expressive tool to visualise anything that is inferred from data evidence, by bringing it to a sensorial and temporal scale fit to human fruition. Such scale adaptation in time and space is a first step towards interactive possibilities, for outreach purposes, but also to test, refine, and imaginatively explore theoretical models. Animation invites the creation of an «image-as-process», and not just of an image which documents a process of scientific relevance, inviting the end user to manipulate it. In the contemporary age, animated digital images for science «are meant to be *used*, cut, correlated, rotated, colored» (Daston & Galison 2007: 383).

Well before that, from the 1910s onward, film animation became consistently involved in the media history of science (Curtis, 2021). More recent scholarship has proposed the umbrella term "useful animation" to describe a wider field of research, thereby moving beyond an exclusive focus on cinema and documentary (Curtis 2015: 23–27; Curtis & Lue, 2018; Cook, Cowan, & Curtis, 2023). Such a perspective acknowledges the pervasiveness of animation in the contemporary media landscape (Buchan, 2013), encompassing thus also museum installations, videogames, graphical user interfaces, data visualisation, virtual reality, and scientific modelling environments.

This expanded range of animation makes it even more urgent to inquire a decisive side of its scientific use: its persuasive power. When scientific animations present models with a high degree of visual coherence, realism, and aesthetic polish, they can facilitate engagement and comprehension while also obscuring the constructed and interpretive character of the images themselves. Viewers are rarely informed about what elements of an image are grounded in empirical data, and what instead derives from inference, or what has been introduced for narrative, metaphorical, or didactic reasons.

This problem has already been addressed from multiple perspectives within animation studies and documentary theory. A key point is that animation does not intend to replace photographic evidence, but it reorganises the conditions under which evidence is read. Animation can stage memory, hypothesis, and embodied experience while still demanding to be taken as "about the world" (Honess Roe, 2013: 7-11). In animated science outreach, this becomes not an option but a foundation, because the representations of entities "invisible" to our common sense (from subatomic particles to black holes, and even to extinct life forms) need to be understood as a reflection of real scientific research. Banner and Ostherr (2015) have noted that digital animation can create persuasive new worlds out of research, but may also claim a problematic neutrality, smoothing over the contexts and conventions behind scientific representation.

The transparency problem reflects a deeper semiotic and phenomenological mismatch between scientific objects and human-scale perception. The animated model does not merely illustrate an entity; as argued before, it acts as a perceptual substitute that satisfies the demand for visibility while concealing the scientific and artistic mediations through which the entity becomes knowable. Mitchell's notion of "image science" is relevant here, since it posits that scientific knowledge circulates through heterogeneous image forms (may them be diagrams, equations, models, metaphors, simulations) rather than through pictures alone (Mitchell, 2015: 21-29). Animation for public outreach inherits the potential and unavoidable shortcomings of all this heterogeneous image ecology and merges them into a unified audiovisual surface, masking the multifaceted epistemological dilemmas of scientific imagery behind the phenomenological authority of a view.

José van Dijck's critique of the "realist paradigm" touches this point by noting that in much contemporary science documentary, animated reconstructions often borrow the visual rhetoric of factual television or commercial spectacle in order to render immediate presence and immersion (van Dijck, 2006; see also Campbell, 2016: 37–41). The issue is intensified by the use of photorealistic digital imagery and by immersive or interactive interfaces, which encourage audiences to feel that they are not simply watching a model but participating in a scientific reality firsthand.

Such staging of scientific animated models, inviting to approach the audiovisual experience as unquestionably true and immediate, contrasts with the philosophical frame of the scientific method. Scientific hypotheses must remain open to falsification (Popper, 2005), and scientific paradigms remain historically contingent, vulnerable to crisis and revision (Kuhn, 2012). Yet, outreach imagery is often slow to register epistemic instability; it tends instead to repeat familiar iconographies because they are communicatively efficient, culturally sedimented, and visually gratifying. Merleau-Ponty's reflections on the visible and the invisible might also be pertinent here: when science gains access to domains not naturally given to human perception, knowledge requires not only more powerful instruments but also more inventiveness about how to mediate what cannot simply be seen (Merleau-Ponty, 1968: 16). Animation answers that need, but its answer should not be mistaken for transparent access.

A telling example is provided by the visual culture of black holes, one of the most recognisable cases in which animated iconography has shaped public expectations in advance of public evidence. The gravitational well, the luminous vortex, and more recently the asymmetrical accretion ring all circulate as if they were straightforward depictions. Yet, as discussions surrounding the Event Horizon Telescope image of M87* demonstrated, even the most authoritative images of black holes are not transparent photographs but complex products of data acquisition, processing, inference, and trained judgement (Daston & Galison, 2007; Davelaar et al., 2018). This does not make them false; it makes them interpretable. Their communicative value depends on how clearly that interpretive status is conveyed.

The present special issue of Mutual Images Journal emerges from the dilemma binding together scientific objectivity and animated representation, and the need to address it through a sustained interdisciplinary dialogue. Rather than proposing a unified model or a prescriptive framework, the issue maps a field of practices and problems, highlighting recurring strategies, tensions, and politics.

2. FICTA SciO: a research framework

This issue was conceived in the context of the Global Marie Skłodowska-Curie Action FICTA SciO – Figuring the Invisible: Conventions and Tactics of Animation for Science Outreach (2023–2025), of which it represents one of the project's intellectual and dissemination outcomes. FICTA SciO was designed to address the structural problem in contemporary science communication described above: animated visualisations of invisible scientific entities circulate widely, yet they are rarely accompanied by guidance that would enable audiences to read them critically and appreciate the interpretive labour embedded in the image.

FICTA SciO addressed this issue by cataloguing animated models of invisible phenomena, analysing their visual conventions and communicative tactics, and promoting transparency as a core value of science outreach, asking how scientific images can remain persuasive without disguising their own conditions of production.

The project's theoretical background draws on animation studies, documentary theory, visual epistemology, media archaeology, and philosophy of perception. It engages with the historical shift from "truth-to-nature" and mechanical objectivity toward "trained judgment" identified by Daston and Galison (2007), with the broader understanding of animation as a pervasive time-based form of synthetic expression (Buchan, 2013; Russett, 2004), and with the phenomenological tenet that scientific visibility always entails approximation and mediation.

3. The Figuring the Invisible conference

The core of this special issue derives from the international FICTA SciO conference "Figuring the Invisible: The Role of Animation in the Communication of Scientific Knowledge," held at the Lucerne University of Applied Sciences and Arts (HSLU) in December 2023. It was chaired by prof. Tina Ohnmacht, prof. Jürgen Haas, and the guest editor and author of this introduction.

Conceived as a meeting point for scholars, artists, animators, scientists, and educators working at the intersection of visual culture and scientific knowledge, the conference balanced theoretical reflection, practice-based research, and case studies. Its programme ranged from astrophysics to medicine, from data visualisation to school education, and from immersive environments to the politics of synthetic imagery. This plurality tried to acknowledge the shifting and transdisciplinary status of the problem, which does not strictly pertain to inaccessible scales or the abstract nature of data, but also to bodily processes, social stigma, or technologically opaque image production.

Several contributions included in this issue originated as conference papers and were subsequently expanded, revised, and peer-reviewed for publication. What unites them is a shared concern with animation's role as a mediator between scientific abstraction and human experience, and with the responsibilities that accompany this mediating function.

4. Scope and structure of the issue

This issue extends the traditional disciplinary focus of Mutual Images Journal, which has historically concentrated on visual cultures in East Asia and transnational image flows. In doing so, it situates scientific images as cultural objects. The shift is less a departure than an expansion: it acknowledges that scientific visuality, too, belongs to the domain of image culture and must be studied as such.

The seven essays collected here approach the problem of the invisible from complementary angles. Together, they show that animation is not a single solution to scientific communication, but a flexible repertoire of audiovisual techniques and rhetorics whose applications and implications draw a complex artistic and ethical landscape.

5. Overview of the contributions

The issue opens with Emma Harper, Hannes Rall, Sabrina Wong, and Gray Hodgkinson's discussion of visualizing medical knowledge through animation. Their case study (*A Choice for Life*, a gamified VR experience focused on diabetes management) makes visible a physiological and statistical problem (diet, metabolism, risk) through embodied interaction. The authors frame VR's relevance through the notions of immersion and presence, drawing on established accounts of how virtual environments can heighten experiential engagement. Their work is situated in relation to prior diabetes-focused VR initiatives. A major focus is the detailed articulation of design tensions, facing questions such as how to simplify without trivialising; how to sustain a serious topic without alienating users; how to structure nutritional data so that it becomes actionable rather than overwhelming; and how participatory feedback reshapes representational decisions across iterations. The paper exemplifies a shift from showing scientific content as *information* to staging it as *experience*. This resonates with broader discussions on how immersive media reframes the relationship between viewer and image. It also foregrounds a core ethical issue: when an experience is designed to persuade users toward healthier choices, transparency about simplification and modelling is not optional. The case of this VR experience demonstrates how representation, affect, and agency can be engineered together.

A medical topic is also at the core of Vincenzo Maselli's essay, which addresses a different dimension of invisibility: the social one produced by stigma. Focusing on animated campaigns related to HIV and AIDS, Maselli analyses how specific graphic languages and narrative strategies are employed to make a stigmatized condition visible without reinforcing fear or prejudice. The paper follows Roberto Bernocchi's typology of social communication styles (sentimental, reassuring, dramatic, accusatory, transgressive, humorous, paternalistic, informative) originally developed to describe awareness campaigns. By applying this grid to a corpus of animated HIV/AIDS-related artefacts identified through organisational archives and bibliographic reconstructions, Maselli discusses the recurrence or rarity of certain visual styles, advancing that transgressive or overtly denouncing tones are uncommon, in favour of perceived friendliness and accessibility, to reduce defensive reactions and to foster empowerment rather than confrontation, even when the topic is structurally political. In this instance, representational "accuracy" is essentially complemented by representational care.

Laurence Arcadias, Robin Corbet, and Emma Booth's article on Astro-Animation turns to cosmological invisibility. By presenting multiple perspectives (those of a scientist, an animator, and a student) the authors show how animation mediates between astronomical data and public imagination. Three intertwined projects are discussed: an astro-animation class in collaboration with NASA astronomers; a STEAM-oriented exhibition concept designed to reach teenagers, including underrepresented communities; and an animation strategy that foregrounds scientists' hand gestures as a bridge between abstract concepts and embodied expression. By treating gesture as both cognitive extension and communicative device, the authors align with research on how hand movements support scientific reasoning and explanation, while also reactivating a long-standing topic in animation studies, pertaining to the hand as a theme and iconography, as well as the origin of indexical traces of making. The "invisible" universe is figured not only through cosmic imagery but through the visible labour of explanation itself. Their account of workshops and surveys frames "science anxiety" as a barrier to learning, and motivates the use of playful, hands-on animation activities to reduce intimidation and build curiosity. This resonates with a broader body of work on informal science learning and the role of creative practice in fostering engagement.

The theme of animation practice and epistemic mediation is further explored in Martina Fröschl's reflection on immersive scientific visualisation. Drawing on the work of the Science Visualization Lab in Vienna, Fröschl examines how animation and visual effects translate scientific data into experiential environments. The "hidden worlds" describe an institutional practice oriented toward rendering microscopic and otherwise inaccessible phenomena tangible through high-resolution imaging data and visual metaphors. Fröschl embeds the Lab's work within longer genealogies of scientific visual culture, from early modern microscopy and its emblematic atlases to contemporary documentary and exhibition formats. The point is not to claim continuity as identity, but to show that visualisation has always combined epistemic aspiration with aesthetic choice. Fröschl also engages the question of objectivity versus subjectivity, emphasising that imaging processes inevitably involve interpretive decisions (thresholds, colour, emphasis), and that integrity depends on how these decisions are managed and communicated. So, immersive and interactive strategies (projection mapping, AR, installation) become ways to reconfigure audiences from observers into participants.

Lorenzi and Vallese offer a further insight into the artistic and conceptual choices behind the creation of scientific animation. Instead of focusing on a single scientific domain, they examine how visual languages circulate across contexts (art historical iconographies, exhibition design, scientific outreach, and immersive media) and how these languages shape what kinds of scientific "invisibility" can be made perceptible. By placing stylised animation (*Pulsars*) alongside a realistic science-fiction VR application (*Nucleosynthesis VR Experience*), the discourse develops a discussion of different rhetorical resources. Stylisation plays a key role by clarifying structure, foregrounding process, and inviting metaphorical reasoning, while realism counterbalances this by providing a feeling of plausibility and embodied scale. The authors' attention to Venetian bas-reliefs and archaeoastronomical iconographies meaningfully underscores that the visualisation of the cosmos has always been mediated by cultural form.

Another practice-based approach is examined in Rachel Landers's article on animated hybrid documentary for children, a collaborative project between scientists and creative practitioners aimed at visualizing microscopic life forms for audiences aged 10–12 . The project connects representational strategy to public engagement goals. The "tiny, invisible things" at stake, that is to say micro-organisms, are scientifically consequential yet culturally marginal because they remain unseen and unnamed in everyday experience. Landers proposes that hybrid documentary, by combining scientific imaging with animated transformation and authorial voice, can produce narratives that connect microscopic phenomena to identity, curiosity, and social imagination, making microscopic science perceptible and making scientific participation imaginable for audiences historically positioned as outsiders. Transparency and interpretive guidance remain central, but so does the question of *for whom* an image is designed and what social futures it implies.

Lawson's essay functions as a critical coda to the issue, questioning the very concept of image and its computable incarnations, that make the threshold between evidentiary recording and synthetic production no longer perceptually stable. The argument proceeds from a technical grounding in digitisation toward the epistemic crisis posed by the capacity of machine learning to generate plausible audiovisual artefacts. Lawson treats this as a political and philosophical problem of truth and potential totalitarian control, not because the technology is inherently malign, but because the contemporary speed needs of mass communication systems undermine the slower infrastructures of verification. From the standpoint of this issue, Lawson's contribution reframes "invisibility" yet again. The scientific referents of a certain image might be inaccessible, but the *operations* producing images render the final media opaque, concealing labour and provenance. In this context, the call for transparency already advanced by some of the previous essays becomes again urgent, but also more difficult. However, Lawson does not declare that images will merely disappear. The inherent warning, instead, is that images may lose their evidentiary privilege, unless new visual literacies and practices are established. It is an implicit call for a new audiovisual education, aligned with the technology and epistemology of the contemporary digital image.

6. Perspectives and future directions

Several questions or reflections might arise from this minimal, tentative map of the negotiation between scientific accuracy, aesthetic form, and ethical responsibility.

First, more fine-grained vocabularies for distinguishing the nature and purpose of animated scientific images might be beneficial. Familiar binaries such as objective/subjective, scientific/artistic, or documentary/fiction are too blunt for the rhetorics of contemporary media. Animated science communication might need to integrate a lexicon or a jargon that sensibly addresses animated images, circumventing any lingering moral implication pertaining to the true/false dichotomy.

Then, any evaluation of animated scientific imagery is context-sensitive. The same representational strategy can be responsible in one setting and misleading in another. A stylised metaphor may be the most effective solution for school education while being inadequate in a documentary framed as authoritative evidence; a photorealistic simulation may support intuitive comprehension while also concealing uncertainty if presented without annotation or contextualisation. The decisive question is therefore not whether an image is accurate in the abstract, but accurate for what use, for which audience, and with what communicated limits.

Further study is needed on the production pipelines of scientific animation and on their epistemological and political effects. Images do not emerge fully formed from scientific data. To study them means examining not only the final artefact but also the infrastructures and decisions that authorize certain visual solutions while excluding others.

Audience literacy also emerges as a central variable. Science outreach animation can certainly foster interpretive competence, but such competence cannot be assumed in advance. It is crucial to understand how different viewers recognize, or fail to recognize, the status of a model, and how annotation, framing, or stylistic choice may support more reflective forms of reception. In this respect, the pedagogical function of science animation extends beyond explanation toward the cultivation of critical visual habits.

Finally, and expanding the previous point, an important need evidenced by the authors of this issue is to acknowledge and decode the social distribution of visibility. Invisibility is also a political condition: it encompasses stigma, marginalisation, and who is invited to receive and understand science outreach. The ethics of "figuring the invisible" therefore includes not only truthful depiction of phenomena, but also the responsibility to avoid reproducing the exclusions that keep certain bodies, experiences, and communities unseen.

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ORIGINAL ARTICLE

Visualising medical information for edutainment through animation: a case study of the Diabetes VR experience "A Choice for Life"

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Abstract: Over 10 per cent of the world's population lives with Type 2 diabetes, making it a significant public health concern. In Singapore, the government launched the "War on Diabetes" in 2016, initiating efforts focused on prevention, early detection, and better disease management. A challenge that remains is promoting informed dietary choices within hawker centres - open-air food complexes central to Singaporean food culture - where diverse offerings can complicate healthy decision-making for diabetes prevention and control. This paper presents a case study of *A Choice for Life*, a practice-as-research project developing a virtual reality (VR) experience aimed at educating users on making healthier food choices in hawker centres. Drawing on evidence that VR experiences can influence real-world behaviour, the project integrates insights from medical professionals, animators, and game designers. The discussion focuses on the iterative development of the user interface and innovative feedback mechanisms, including emoji responses that reflect the nutritional value of users' food selections in the virtual setting. Presenting initial findings from prototype testing, it reflects upon the value that immersive experiences hold for the future of diabetes education and plans for the further development of the project.

Keywords: diabetes; edutainment; serious games; Virtual Reality; health games

1. Introduction

Type 2 diabetes is a major international public health concern, a chronic condition which requires patients "to make a multitude of daily self-management decisions and to perform complex care activities" (Powers et al., 2016: 70). Globally, the International Diabetes Federation estimated that there were 536.6 million people with Type 2 diabetes in 2021, representing over 10 per cent of the world's population, with the number rising year on year (Hong et al., 2022: 1). Singapore, where this paper's authors are based, is representative of this wider global trend, with its own specific challenges. Recent decades have seen the country's population undergo significant changes in lifestyle, diet and other environmental influences that are typical of a high-income society, yet which are associated with a rapid ageing and increasingly sedentary population (Phan et al., 2014: 1). In the 1980s, the rate of Type 2 diabetes amongst the Singaporean population was 5 per cent - this number had more than doubled to 11 per cent by 2010 (Thai et al., 1990: 517; Ministry of Health Singapore, 2011). Hand in hand with the rising prevalence of the disease comes rising costs for public health. In 2010, Type 2 diabetes cost Singapore more than S$1 billion and this figure is estimated to soar to beyond S$2.5 billion annually by 2050 (Saw Swee Hock School of Public Health, 2016). These costs consist of diabetes-related medical treatment as well as productivity losses related to morbidity and early mortality as a result of the disease.

In April 2016, Singapore's Health Minister Gan Kim Yong declared the "War on Diabetes" (WoD) – a series of initiatives and programmes rooted in three key pillars of healthy living and prevention, early detection and intervention, and better disease management (Ministry of Health Singapore, 2019: 1). The "war" aimed to rally the nation as a whole and involved the participation of government agencies, healthcare providers, community-based organisations, industry partners, academics and individual Singaporeans to educate those at risk of, or living with, Type 2 diabetes. Initiatives included public outreach programmes, promotion of healthier food choices and incentive schemes for improved diabetes management (Ministry of Health Singapore, 2023).

However much remains to be done. In a 2021 review of the "war", Singapore's Ministry of Health acknowledged that they were "unable to support at present" the implementation of a system of rating hawker centres based on their provision of healthy food options (Ministry of Health Singapore, 2023). Hawker centres are open-air food complexes that house many stalls selling a wide variety of affordably priced food options (Tung, 2021). Conveniently located across the city state, hawker centres are a unique aspect of Singaporean culture and lifestyle, functioning both as a staple of dietary behaviour and an important place for social interaction and community bonding. Hawker centres are emblematic of Singapore and its culinary culture – in December 2020, Singapore Hawker Culture was inscribed on UNESCO's Representative List of Intangible Cultural Heritage (Tung, 2021). In 2018, 83 per cent of Singaporeans ate at hawker centres at least once a week (National Environment Agency, 2019). However, many of the dishes on offer are rich, fried, and less nutritious, which can prevent a challenge to those living with diabetes and aiming to control their nutritional intake.

Against this backdrop, in 2021 an interdisciplinary project team from Nanyang Technological University and the National Healthcare Group, Singapore was assembled with the aim of considering new ways of informing patients about the impact of diet on diabetes management through the development of an interactive animated VR serious game, designed to be used in conjunction with traditional forms of physician-led care which are rooted in the specific medical histories of individual patients. Of note is this project's intention to work towards a virtual representation of consuming hawker food as a characteristically Singaporean model of dietary behaviour which presents a specific challenge to those attempting to make healthy, informed food choices, which is absent from existing VR games created elsewhere in the world for diabetes education. The project aims to leverage upon immersive animation's potential to create a sensory perception of reality in which participants are physically and mentally fully immersed within a computer-generated 3D world (Rall et al. 2024: 111). However, it also needed to represent the "invisible" in the form of nutritional information and the health consequences of poor food choices on diabetes management in both the short and longer terms.

The need to represent these somewhat intangible elements was closely linked to the challenge that presented itself with the project more broadly – how to best leverage on the knowledge and experience of the cross-disciplinary team to use creative design to support and enhance medical messaging with the aim of enacting real world behavioural change. The experience needed to be engaging, visually appealing and technically sophisticated, yet underpinned by verifiable medical facts and knowledge that could be transferred to players' real-world experiences and daily lives, specifically related to choosing food in a hawker centre environment.

This paper will outline the development process of this experience – titled *A Choice for Life* – with a particular focus on how the production of the initial prototype integrated creative design with medical knowledge. Particular attention will be paid to one specific aspect of the project, the emoji responses which the player receives as part of the evaluation at the end of the experience. These emojis function to provide the player with feedback and guidance on their food choices within the game which can be transferred into life outside the virtual world. They also represent a moment in the project development that required particularly close collaboration and conversation between doctors, dieticians, technical developers, illustrators, and animators. It is hoped that this discussion will provide an insight into the process of practice-led-research at the heart of the project and offer broader recommendations for mediating medical science through animated immersive media.

2. VR for Diabetes Education

A January 2024 paper by Neil Vaughan provides a comprehensive overview of VR and AR (augmented reality) applications in diabetes. Vaughan (2024: 810) outlines that "for diabetes training, VR is particularly suitable, because the physiological characteristics are especially responsive to patients' lifestyle, physical and cognitive change," categorising applications as focused around either education, prevention, or treatment.

He further states (2024: 817) that:

> *'For VR patient education of diabetes, VR simulators provide the immersive platform on which to deliver real-world scenarios and information for training patients in self-management behaviors which can be experienced anywhere, anytime in a safe training environment without risk to the patient.'*
>
> *(Vaughan, 2024, p. 817)*

In creating an environment that simulates and represents the "real world", VR allows patients to experiment and make health decisions without facing real-life health consequences on their real-world physical bodies yet also allows them to test out decisions and behaviours which they can then easily translate into their lives beyond the VR environment. The benefits of a virtual environment for diabetes education are also highlighted by Johnson et al. (2014) in their discussion of the creation of a Second Life virtual diabetes community – which, despite taking place on a 2D computer screen, further reinforces the idea that such environments can offer platforms through which healthcare providers can "promote skill building via interactive simulations and scenarios."

Recognising the value of VR for diabetes education, several existing projects have been developed which have made use of the medium, leveraging specifically upon the fact that Type 2 diabetes can be prevented, controlled or even reversed through changing dietary and exercise habits. Examples of VR education for adults with diabetes include Neira Tovar and Elizondo Elizondo's work in Mexico to develop a serious game to promote physical activity through a combination of VR and movement sensor technology (2018); a project at the University of Exeter, UK in which a prototype VR diabetes training platform for people with diabetes offers patients the chance to learn about exercise, carbohydrate counting, blood glucose testing and monitoring, (Vaughan, 2024: 812), and The Boston Medical Center/University of Massachusetts Medical School's pilot project *Women in Control*, which delivered an education programme to African American patients with diabetes or pre-diabetes through interactive sessions within a virtual world (Rosal et al., 2012: 1).

The discussion of games within the context of VR diabetes education is largely limited to projects targeted at children. This is despite a widespread acknowledgement that

> *'Digital games for teaching about T1D [Type 1 diabetes] and T2D [Type 2 diabetes] can help children, adolescents, and adults with diabetes to better cope with their lifelong condition. This demonstrates the potential of diabetes VR integrating gamification…to motivate and educate patients to positively change behavior and lifestyle.'*
>
> *(Vaughan, 2024, p. 813)*

'Gamification' here refers to "the use of game design elements in non-game contexts" (Deterding et al., 2011: 9), a process which has been demonstrated to facilitate "significant, positive effects" on "cognitive, motivational, and behavioral learning outcomes" (Sailer and Homner, 2020: 77), "since it is motivating and fun and consequently, more efficient for the learning process and the management of the disease" (Martos-Cabrera et al. 2020: 2). Existing studies have demonstrated that:

> *'Gamification offers the advantages of enhancing patient care without face-to-face contact and with flexible timing, thereby reducing transportation time and cost for patients with T2DM [Type 2 diabetes melilites]. Virtual gaming also provides a novel way for the DCES [diabetes care and education specialists] to engage with patients to provide education and assess the attainment of knowledge.'*
>
> *(Brady et al., 2023, p. 510)*

It was with this in mind that this project aimed to not only create an entertaining educational experience in VR for adults but to incorporate ideas drawn from game design and development throughout the project development process.

3. Project Development

Vaughan (2024: 810) states that "when future VR systems are being developed for diabetes, they should include a wide range of stakeholder inputs, including from people living with diabetes, pharmacists, practitioners, and diabetes educators." Our project not only integrated the opinions of medical professionals throughout and brought in the feedback of Singaporeans with diabetes at the prototype testing stage but also closely involved animators and game designers within the development process. This collaboration aimed to bring together expertise in topics ranging from data visualization and information graphics to visual and interactive storytelling to enhance the educational experience and harness the visual and technical possibilities offered by VR.

While a VR simulation can be extremely immersive and as a result demonstrate benefits for engagement and education, *A Choice for Life* was conceived of throughout as a serious game rather than simply a simulation experience. The application of game principles such as interface, interaction, feedback, navigation, engagement and reward creates an enhanced experience for the player as they move within the experience (Hodgkinson, 2023). When combined with a stimulating animated visual environment, the VR experience becomes invigorating, loaded with significant learning outcomes within the context of healthcare. This project represented a somewhat unorthodox approach to game design – the design team were available immediately from the start of the project, meaning that characters and environment could be developed before the central game mechanics – the procedures and rules which structure the game experience and the player's expected behaviour – were established (ibid). This placed the interaction between designers and medical experts at the centre of the project from the outset.

The narrative at the heart of *A Choice for Life* follows the player as they find themselves within a virtual hawker centre. They are free to explore the environment, which includes a minimart, food stalls and vending machines. Upon moving towards the stalls, they can interact with the hawker and select the food they would like to order. They can choose not only which food elements to consume, but also portion sizes, in the same way they might do so in a real-world hawker centre. The food is then plated, and the player is guided to a table, where they sit and consume their selection. After the food has been consumed, players are presented with an evaluation of their choices. This evaluation highlights positive elements as well as making suggestions on adjustments that they could make to improve their diet and as a result improve their diabetes control.

3.1. Integrating Medical Knowledge: Behavioural Change

The foundation of the *A Choice for Life* project is the idea that experiences in a virtual world can encourage real-world behavioural change (Wong, 2023). This idea is founded upon theories drawn from medical psychology and is of particular relevance to diabetes care. Diabetes self-management education (DSME) relies upon

> *'...the transfer of knowledge and addressing and supporting behavioral change to improve clinical and health-related outcomes. The outcome of DSME is "behavior change," which is evaluated based on...healthy coping, healthy eating, being active, taking medication, monitoring, reducing risk, and problem solving.'*
>
> *(Brady et al., 2023, p. 493)*

Michie et al. (2011: 4) propose that behavioural change interventions be conceptualised according to a framework based upon a behaviour system involving three essential conditions: capability, opportunity, and motivation (what they term the "COM-B system"):

> *'In this 'behaviour system,' capability, opportunity, and motivation interact to generate behaviour that in turn influences these components... Capability is defined as the individual's psychological and physical capacity to engage in the activity concerned. It includes having the necessary knowledge and skills. Motivation is defined as all those brain processes that energize and direct behaviour, not just goals and conscious decision-making. It includes habitual processes, emotional responding, as well as analytical decision-making. Opportunity is defined as all the factors that lie outside the individual that make the behaviour possible or prompt it... Opportunity can influence motivation as can capability; enacting a behaviour can alter capability, motivation, and opportunity.'*
>
> *(Michie et al., 2011, p. 4)*

Studies within a range of fields with an interest in human behaviour have established the link between experiences in VR and real-world behavioural change. In a 2021 review of existing literature concerning the use of VR in consumer research, Taufik et al. (2021: 1) state that:

'VR can potentially be validly used in consumer research aimed at behaviour change in a consumer setting, as findings in real-life were mostly replicated in VR (or vice versa)… Studies which used VR as a behaviour change tool were generally effective in changing consumer behaviour in desired directions, more so than when less immersive (2d), equivalent treatments were used'.

(Taufik et al., 2021, p.1)

The work of Morina et al. (2015) has demonstrated that this conclusion is also applicable when the intention is using VR in psychological treatment. Their case study, based around the use of virtual reality exposure therapy (VRET) to treat patients diagnosed with anxiety, demonstrated that virtual reality interventions can indeed lead to behavioural change in daily life, and that virtual reality interventions for specific phobias are as effective as traditional behaviour therapy methods. What these examples demonstrate is a cross-disciplinary acknowledgement of the potential that VR holds for influencing behaviour in the real world.

Figure 1 outlines how specific elements of our VR experience were selected to create particular responses on the part of the user, which function to facilitate behavioural change. It also explains how this relates to Michie's COM-B behaviour system discussed above.

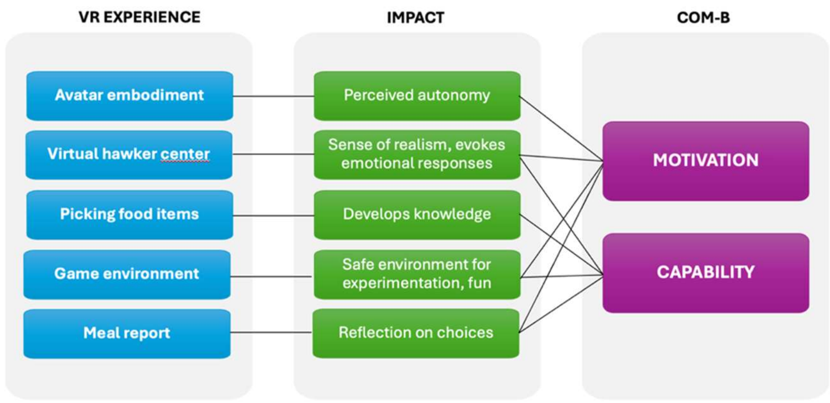

Figure 1. Diagram showing relationship between aspects of our VR experience and models of elements of behavioural change drawn from the COM-B model.

Having established the precedent on which our VR experience is constructed, we now move on to a discussion of a case study which demonstrates how creative design and scientific medical knowledge were integrated when designing the prototype version of our VR experience.

3.2. Subverting Expectations: A Stylised Approach to Design in VR

Many discussions of the ability of VR to enact behavioural change attribute its success to its ability to closely "simulate" players' everyday lives and experiences. However, arguably empathy and authenticity can be created by adopting a stylised, non-photorealistic (NPR) approach to visual design rather than a photorealistic depiction. Whilst some existing virtual diabetes education projects, such as the Second Life virtual community created by Johnson et al. (2014) have leveraged upon virtual environments' ability to closely replicate the real world, others, including the app games discussed by Alsalman et al. (2020) which require a player to interact with a cartoon bear, dragon or other character instead leverage animation's potential for abstraction. Earlier research by this paper's second author has demonstrated how empathy and authenticity might be created in VR through the adoption of a stylised animated approach. Stylized animation "reveals its artificiality instantly… The spectator is alerted to a constructed reality with fictional elements that might very well be based on correct facts, yet does not force a suspension of disbelief" (Weber and Rall, 2019), with the artistic subjectivity that this approach creates adding new layers of truth, and in fact serving the concept of authenticating facts. Indeed, previous research has demonstrated that stylised characters can evoke or even heighten empathy or emotional engagement on the part of the user when compared to photorealistic approaches to design. Work by Park et al. focusing specifically on character design found that users did not empathise or sympathise more with more realistic designs, and that "the lack of significant difference in sympathy and empathy ratings between character types suggests that the cost/benefit ratio for iconic characters may be best for situations in which the animator is seeking to elicit emotional responses from the viewer" (Park et al., 2019: 486). Van Rooij (2019) has further demonstrated how a shared style of character design, combining aspects of lifelikeness with deliberate abstraction, contributes to audiences' emotional response to, and the resulting success of, American animation films by leading studios including Pixar, Disney and DreamWorks.

What is important to take from this is that stylized animation can indeed create empathy in viewers. In the context of this experience, empathy between user and in-game character is considered desirable for the way that it allows for us to "transform visual in-formation about someone else's emotional state into similar emotional dispositions of our own" (Morrison and Ziemke, 2005: 73), thus heightening the real-world impact and translatability of the lessons learnt within the context of the virtual environment. The effectiveness of empathy induction is arguably influenced more by the narrative and expressive behaviours of characters rather than their visual style. Simple and iconic designs can be as effective as realistic ones, and congruence in appearance and facial expressions enhances emotional engagement. While challenges exist in conveying genuine emotions through animated characters, the strategic use of design principles and expressive behaviours can overcome these hurdles, making stylized characters powerful tools for evoking empathy. Although computer generated animated characters do not possess experiences or emotions which can be drawn upon to create a performance in the same way that human actors do, "when an outstanding animated performance is married to classic cinematic principles the emotive power of animation… can be genuine and powerful" (McIntosh, 2018: 557).

A Choice for Life aims to explore whether a gamified experience can lead to real-life behavioural changes, and as such cannot abandon all sense of reality, however this does not necessitate a reliance on photorealism. The project thus adopted an approach which incorporating medical facts into a stylised approach to design to allow the lessons learnt in the virtual world to be enacted in the player's life beyond the game.

Makhlysheva et al. (2016: 422) state that a successful VR health game needs an "attractive design… to more deeply immerse a player into the game." Considering how to create this attractiveness was thus a fundamental concern of the design approach, particularly when attempting to visualise abstract or serious elements such as nutritional categories and health consequences. When approaching environment design, the aim was to create something that was recognizable to the Singaporean audience of our game design in the form of a hawker centre, yet also functioned as a visually innovative, whimsical environment that prompts the player to explore and interact. Stalls offer cuisines and menu choices that are immediately recognizable to a Singaporean audience, yet presented in an exaggerated, stylized way to increase the playfulness and abstractness of the environment and the interactions that occur within it. It was also important to incorporate the requirements and demands of user experience in VR, for example by reducing spaces between stalls, and enclosing the hawker centre space to limit the zone which the player can explore to enable them to remain focused on their overall objective of making dietary choices.

In our designs for items within the hawker centre environment we aimed to create a sense of both relational and personal authenticity by evoking recognisable items despite stylized visual forms, based on the assumption that Singaporean game players will respond to the items in a particular way and relate them to their real-world experiences. This draws upon the concept of "existential" authenticity – experiences within the game environment are deemed authentic as they are connected to personal emotions, bodily feelings and emotions whilst engaging in specific activities, an emotional and creative experience defined by the individuum rather than something that relies solely on objective facts and realities (Rall et al., 2024: 113). The experience incorporates playful re-interpretations of well-known brands and food items, thus creating a response reliant on the players' instinctive, feelings-based reaction to the virtual items. Van Rooij (2019: 196) states that major animation studios generate empathy by adopting a visual style that sees characters depicted as "clearly human, displaying all the basic physical indicators; however, their features are often caricatured. In general, they have disproportionally large heads for their bodies and large eyes for their faces, and they often seem to miss certain details such as small lines, hairs and blemishes." *A Choice for Life* thus aimed to create empathy and authenticity in its visual style through the adoption of an approach that clearly resembled the real-world elements that the game is meant to represent (the hawker centre environment, the human characters, and the food items) through the inclusion of basic physical indicators, yet were suitably caricatured and stylised to hit what Van Rooij (2019: 203) terms the "sweet spot on a scale of lifelikeness and abstraction, while generating the highest levels of empathy from the audience" (figure 2).

Figure 2. Illustration demonstrating visual style of characters and environment in *A Choice for Life.*

4. Case Study: Emoji Design

Makhlysheva et al. (2016: 421) state that "interactive, visualized game feedback on a player's action in the game contributes to the player's experiential learning," and considering how to represent this feedback was the most important way in which our project engaged with the idea of representing abstract concepts in visual form. The game required medical information in the form of nutritional data and the consequences of poor food choices to be presented to players to fulfil its educational intentions, yet in line with its overall framing as an enjoyable virtual experience hoped to avoid overwhelming players with large amounts of data or make them feel as if they were being lectured about or punished for poor dietary choices. Taking this into consideration, the decision was made to create of a series of emojis which informed the player of the nutritional value and health impact of the food choices made within the virtual environment during the final stages of the experience.

The issue of emoji design thus emerged as the most important collaborative element in our project, requiring constant dialogue and revisions to approaches to illustration and animation design based on suggestions of medical professionals. Work by Rodrigues et al. (2018: 401) based on the Lisbon Emoji and Emoticon Database (LEED) has established that emoji are perceived as "aesthetically appealing, familiar, clear, and meaningful", high in "familiarity, clarity, arousal, and meaningfulness," with their appeal and relatability linked to their close proximity to human facial expressions. Emojis should be clear and easy to understand, and whimsical and playful in design in keeping with the approach to stylization, realism and empathy discussed above. Effective emoji design requires balancing these factors to create symbols that are inclusive, meaningful, and functional, aiming to avoid any misrepresentation or subjectivity in terms of emotion being conveyed.

The initial approach to emoji design saw each emoji linked to an emotional state – health, hunger, happiness, energy and desire. This was rooted in the idea that an emotional response is fundamental to the enactment of behavioural change.

Emotion	GOOD	NEUTRAL	BAD	VERY BAD
HEALTH (How healthy is it?)				
HUNGER (Is it satiating?)				
HAPPINESS (Does it make you happy?)				
ENERGY (Does it give you energy?)				
DESIRE (Is it desirable?)				

Figure 3. Categorisation of emoji designs reflecting emotional responses to food consumed in-game.

The emoji designs created were chunky and bold, as current consumer VR headsets offer limited resolution, with bright colours and simple shapes used to distinguish each of the five designs (figure 3). It was important that the emojis were readable as thumbnails within the wider user interface (UI), immediately suggesting the intended meaning. The overall design of the UI was bright, clear and simple to understand, however, the adult audience of the project also needed to be considered, and the typography and interface designed in a way that avoided appearing overly childlike or patronising (figure 4).

Figure 4. In-game screengrab demonstrating initial design for UI within virtual hawker centre environment.

Playful, whimsical animation loops helped to further clarify the positive and negative associations of each emoji, with their style creating a sense of amusement rather than emphasising the serious negative health consequences of poor dietary choices. The emojis were designed to be present in their "neutral" state at the start of the game and reacted to the points assigned after each dish was consumed (figure 5). The overall state of each emoji is presented on a final evaluation screen alongside qualitative comments on a participant's dietary choices.

Figure 5. Preliminary layout design demonstrating proposal for displaying emoji responses to food consumed within the virtual environment.

Once the designs had been produced, they were presented to the medical professionals on the team. Whilst the overall response to the visual approach was positive, they questioned the appropriateness of the system of emoji categorisation. In particular, they stressed the subjectivity of ideas such as fullness, happiness and based on individual preferences and biology.

They furthermore highlighted the importance of improving knowledge of nutritional content in diabetes education, something that was overlooked in this initial approach to narrative and feedback. As such, the decision was made to replace the subjective emoji categories with nutritional groups – protein, carbohydrate, sugar, fat and salt. The design for the emojis was slightly revised so that they could be transferred from representations of emotional states to representations of specific nutritional categories – e.g. the emoji representing hunger was reconceptualised as protein, and the design adjusted to more closely resemble a bean.

Dieticians and doctors provided feedback on the nutritional information of each individual food element present in the game, which then allowed for a total amount of carbohydrate, protein, fat, salt and sugar to be calculated for a combination of food elements that together comprise a dish. Calculations using the recommended daily intakes of each of these food groups were used to create thresholds at which a meal might be considered "good", "neutral" or "bad", which in turn corresponded to the reactions of the emojis in response to a player selecting a particular combination of food elements. Thresholds were coded for both male and female patients, offering a limited level of customisation of the feedback within the game experience based on the gender of the patient participant. For the final evaluation screen, the responses of each emoji are totalled up to calculate a star rating out of 5 which is presented to the player at the end of the experience – 5 stars reflecting a full set of "good" nutritional categories and representing a nutritionally complete, healthy meal, and 1 star reflecting an unbalanced unhealthy selection that has been graded "bad" in most categories. This was presented as part of a broader two stage "report card" which provides a detailed nutritional breakdown of the food consumed, and an overall statement evaluating the players' choices and making suggestions for simple adjustments that could be made to improve their selections from the perspective of diet and diabetes management (figure 6)

Figure 6. Design for UI screen providing player with feedback on nutritional content of food consumed.

Interaction between medical professionals and creative practitioners was thus placed at the heart of the design process. This included a continuous feedback loop to find the right balance between immersive entertainment and communication of medical authenticity, in which both design decisions (e.g. font sizes and emoji styles) and the data that underlay the visualisations were passed by medical experts to gauge their feedback on comprehensibility and patient sensitivity. And guarantee the correctness of the nutritional information.

By doing so, we built upon existing methodical frameworks for our own specific purposes. In his triadic framework-approach Harteveld (2010) emphasizes the need for balance between fun, learning outcomes, and medical authenticity when creating a serious game, whilst Vanden Abeele et al. (2012: 82) highlight that collaborative effort is required among game designers, programmers, artists, and domain experts throughout the process of game development. *A Choice for Life* has expanded upon these frameworks by focusing on storytelling and aesthetics to enhance player engagement while maintaining scientifically accurate information at all times, forming a Medical Game Design Iteration Loop (MGDIL) for serious game development.

5. Prototype Testing and Feedback

The VR prototype underwent a first round of pilot study testing in November 2023 and January 2024. 12 patients with Type 2 diabetes experienced the VR prototype and provided feedback through pre- and post-participation questionnaires and a semi-structured interview conducted immediately after experiencing the prototype. Participants were between the ages of 34 to 52 and represented both males (66.7 per cent) and females (33.3 per cent) and a range of ethnicities (Chinese, Malay, Indian) representative of the Singaporean population more broadly. For this prototype, the hawker centre environment was fully modelled (figure 7), however only one stall was “open” for players to interact with. In addition, the UI discussed above was not fully implemented, with the emojis appearing only on the final evaluation screen.

Figure 7. Screengrabs of prototype VR experience showing hawker centre environment and Yong Tau Foo stall.

The stall available in the prototype offered Yong Tau Foo – a Chinese dish based around stuffed tofu – which was selected due to the multiple options that customers can select from and thus allows for the construction of meals that are extremely varied in their nutritional content. Users were required to move towards the stall and interact with the hawker stallholder via an in-game interface to select a maximum of 10 items which were combined into their bowl.

They then were instructed by the UI to walk over to a nearby table, where they sat down and "consumed" the prepared dish. After indicating that they had finished eating via a pop up, they received feedback on their dietary choices using the emoji system outlined above, as well as a numerical breakdown of the nutritional information which their selection contained. After completing the experience for the first time, players were offered the chance to repeat the experience and implement the feedback received to improve their score.

Overall, responses to the experience were positive with regards to both the VR experience and its potential for educational messaging that enacted dietary change. Several participants expressed dissatisfaction with traditional methods of dietary education offered by nutritionists and dieticians and suggested that VR offered the possibility of user-directed learning and facilitated more vivid memorisation of educational content. In the words of one participant "using this VR, I'm the one experiencing it, I'm the one who take the stuff and everything. So basically, I'll remember it because I'm the one who play the game, I'm the one who go through the experience." With the exception of one participant who stated that a "more realistic [visual approach] would be more enjoyable," participants overall responded positively to the design approach and visual style of the experience, stating that they "enjoyed the look" and overall aesthetic approach of the VR experience. One participant praised the way that the simplified, stylised design approach helped to remove any sense of disorientation and overwhelm associated with VR, making the required movement and interaction "easy for you to do".

The importance of the emojis was highlighted through several comments which reported difficulties in reading the text in the final evaluation screen. Words were described as "not sharp" and "blurred" and the UI pop up was criticised for appearing too close to the user's face which made legibility challenging. Whilst on the one hand this suggests an area that must be improved in future versions of the game it also highlighted the important role played by the emojis in offering a clear, visual form of feedback that is immediately understandable in contrast to the text-heavy nutritional data.

This initial testing also suggested that the experience in its current form provided useful insights that improved patients' dietary knowledge. Multiple participants expressed surprise at learning about the high sodium content of the items they selected and stated that this information would prompt them to make different decisions when choosing food in a real-world hawker situation. In contrast, pre- and post-participation surveys indicated that there was little evidence that participation in the experience had an impact on the dietary fat and fibre consumption of participants. This was likely attributable to the fact that the evaluation screen did not include a category for fibre, focusing instead on fat, protein, carbohydrate, sugar and salt, and again highlights that the information included in this evaluation section, and its visualisation, is an important component in the creation of an experience which aimed to achieve behavioural change.

The prototype testing also raised several valuable suggestions relating to potential improvements to the experience which we plan to use to drive the project forward. Participants were divided over whether adding more interactive game elements would enhance the experience or create an unnecessary distraction from the task of selecting food which lies at the heart of the experience. We will also revisit the possibility of having players experience the virtual environment through the persona of an avatar, an idea which was raised earlier in the project yet ultimately not included in the initial prototype due to development constraints. In line with ideas discussed above regarding the relationship between VR and behavioural change, several participants raised the possibility that playing as an avatar would increase their willingness to experiment and make decisions within the virtual environment. However, others felt that this extra layer of mediation was unnecessary, and that playing as themselves within a first-person VR experience was more effective in creating a sense of empathy and identification that would translate to real-world behavioural change. Indeed, it is possible that the level of personalisation required for an avatar to reflect the specific medical histories and physiological complexities of a patient with diabetes is beyond the scope of any game.

6. Conclusions

A Choice for Life provides a case study that demonstrates how complex and detailed nutritional data can be integrated into a visually appealing and user-friendly animated interface, as well as prompting reflections upon the value of interdisciplinary collaboration within the iterative design process. By outlining the collaborative development process behind the creation of the VR experience's UI and emoji design this paper has provided an insight into how "invisible" medical information might be visualised and depicted within the context of an immersive experience for diabetes education.

Moving forward, the next stage of this project hopes to further develop the initial prototype in line with suggestions drawn from the participant testing stage. Funding applications are in progress to extend and expand the scope of the project to introduce new stalls to the virtual hawker centre, refine the UI and in-game elements, and populate the virtual environment with additional interactives to create a fuller game experience. Once a more developed version of the experience has been created, we hope to carry out further patient testing to increase the sample size and thus the representativeness of our findings. We also hope the track the dietary habits and diabetes management of participants over a longer period, and allow for further quantitative analysis alongside the qualitative feedback provided by the semi-structured interviews carried out to date.

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Maselli, V. (2025). Breaking Stigma and Dispelling Invisibility: Animated Languages for Communicating HIV Disease. *Mutual Images*, 13, 37-52. https://doi.org/10.32926/2025.Maselli

ORIGINAL ARTICLE

Breaking Stigma and Dispelling Invisibility: Animated Languages for Communicating HIV Disease

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Abstract: Numerous chronic diseases do not involve particular aesthetic indications and, for this reason, are considered "invisible". These diseases represent a large percentage of current ailments and people affected by them tend not to reveal their pathology, because it is stigmatizing. In recent years there has been a significant increase in social campaigns that have made great use of audio-visual artefacts, produced with the aim of educating, informing, raising awareness and giving to patients the possibility of emerging from invisibility. The article aims to focus on communication strategies using animated artefacts to dispel the invisibility of HIV, a virus considered deadly until the early 90s and which still today causes stigma, shame and desire for invisibility for those affected. Non-profit organizations and independent directors have worked on animation projects aimed at conducting information and awareness-raising actions, at suggesting avoiding risky behaviours, and at helping those affected escape from social isolation in which stigma and prejudice have confined them. These projects will be, therefore, selected, sorted and analysed according to the adopted different graphic languages and narrative approaches. The analysis considers the eight categories of communication styles formulated in 2008 by Roberto Bernocchi in the study of the communication artefacts produced as a tool for social awareness, and seeks to identify the linguistic and stylistic most adopted approaches in animated products that deal with the stigma of HIV and AIDS.

Keywords: Animation; Communication strategies; Invisible diseases; HIV; Stigma; Social awareness.

1. Introduction: invisible diseases

According to the World Health Organization, invisible diseases represent the major cause of death globally, and one of the main health and psychological challenges of the 21st century (World Health Organization, 2018: 10). These conditions have a double dimension of invisibility, as they do not show obvious symptoms or physical manifestations – they are invisible to the gaze of others – and, for those affected, they can lead to feelings of isolation and a desire to remain unseen. Epilepsy, cancer, HIV, diabetes, endometriosis, to name a few, are generally not visible but extremely painful for those affected, who often carry a heavy burden of shame and social stigma.

The psychiatrist Donald Nathanson in 1990s proposed a model named "The Compass of Shame" in which he synthetized the possible different responses for defending against shame and stigma, which will depend on the situation and the individual's personal style (1992: 30). In Nathanson's theory social isolation and avoidance are among the most common strategies engaged to handled shame especially when the shame is caused by health conditions (Ibid.). This idea has been expanded by the English psychologist Christiane Sanderson who argued that shame over a medical condition is an emotion strongly influenced by social discrimination that mistakenly associates the state of illness with behaviours judged far from decorous or with a specific sexual gender (Sanderson, 2015: 107). In Sanderson opinion shame develops more often if a socially "execrable" disease such as AIDS or sexually transmitted diseases is involved.

Stemming from this premises this article focuses on the use of animation and motion design to dispel the invisibility of a specific disease, AIDS, and the virus that causes it, HIV, – considered deadly until the early 90s – that does not involve particular aesthetic indications and, for this reason, can be considered "invisible", and which still today causes stigma, shame and desire for invisibility for those affected (Kennedy and Vader, 2017).

A selection of animated artifacts produced within communication campaigns developed by public or private institutions from different countries will be selected, classified and analysed from both a technical, aesthetic and linguistic perspectives, considering the communication styles, the different graphic languages and narrative approaches that take advantage of animation power to pursue a social agenda.

2. Animation social agenda: a quick overview

Since the 1970s, communication artifacts with a focus on social responsibility have emerged as a significant contribution for driving positive transformations in social, economic, political, and environmental domains (Papanek, 1971; Heller and Vienne, 2003). Historically, these issues have been primarily addressed through traditional media, such as print journals, posters, and television advertisements – collectively referred to as "progress advertising" (Gabardi, 2011). However, the emergence of the internet and social media has introduced a wide array of communication technologies, channels and languages. New media and platforms have revealed to be particularly appealing to a broad audience, conveying a variety of messages highly effectively (Bernocchi et al., 2018). Some of these messages have been delivered making great use of animated artefacts, produced with the aim of educating, informing, raising awareness and engaging the viewer through different graphic languages, narrative approaches and media platforms, including television, cinema, social media, and the web (Lonardi and Fraccaroli, 2021). Animation, due to its pervasiveness and cross media adaptability (Buchan, 2013) can be efficiently tailored to deal with different messages and subjects, and to tell visually compelling stories that provoke strong emotional responses. Animated artefacts offer a clear, concise explanation of issues, alleviating viewers' concerns while offering a forward-looking perspective and fostering a deep emotional connection (Normoyle, 2019; Uhrig, 2019). In this scenario, the use of animation in social advertising has become a pivotal tool even for ministerial communication, non-profit organizations and NGOs (Panadisi and Maselli, 2024). The visual language of animation allows these organizations to immediately capture the audience's attention, evoke strong emotions, and encourage further engagement with the addressed topic (Waters and Jones, 2011).

A significant number of animated videos have been produced in recent years to address social and environmental issues. Among the most well-known animated campaigns, it's possible to mention *The clock is ticking,* a motion graphic video made by the organization GirlEffect.org in 2009. In the video moving typographic element and animated signs explain that, at the age of twelve, girls in developing countries risk getting caught in a cycle of poverty, due to the lack of economic opportunities, diseases, pregnancy and other factors. The 3D animation *One human family, food for all* (2015), created by the Eallin animation studio for Caritas International, is based on an ancient story about hunger and sharing. A circle of people tries to feed themselves from a cauldron using a very long spoon which allow to take the food but not to bring it to the mouth; after a phase of tension in which the diners compete for the dish, the fall of a spoon leads to a gesture of solidarity in which everyone contributes to feed one person at a time. Another good example is the campaign developed by Childline with the stop motion short film *Nobody is normal* (2020). The film tells the story of a boy-monster who tries to hide himself behind a mask and some "normal" clothes he wears for school, before realizing that all his apparently "normal" colleagues also turn out to be monster-guys and, however much he may feel alone and misunderstood, he is not really alone, because deep down no one is normal.

On the environmental awareness front, a powerful example of an animated video made for the NGO Greenpeace is *Turtle Journey* (2020), produced by Aardman Animations. It is a poignant stop-motion short film that sheds light on the urgent environmental crises threatening the world's oceans. The film follows a family of turtles navigating their way through a hazardous and increasingly devastated marine environment. As they swim through the ocean, the background reveals distressing signs of human-caused destruction: plastic pollution, oil drilling, and overfishing, all exacerbated by climate change. The film's climax occurs when the family finally comprehends the gravity of the damage, but by then, it's tragically too late. Aforementioned animated works utilize various narrative and visual strategies to communicate the values and concerns of non-profit organizations in a visually compelling and effective manner (Alam, 2022). The next sections will focus on communication strategies that have utilized animation power to address HIV and AIDS' social and health related issues.

3. AIDS: Stigma and (dis)information

Just over 30 years ago the world discovered the existence of a terrible new disease: AIDS. The media talked about it, sometimes even with nonsensical statements, such as the "gay syndrome" or the "gay cancer" (*Le Figaro, 1982*, in Lestienne, 2021). The reaction of the institutions was very different from country to country and sometimes very slow (Swenson, 1988). HIV is a virus that attacks the body's immune system. If HIV is not treated, it can lead to AIDS. HIV is a sexually transmitted infection and can also be spread by contact with infected blood and from drug use or sharing needles. There is currently no cure. Once people get HIV, they have it for life. But with proper medical care, HIV can be controlled. People with HIV who get effective treatment can live long, healthy lives and protect their partners.

Stigma and discrimination associated with HIV/AIDS are viewed as one of the greatest challenges for HIV infection and the communication strategies experimented worldwide have had a high responsibility from a social perspective (Gabardi, 2011). HIV-infected people are considered still today socially unacceptable, unpleasantly different from the public and even a threaten for other people, therefore treated unequally and unfairly and often subjected to isolation, rejection and blame (Castro et al., 2010). The lack of information and awareness combined with outdated beliefs lead people to fear getting HIV. Many wrong ideas about HIV come from the HIV images that first appeared in the early 1990s (Swenson, 1988) (Figure 1). There are still misconceptions about how HIV is transmitted and what it means to live with HIV today. This stigma seriously affects people with HIV, and it may force the infected people to delay or refuse treatment or hide their disease from others. The fear from stigma causes denial, secrecy, depression and shame.

In the last decades both non-profit organizations and independent activists have worked on projects dedicated to the communication of this stigmatizing disease through social media campaigns aiming at improving the life-conditions of those affected by the virus both on a social level, by disproving some misconceptions, and on a medical level, by promoting correct behaviours to prevent or treat the virus (Gabardi, 2017). In the following section audiovisual artifacts and awareness campaigns that used animation to inform, sensitize and arouse emotions will be explored and classified according to the communication styles identified by the Italian sociologist Roberto Bernocchi in 2008.

Figure 1. *Dying on AIDS* (1992). Bill-board advertisement designed by Oliviero Toscani © Benetton

4. Animated videos for AIDS

4.1. Criteria of selection and categories

Among the several awareness campaigns against AIDS led by NGOs and organizations in the last decades a few of them have made use of animation. By delving into the archives of these organization and consulting bibliographical references that have reconstructed the evolution of social communication of HIV and other socially stigmatized conditions – such as the books *Stop Aids* (2017) and *Social Advertising* (2011) by Emanuele Gabardi – it has been possible to identity twenty-nine animated artifacts addressing AIDS and HIV from different perspectives for social purposes. An interesting finding emerged from the scouting, i.e. the presence of several awareness raising videos produced or co-produced by those same foundations and international organizations not belonging to any specific transmedia and cross media campaigns. Due to this observation the analysis has required to separate artefacts belonging to communication campaigns from standalone videos dealing with the same social issues as independent productions.

In the next section the collected case studies will be classified according to the list of communication languages and styles formulated for the first time in 2008 by the Italian sociologist Roberto Bernocchi,[1] who named and described the following categories: sentimental, reassuring, dramatic, accusatory, transgressive, humorous, paternalistic, and informative. The sociologist defines as "sentimental and moving" artifacts that show helpless people, caught in moments of difficulty or suffering, and that stage images and narratives that tend to move; "reassuring and positive" are those artifacts that address the issued problem in a light way, to play down the drama, making people understand that a better, positive future lies ahead; "dramatic" are the communication artifacts that get advantage of the "fear arousing appeal", and provoke a reminder of fear through anxiety-provoking and highly dramatic images; "accusatory and denouncing" are those that stimulate a sense of guilt in people, shake them from apathy and lack of interest; similarly, "provocative and transgressive" ones stimulate a strong emotional reaction by arousing feelings of guilt through shocking or very harsh images; "ironic" are those artefacts that use explicit humorous figures, which raise a smile; "paternalistic and prescriptive" artifacts aim to make people responsible, avoiding dramatic tones, rather placing themselves almost at the level of an educator; finally the "Informative and documentary" ones aim to inform in a didactic way, without raising emotions (see Bernocchi, 2008: 165-186).

4.2. Sorting and classification

The twenty-nine selected films consist of eighteen animations belonging to nine awareness campaigns and eleven animated awareness videos that have used animation as their primary technique and communication language. In Figure 2 these videos have been inserted in a timeline that orders them in chronological order (year of production). Starting from the first identified animated video, produced in 2000 for the awareness campaign of the Italian Ministry of Health that featured the characters from Guido Silvestri (aka Silver)'s cartoons Lupo Alberto[2] and the mole Enrico, the films, the campaigns and the associations that funded these productions can be listed as follows:

- the video of Lupo Alberto produced by the Ministry of Health in 2000 as part of the sixth ministerial awareness campaign;

[1] Bernocchi categories root in the attempts of formulation of communication strategies that has enthused scholars in the fields of media studies and advertising since the 1980s. The first classifications have been provided by Jasjit Singh Johar and Joseph Sirgy (1991) and by John R. Rossiter and Larry Percy (1987), who identified two macro-categories: "Informational advertising", which refers to appeals entrusted by facts, useful information and functional aspects of the products/services they communicate, and "Transformational advertising", that evokes positive (or negative) emotions (Cadet et al. 2017). Marketing and advertising researchers have progressively distinguished communication models between messages capable of eliciting positive and negative emotions (Brennan, 2010; Higgins 1997), and strategies that leverage the persuasive power of humour (Mukherjee, 2012; Yoon, 2013) and the evocative power of images (Gallopel-Morvan, 2009).

[2] Lupo Alberto was the protagonist of a controversial pamphlet on AIDS distributed in schools, which was censored by the Italian Minister of Public Education Rosa Russo Jervolino. The 2000 Campaign, instead, included four posters and a 15-minutes video, which was soon censored and is now untraceable, except from the descriptions provided by some bibliographical sources (Bernocchi and Sorbero, 2011: 199; Gabardi, 2017: 31).

- a video produced by Médecins Sans Frontières for the MSF Campaign in 2012;
- a video produced for the Nucleus Medical Media Campaign 2013;
- a video produced for the AIDS Prevention Platform Campaign 2018;
- a video for the "Magari Fosse un gioco" Campaign by NPS Italia in 2020;
- 10 videos produced by high school students for the #HIVSTOPTHEVIRUS Campaign (2020) and #cHIVuoleonoscere Campaign (2021) promoted by Gilead Sciences;
- a video produced for the AID FOR AIDS 2022 Campaign by the communication agency Satchi & Satchi;
- a video produced for the "Have Fun But Play Safe" Campaign 2023 by Creativa's Innovative.

The identified awareness videos produced by organizations and associations but not linked to specific awareness campaigns are eleven:

- five videos produced by the French non-profit organization AIDES between 2005 and 2011;
- the video "How HIV is treated" produced by Body and Soul Charity in 2014;
- a video produced by NPS Italia (2016);
- a music video produced by Mercury Phoenix Trust in 2019;
- a video produced by ITPC Global in 2020;
- two videos produced by ViiV Healthchare in 2020 and 2022.
-

Afterwards, the selected artefacts have been categorized according to the communication styles identified by Roberto Bernocchi (see previous section). Animation's versatility allows for a broad spectrum of styles, from emotional and dramatic storytelling to humorous and light-hearted narratives, each tailored to reach specific audiences and achieve distinct communication objectives. By classifying these animated campaigns and videos based on Bernocchi's styles, it is possible to gain a better understanding of how different tones and approaches are utilized to inform, educate, dispel myths, and foster understanding about HIV and AIDS. Among the animated videos identified, none could be classified under the categories of "transgressive" or "paternalistic ", and the categories "dramatic" and "denouncing" have been merged in one category, as the selected videos belonging to this category stimulate a sense of guilt by showcasing highly dramatic images. The absent categories suggest that certain communication styles may be less suited to animation or, alternatively, that those creating animated content for HIV and AIDS awareness may prefer more supportive, engaging, and informative approaches. In Figure 2 the five remaining categories have been associated with a specific colour value. The classification result is the following:

- The category of videos classified as "reassuring/positive" has been associated with green, and this category includes the video of Lupo Alberto produced in 2000 by the Italian Ministry of Health, two videos produced by students for the #HIVSTOPTHEVIRUS Campaign in 2020, two produced by students for the #cHIVuoleonoscere Campaign in 2021, and the animated short film "The Story" produced for the AID FOR AIDS/AID FOR LIFE campaign by Satchi & Satchi in 2022;

- the “funny/ironic” category has been associated with yellow, and in this category were classified the videos BABY BABY (2005), SUGAR BABY LOVE (2007), LOVE STORY (2008), ZIZI GRSFFITI (2010), SMUTLEY (2011) produced by the French non-profit organization AIDES, the video of the “Magari Fosse un gioco” Campaign (2020) by NPS Italia, and one of the videos produced by the students for the #cHIVuoleonoscere Campaign of 2021;
- the “dramatic/denouncing” type (result of the blend between Bernocchi’s “dramatic” and “accusatory” categories) was associated with the colour red and two videos belonging to this category were identified: the video “Human Ball” produced by the Médecins Sans Frontières MSF Campaign of 2012, and one of the videos produced by students for the #cHIVuoleonoscere Campaign of 2021;
- the “Informative/documentary” category, the largest, has been associated with indigo, and the videos that fall into this category are very different between each other for style, technique, narrative approach and graphic quality: the scientific 3D CGI film produced for the Nucleus Medical Media campaign in 2013, the informative video “How HIV is treated” produced by Body and Soul Charity in 2014, the infographic animation “10 things to know about HIV” produced in 2016 by NPS Italia, the typographic animation created for the AIDS Prevention Platform Campaign in 2018, the scientific motion graphics “Understanding UIV” by ITPC (2020), two videos produced by students for the #cHIVuoleonoscere campaign in 2021, the two character animation videos “THE CD4 STORY” and “Approach to HIV” designed by ViiV Healthcare respectively in 2020 and 2022, and finally the video produced for the "Have Fun But Play Safe" Campaign 2023 by Creativa's Innovative;
- the “sentimental/moving” category, associated with the colour petrol, has three videos: the animated video clip “Love me like there’s no tomorrow” produced by Mercury Phoenix Trust (2019) and two animations produced by students for the #HIVSTOPTHEVIRUS Campaign of 2020. As anticipated, selected animations show very heterogeneous visual languages, techniques and graphic styles, and as an example in the next section a film will be described for each of the categories of communication styles identified.

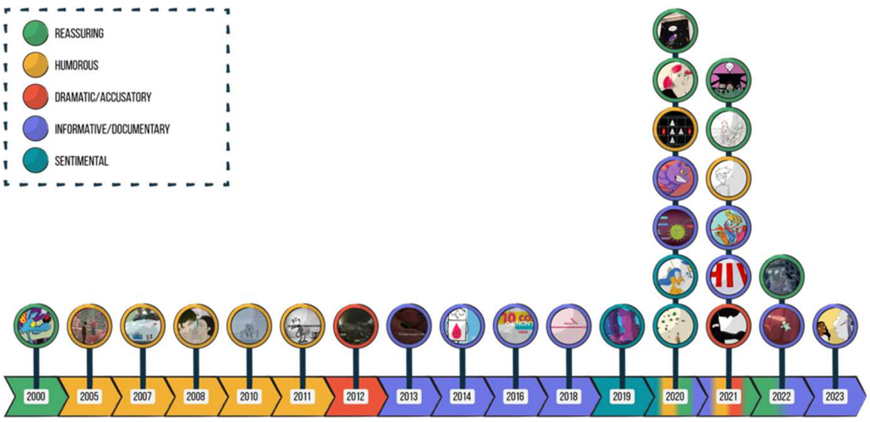

Figure 2. Animated videos on AIDS and HIV designed by NGOs and private organizations between 2000 and 2023 and classified according to the production year and the communication style © Maselli

5. Analysis of selected case studies

5.1. The Story (AID FOR AIDS / AID FOR LIFE, 2021) [reassuring/positive]

The short film "The Story," produced for the AID FOR AIDS/AID FOR LIFE campaign by Saatchi & Saatchi in 2021, combines effective technical elements and a delicate but powerful communicative tone to raise awareness about HIV/AIDS societal impact. The film tells a story of hope, optimism, and determination, highlighting the achievements obtained by AID FOR AIDS / AID FOR LIFE to go to get help where it is needed. The Saatchi team chose to tell this story through animation to emphasize the dove, AID FOR AIDS' logo, but also to discuss a complicated topic in an "easily digestible" way to evoke understanding and appreciation from the viewer.

Technically, the short film employs a minimalist yet visually impactful approach, using a flat digital 2D animation with rough drawings and imprecise lines, emphasizing the human aspect of the narrative, and allowing the audience to connect on an emotional level. The colour choices reflect moments of joy and optimism (with light and pastel colours), and moments of despair and difficulty (with shady colours and a dark atmosphere), reinforcing the emotiveness of the stories being told (Figure 3). The tone of the communication is heartfelt, empathetic, and hopeful. It emphasizes the difficulties in receive medical support and the resilience of people living with a disease and underscores the importance of empathy and support from the community. The message "help always finds a way" is emphasized by the story using a metaphor: a dove must deliver the medicine to a children's hospital but is hindered by a cat symbolizing the social stigma and prejudice, which very often affect the choices and serenity of leading a normal life for those affected by HIV/aids. The animal manages to overcome the obstacle thanks to the collaboration of the community (Figure 4). The storytelling approach, therefore, is designed to metaphorically break down barriers of stigma, offering a human perspective rather than focusing solely on statistics or medical information. However, the virus in never mentioned apart from the final message that declare that AID FOR AIDS has helped more than 20,000 people in 70 developing countries and the used visual language is generic and relatable, ensuring that the message is accessible to a broad audience.

Figures 3-4. *The Story* (Saatchi & Saatchi, 2021). Screen captures © AID FOR AIDS/AID FOR LIFE

5.2. Love Me Like There's No Tomorrow (The Mercury Phoenix Trust, 2019) [sentimental/moving]

In 2019, the two directors Esteban Bravo and Beth David released a four-minute animated music video commemorating the Queen frontman twenty-eight years after his death, accompanying his 1985 song "Love Me Like There's No Tomorrow". The video uses a blend of emotional storytelling and stylized animation to communicate a poignant message about love, acceptance, and the fight against AIDS, adopting a "microscopic" perspective. The images speak metaphorically of the strength of human solidarity by telling the love story between two anthropomorphic white blood cells, one of which is affected by the virus, using their relationship to symbolize the universal nature of love and the challenges faced by those affected by HIV (Figure 5). The storytelling is nuanced, capturing both the euphoria of love and the heartbreak of struggle, ultimately leading to a hopeful resolution. The directors focus heavily on visual metaphor and symbolism. For instance, the portrayal of the virus is represented abstractly, allowing viewers to understand the struggle without being overly literal (Figure 6).

From a technical perspective, the animation employs a vibrant, hand-drawn style reminiscent of classic 2D cartoons, which evokes a sense of nostalgia and warmth. The characters are depicted with expressive features, allowing for a deep emotional connection with the audience despite the absence of dialogue. The colour palette shifts throughout the video, reflecting the emotional journey of the protagonists – from warm, bright tones that symbolize joy and love to darker, muted shades that convey moments of tension and uncertainty. The tone of the communication is both tender and hopeful. By using animation, the video manages to address a serious topic in an accessible and profound way, encouraging empathy and understanding without resorting to fear or stigma, and emphasizes the emotional dimension of scientific communication, spotlighting the need for welcome, acceptance and humanity.

Figures 5-6. *Love Me Like There's No Tomorrow* (Universal Music Group, 2019). Screen captures © The Mercury Phoenix Trust

5.3. Human Ball (Médecins Sans Frontières, 2012) [dramatic/denouncing]

The animation "Human Ball," produced in 2012 for the Médecins Sans Frontières (MSF) Campaign, uses impactful visual storytelling to raise awareness about the urgency of humanitarian help and the challenges of fighting the AIDS epidemic in developing countries. The animation conveys a dramatic social situation through strong imagery and symbolic elements, designed to raise awareness about the impact of AIDS and the importance of accessible treatment.

In an African country a man is walking when he suddenly falls to the ground and drags other people with him. As it rolls, a dark ball is formed and, as it travels, destroys a village and other innocent people, growing exponentially (Figure 7). When it arrives in a city it is now a giant-sized sphere, a metaphor for the spread of the disease on the African continent. The narrative is highly metaphorical, portraying human figures being tossed around like a ball in a chaotic and relentless environment. This symbolizes the lack of control and agency, stressing the urgency of support and advocacy for those in need. Technically, the video produced in 3D CGI uses a simple yet striking animation style. The characters are depicted as faceless figures, which helps convey the invisibility and dehumanization often experienced by people affected by AIDS (Figure 8).

Figures 7-8. *Human Ball* (Médecins Sans Frontières, 2012). Screen captures © MSF

The animation employs a limited colour palette, primarily using muted tones such as greys and browns, which contribute to create an oppressive atmosphere. The tone of the communication is dramatic, shocking, and thought-provoking. By using metaphorical imagery, the video denounces a humanitarian urgency and encourages viewers to see the reality behind the statistics, invoking empathy and highlighting the necessity of intervention. The storytelling and animation choices create a powerful and direct message, urging action and support for those in need of medical care and protection.

5.4. Zizi Graffiti (AIDES, 2010) [ironic/irreverent]

The fact that the transmission of the virus occurs mainly through sexual intercourse constitutes the stimulus for the use of explicit humorous figures, which raise a smile. The animation *Zizi Graffiti*, produced in 2010 by AIDES, a French association working to prevent the spread of HIV and viral hepatitis, uses humour animation to promote safe sex and raise awareness about HIV prevention. The protagonist of the short film is a penis, Zizi, drawn inside a public toilet. Every time he approaches the drawings representing female organs, they run away in fear (Figure 9). Very demoralized, Zizi walks over to the sinks. Here he sees a girl who, with the pencil with which she was applying make-up, draws the outlines of a condom for him. At this point Zizi, now protected, becomes the object of desire of all the female graffiti around him (Figure 10). The short video focuses on promoting safe sex through humour, using playful and irreverent scenarios involving animated characters, with the aim to normalize conversations around sexuality and condom use, to reduce stigma and encourage positive sexual health behaviours, especially among younger audiences.

The animation has a cartoonish and exaggerated style. The visuals are lively, featuring fluid character movements that convey a sense of energy and humour. The characters are highly stylized and depicted in an over-the-top manner, which adds an element of fun and lightness to a topic that is often considered difficult or uncomfortable. The tone of the communication is light-hearted, direct, and playful, effectively breaking down barriers to discussing sexual health openly. By combining humour with clear messaging about condom use, *Zizi Graffiti* delivers a serious message about HIV prevention in an approachable and entertaining way, ultimately aiming to promote safer sex practices.

Figures 9-10. *Zizi Graffiti* (TWBA, 2010). Screen captures © AIDES

5.5. Understanding HIV and its Treatment (ITPC, 2020) [informative/documentary]

Informative and documentary communication style includes videos that aim to inform in a didactic way, without raising emotions, through different animation techniques and tones of voice, from motion graphics to videos that "humanize" the microorganisms of the human body. Selected case study is the motion graphic video *Understanding HIV and its Treatment*, produced in 2020 by the International Treatment Preparedness Coalition (ITPC), based in Botswana.

The video describes in an understandable but precise language and with flat graphics combined with moving typographic elements the ways in which the HIV virus spreads in the human body and how antiretroviral therapies reduce HIV reproduction by interrupting the virus life cycle. The technical, linguistic, and aesthetic elements are designed to inform and make complex medical information accessible. Technically, the video features moving icons, infographics, and text overlays that break down information into easily understandable parts (Figure 11). The use of bright, contrasting colours is effective in guiding the viewer’s attention and maintaining engagement. The visual style is minimalist yet vibrant, avoiding overwhelming detail to keep the focus on key messages. Linguistically, the video uses straightforward, non-technical language to make the information accessible to a wide audience, including those without a medical background. The script opts for relatable terminology, often supplemented with visual aids to reinforce understanding. The delivery of the information is calm and measured, which matches the educational purpose of the video. The tone of the communication is informative, educational and supportive. By combining clear language with visual metaphors and graphics, the video aims to reduce misinformation, providing viewers with the knowledge needed to understand HIV and the available treatments. This approachable and informative style helps both a wide audience not enough informed about the disease and the medical condition of those affected, and HIV positive people in fostering a sense of empowerment, encouraging them to take control of their health.

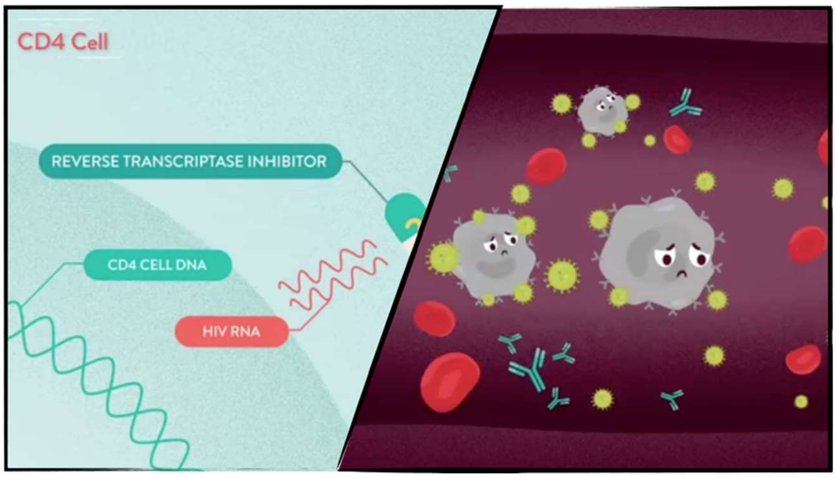

Figure 11. *Understanding HIV and its Treatment* (ITPC, 2020). Screen captures © ITPC

6. Discussion and conclusion

Figure 2 revealed that, in recent years, it has been possible to observe an increased use of animation in HIV awareness campaigns, particularly from 2020 onwards. This trend highlights the growing recognition of animation as an effective medium for addressing sensitive topics like HIV and the associated stigma. Animation offers a unique combination of accessibility and visual storytelling that can convey complex messages in an engaging way, making it well-suited for educational and awareness purposes (Honess Roe, 2013).

Most of the videos analysed in this article tend to fall into a few key categories – sentimental and moving, reassuring and positive, funny and ironic, or informative and documentary – that reflect a preference for approaches that evoke specific emotional responses and foster empathy, understanding, and a sense of empowerment among audiences. Interestingly, none of the videos employed transgressive or provocative language, and only a couple used a dramatic or denouncing tone. This suggests that most campaigns prefer to communicate in ways that are accessible and emotionally appealing, rather than confrontational or shocking. Despite these insights, there remains a need to continue consulting the archives of foundations, associations, and NGOs to gain a more comprehensive understanding of the strategies being employed. Expanding this research could reveal additional trends and approaches that might contribute to more effective awareness campaigns in the future.

Finally, it is worth observing the innovative direction taken by the Gilead Sciences Campaigns in 2020 and 2021, which involved the participation of students. This initiative opened new perspectives for integrating HIV-related topics into educational settings, using animation as a collaborative tool for learning (see Pithouse-Morgan et al., 2015). Engaging students in the co-creation of these animated artifacts not only helps them develop skills in handling scientific data and narrative content but also fosters greater awareness and understanding of the issues surrounding HIV and AIDS (Friendlytest, 2022). This participatory approach could serve as a model for future campaigns, combining education with creative engagement to combat stigma.

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ORIGINAL ARTICLE

Astro-Animation - How Artists and Scientists Envision the Universe

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Abstract: For several years, students at an art college, working with NASA astronomers, have produced animations inspired by research on black holes, dark matter and more. They can be whimsical or poetic but still constrained by scientific rigour. The animations are used for scientific outreach and are freely available. Our program received a positive assessment through an evaluation we undertook. We are now planning a mobile STEAM exhibition to engage teenagers from underrepresented communities who may not typically consider STE(A)M for their studies. "Science anxiety" has been reported to be a significant barrier to learning. Mixing animation with astronomy can stimulate interest in STEAM, making science engaging in an unconventional way. One component would be activities where participants create artistic responses to astronomy. We undertook a workshop at a local city-run school, specialising in the arts for ages 14-17, to brainstorm the art/science activities. There we gave short scientific presentations leading to art activities: a giant colouring wall with projected celestial phenomena, a stop-motion station, and colouring images of comet 67P to produce an animation. Surveys before and after the activities showed positive responses. The hand of the artist has long been an important concept in animation (Crafton 1991). In a film entitled "The Movements of the Universe", this concept is adapted to the hands of scientists. Combining animation, filmed interviews at NASA (including a Nobel prize winner), and the scientists' hands, bring unexpected feelings of dream and humour to the audience. In this paper we explore three different viewpoints of these activities from a scientist, an animator, and an animation student.

Keywords: Astronomy; Animation; Visual representation; Scientific communication; Public engagement

1. Introduction - A Comparison of Views

This paper explores how art and science can come together to make the invisible universe visible—and emotionally accessible—through collaborative animation. We examine this through three distinct lenses: that of a scientist, an animator and professor of animation, and an animation student who interned at NASA. Each offers a unique perspective on how complex astronomical phenomena can be interpreted and communicated through visual storytelling.

This paper begins with a review of the theoretical frameworks that underpin visual science communication and interdisciplinary collaboration. Next, we introduce the Astro-animation project and its core components. We then present three perspectives—those of a scientist, an animator, and a student—to illustrate how Astro-animation operates in practice. This is followed by an analysis of educational and public engagement outcomes. Finally, we discuss the broader implications for science communication and STEAM education.

2. Theoretical Framework: Narrative, Inclusion, and Cultural Framing in Science Communication

Astro-Animation's integration of storytelling with astronomical content aligns with a growing body of research that positions narrative as a powerful tool for science communication. Jerome Bruner (1986) distinguishes between two fundamental modes of human understanding: the logico-scientific, which relies on empirical reasoning and structured explanation, and the narrative, which constructs meaning through story, emotion, and context. Avraamidou and Osborne (2009) build on this distinction, arguing that blending these modes enhances accessibility and engagement in public science contexts—a strategy central to Astro-Animation's student films and public workshops. Egan (1986) similarly views storytelling as a primary pedagogical structure, supporting the use of narrative arcs in educational design to deepen learners' emotional and conceptual connections with scientific content.

This narrative framing is also a tool for inclusion. Archer et al.'s (2015) theory of science capital shows how social and cultural resources shape access to science participation. Astro-Animation expands this capital by offering culturally relevant, emotionally engaging ways into STEAM for underrepresented youth. This is especially significant in astronomy, a subject shown to inspire cross-disciplinary curiosity but often underrepresented in formal education (Salimpour et al., 2021).

Finally, Salimpour and Fitzgerald (2024) argue that astronomy is not only scientific but deeply cultural, understood through symbolic, narrative, and embodied lenses across societies. Astro-Animation's use of gesture, metaphor, and visual storytelling supports this pluralistic vision, reframing scientific communication as a form of semiotic translation rather than a simplification.

These theoretical perspectives lay the groundwork for the interdisciplinary practices explored in the next sections. We begin with the scientist's view, examining how astronomical knowledge is constructed, visualised, and shared—and how collaboration with animators reveals new layers of meaning in both research and communication.

3. The Astro-Animation Project: An Overview

The Astro-animation initiative began with a course at the Maryland Institute College of Art, co-taught by an animator and a NASA astrophysicist. Students work with scientists to translate current research topics—such as black holes, pulsars, and lunar missions—into short, animated films. The course integrates scientific accuracy with metaphorical and poetic expression.

Over time, the project expanded to include public workshops and a traveling exhibition titled *Look Up at the Sky, Draw Down the Stars*. These workshops take place in libraries, conferences, and schools, particularly targeting underserved youth. Participants learn basic astronomical concepts through short talks, then create drawings or animations that interpret these ideas. These experiences culminate in collaborative films that are shown at festivals and exhibitions.

The project also developed a toolkit to support facilitators, including step-by-step instructions, visual aids, and evaluation materials.

4. Perspectives on Astro-Animation

4.1. How a Scientist Envisions the Universe

Astronomers follow the general scientific method of performing observations, formulating hypotheses, testing these, and then reformulating hypotheses if required and conducting further tests. Astronomy, however, differs from many other fields of science in that typically direct experiments cannot be performed, but instead “natural” experiments must be found in the Universe. Also, the scope of astronomy is incredibly broad, comprising the entire Universe since its birth, and can involve physics in much more extreme conditions of temperature, gravity, density and magnetic fields than can exist on the Earth. Astronomers’ views of the Universe primarily come from light, although the range of light that be studied has increased, and other “messengers” can now also be used such as cosmic rays, neutrinos, and gravitational waves. In the next section we describe the various types of light, with an emphasis on the high-energy regimes of X-rays and gamma-rays, which author Robin Corbet is primarily involved with, and give an example of a type of binary star system that emits at these wavelengths.

4.2. The Different Types of Light

The light that we can see with our own eyes is only a small slice of the broad spectrum of light that exists - or electromagnetic spectrum to use the technical term. Beyond the reddest light that the human eye can see exists infrared light, going beyond this to redder and redder parts of the spectrum, we reach radio waves of longer wavelengths. In the other direction beyond the bluest light, we can directly perceive exists ultraviolet light, going further we find X-rays and then gamma rays. We note in passing that the centuries long debate about whether light is a wave or a particle was resolved by quantum mechanics which shows that light has both properties.

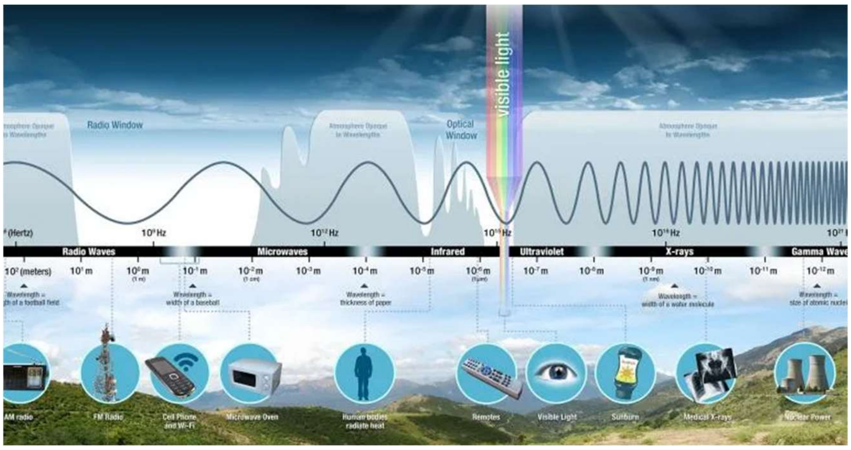

Figure 1. The electromagnetic spectrum, covering, from left to right, radio waves to gamma rays. The diagram indicates wavelength and frequency and shows atmospheric transparency at each wavelength. Visible light occupies a narrow band, highlighting the limited range perceptible to the human eye. At the bottom are shown examples of terrestrial sources of "light" at each wavelength. (Courtesy NASA).

The Fermi Gamma-ray Space Telescope was launched into low-Earth orbit in 2008. The mission is an international collaboration led by NASA. It carries two instruments to detect gamma rays, which are the most energetic form of "light". The main instrument onboard Fermi is the Large Area Telescope or LAT (Atwood et al., 2009). While the telescope name is not very exciting, the LAT studies some of the most extreme and exotic conditions in the Universe, such as the environments around black holes, or rapidly rotating neutron stars, the remains of a massive star after it has exploded as a supernova.

The mirrors and lenses which are used for telescopes that detect visible light do not work for gamma rays. The LAT instead relies on the creation of antimatter within the telescope (e.g. Funk, 2015). When antimatter and matter meet, they annihilate each other and produce a pair of gamma-ray photons. Thanks to Einstein's $E = mc^2$, the process can also work in the other direction and a gamma ray, in the right situation, can convert into antimatter and matter. In the LAT a gamma ray can hit an atom in a metal sheet and change into an electron, and the antimatter version of an electron known as a positron. As the electron and positron move through sheets of silicon, they produce an electronic signal that is then transmitted to the ground. Subsequently computer algorithms calculate where on the sky the gamma came from, when it arrived, and how much energy it had.

This computer file, which contains a list of information about each detected gamma ray, is what scientists use to study the very high-energy Universe. While the LAT does not produce a direct image of the Universe within it, this computer file can be used to produce a gamma-ray view of the sky.

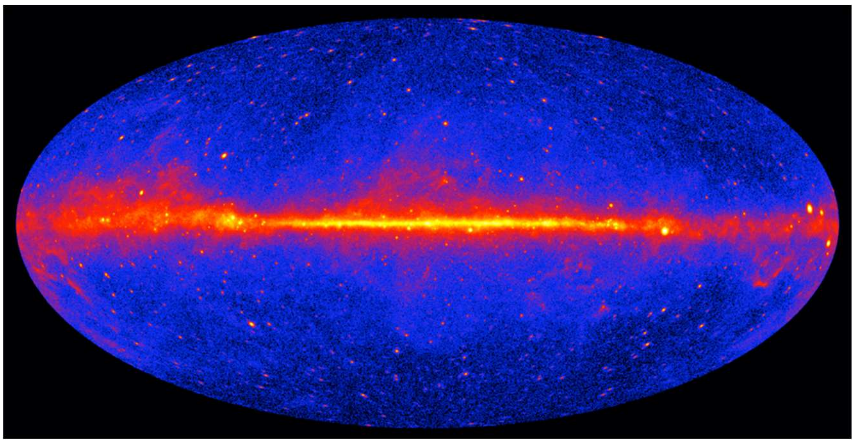

Figure 2. The entire gamma-ray sky as viewed by the LAT detector on board the Fermi satellite. The centre of the image corresponds to the centre of the Milky Way Galaxy. (Courtesy NASA).

4.3. "Carnivorus Spider" Binary Star Systems

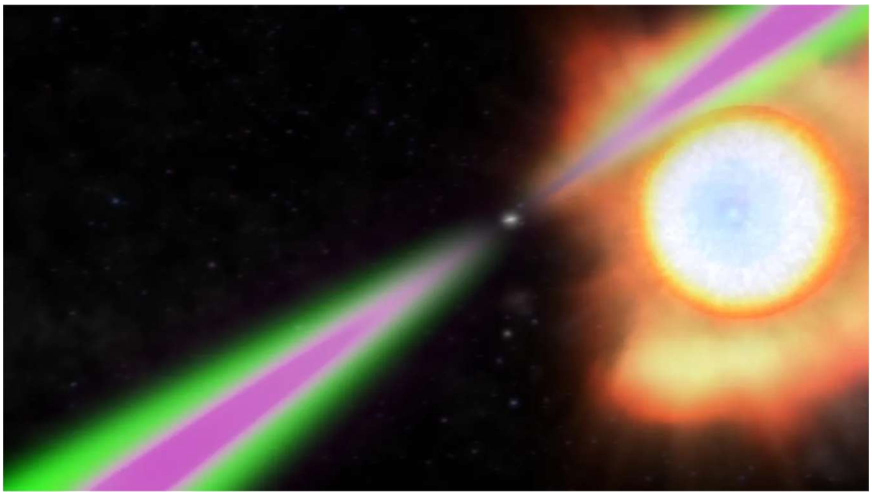

Figure 3. An artist's concept of a black-widow binary star system produced by the NASA Goddard Scientific Vizualization Studio. (Courtesy NASA).

An example of the type of object that the Fermi LAT studies is a special type of binary star system. In a binary star system, the two stars orbit around each other, similarly to how the Earth and the Moon orbit each other. In this particular system one of the components is a rapidly rotating neutron star, a pulsar. A neutron star is the core of a massive star left after a supernova explosion that has been compressed down to the size of a large city but has a mass of approximately 1.4 times that of the Sun (e.g. Shapiro & Teukolsky, 1983). In this object most electrons and protons are forced to combine into neutrons, and it is essentially a giant atomic nucleus with incredibly strong gravity and magnetic field. Many of these objects are pulsars that emit regular flashes of electromagnetic radiation. In some systems the neutron star can rotate very rapidly, taking just a few milliseconds to complete one rotation. The energy emitted from the pulsar can be enough to slowly evaporate its companion. These have been named after two species of carnivorous spiders - black widows and redbacks (e.g. Roberts, 2013).

The question then arises of how to communicate the excitement scientists feel for a subject such as the “spider binaries” with a general audience, and how best to deal with the physics involved. Traditionally NASA has provided films that attempt to be rather strict visualisations of a subject. But this is often impossible, and sometimes the underlying sense of wonder may be lost. An alternative approach, and one that is described in this paper, is that while there must be underlying scientific accuracy, it can often be more inspiring to provide animations that take a much freer approach to the material.

4.4. Creation of an Astro-Animation Class

To explore the interactions between science and art in a way that can present scientific results in a very different way we created an undergraduate class in Astro-Animation at an art college. The class consists of two interlocking parts, one focused on astronomy and one on animation. The class starts with the astronomy section, taught by the author of this section, and this meets the science requirements for the students’ Bachelor of Fine Arts degrees. For the animation component, the students are supervised by author Laurence Arcadias, but they also work directly with NASA scientists as mentors for one semester. The students produce animations on a wide variety of astronomical topics that have included black holes, life on Mars, gravitational waves, and many others. The students are asked to incorporate the scientific concepts in their animations through artistic vision, but still with underlying scientific rigour. For example, they can use metaphorical or poetic interpretations. The students are given an overview of the scientific process including rigorous testing of hypotheses as part of the astronomy component of the class.

4.5. Astro-Animation class timeline

During the first two weeks, students learn about the overall class goals, and undertake some warmup exercises doing very brief animations on drawings on either the scale of the Universe or gravity. Then, in the third week, the NASA scientist mentors come to the class and give a couple of minute presentations on the topics they are working on. Typically, there are six projects. Teams of three students are then randomly assigned to each topic/scientist, and the animators and scientists discuss their thoughts on how the project will proceed.

For the next two weeks, the student animators work on their ideas and put together short presentations incorporating animatics and sketches. Then they are taken on a visit to the NASA Goddard Space Flight Center. After a tour of the centre, where they can view satellites being constructed and tested, they present their ideas to a group of scientists and science outreach experts. They then again split into groups to receive detailed feedback and discuss how the project will continue for the rest of the semester. After returning to the art school, they work on the animations and get regular feedback from the animation instructor and other students, as well as remaining in close contact, typically remotely, with the scientist mentors.

The students again return to NASA GSFC one week before the end of the semester to screen their films. Coincidentally, the day of the class coincides with the annual Take Your Child to Work Day, and the students have a large audience of both adults and children. Afterwards, a few final tweaks and corrections may be made to the films.

Currently there is a collection of 73 short animations that have been made through our class that are freely available, and this number continues to increase each year. These have been used in a variety of ways by scientists, teachers, and outreach specialists. In addition, the animations have been shown at a variety of venues over the years that have included art and film festivals, science events, and science fiction conventions.

4.6. Evaluation of the Astro-Animation Project

We received funding from the US National Endowment for the Arts (NEA) to evaluate the benefits and outcomes of our class. We conducted surveys and interviews of scientists, animation students, and non-specialist audiences. From these, we found that presenting astronomy via animation is highly attractive to a range of audiences. Just screening the animations on their own has a visual impact. However, for science learning it is valuable to have some additional scientific material (Arcadias et al., 2020).

4.7. Expanding Beyond the Classroom to Unusual Locations - A Pilot Study

With the success of our class in getting students enthusiastic about astronomy, and the sense of wonder that the animations helped to bring to the audiences for these films, we wanted to build on this to reach out to a much wider community. A particular goal is to bring science and art to underrepresented teenagers outside of a traditional classroom.

Our concept is to construct an exhibition that would combine animations with deeper scientific information in events that would involve participants as active members, and not just passive viewers. The plan is to incrementally develop, test and expand the exhibition concept, taking into account feedback from stakeholders at each step.

The working title for the exhibition is “Look up at the Sky, Draw Down the Stars” that reflects both the astronomical content, together with the participants involvement with art/science activities. The exhibition would involve a variety of collaborators bringing a range of expertise. It would include people at our art school, a large research university with expertise in both scientific research and science education, outreach specialists at NASA, and community leaders at the library.

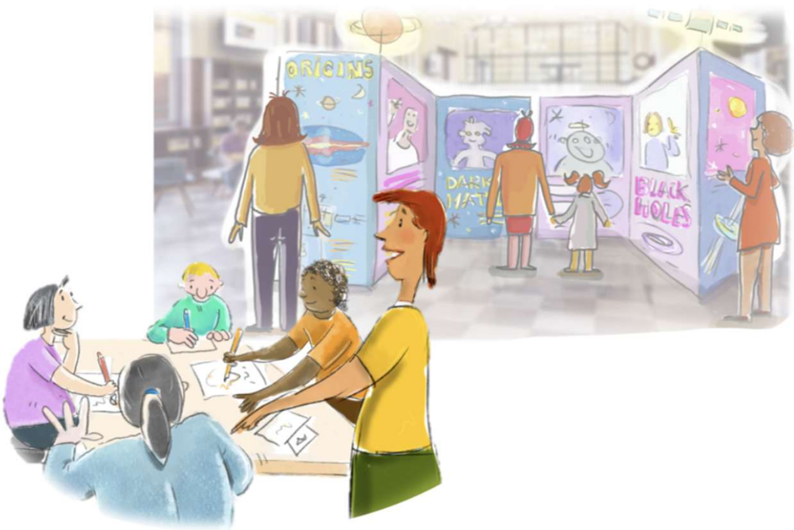

Figure 4. The concept for the “Look Up at the Sky, Draw Down the Stars” exhibition.

4.8. Astronomy topics, animations, and interviews of scientists

The exhibition would include several panels, each of which with a particular focus combining a relevant animation and the scientific background. An introductory panel would focus on women astronomers through time and Indigenous artists' views of the sky. For a first location of such an exhibit beyond the art school, the local large public library in our city provides an ideal location. The library provides significant community youth services to attract participants. At the same time, it is a somewhat curated environment that provides physical security for equipment.

A crucial part of the planned exhibition is to include hands-on art and science activities for the audience to make them fully a participant rather than just a viewer. Before moving to a full exhibition at the library, we wanted to prototype the various activities. We therefore conducted workshops at a local high school to test the concepts. This was at a city-run school that is specialised in the arts. Two sessions were held, with school educators also taking part.

Two sessions were held, with educators at the school also contributing to the process. To evaluate the workshops, anonymous surveys were given to the school students before and after each session. These both collected demographic information and students' attitudes toward science and animation to determine how these were affected by the workshops. Six scaled questions on attitude were given before, and eight were given after the activities. The latter survey also gave the students the opportunity to provide free-form responses). For the list of questions asked, see Arcadias & Corbet 2022, figures 4 and 5

4.9. Conclusion to a Scientist's Vision of the Universe

Scientists find it easy to become lost in their day-to-day of creating graphs of scientific values and applying equations to determine the details of an astronomical phenomenon they are working on. Participating in the astro-animation project arguably allows to step back a little and see more of the overview. In describing fundamental astronomical principles and how the work of a scientist fits into this context can also provide with perspective. It has been very satisfying to see the great responses to combining animation with astronomy. An itinerant exhibition could make astronomy and animation available to a broad audience, especially teenagers. We believe this can help to increase diversity in STEAM.

5. Astro-Animation, How an Artist Envisions the Universe

While the first part of this research focused on interdisciplinary collaborations to engage students and underrepresented communities in STEAM education, this section delves deeper into the creative process of astro-animation. As an artist and professor of animation, author Laurence Arcadias has developed techniques to visually interpret complex astronomical concepts through animation. By integrating artistic methods—such as hand gestures and visual metaphors— we aim to make the invisible aspects of the universe both accessible and engaging to the public.

5.1. The Movements of the Universe: The Role of Hand Gestures

By applying these principles of combining art and science, Arcadias created a film called *The Movements of the Universe* that further explores how to represent graphically complex astronomical ideas. The film uses the scientists' hand gestures enhanced by animated visual metaphors, to communicate intricate scientific concepts. We observed that these hand gestures often extend the scientists' thoughts, serving as a bridge between abstract ideas and their physical representation. This was an inspiration to incorporate hand gestures as a key element in the animation process. The insights gained while working with NASA scientists during *The Movements of the Universe* were a motivation to further explore the role of hand gestures in scientific communication (Roth & Lawless, 2002).

5.2. Analysing Hand Gestures in Astronomy

In the Astro-Animation class, which Arcadias co-teaches with a NASA astronomer, it was noticed that many scientists naturally use hand gestures to convey complex ideas to students. These gestures visually illustrate abstract phenomena, such as the movement of galaxies or the expansion of the universe, and have sparked Arcadias's interest in capturing, analysing, and expressing these movements through animation.

Figure 5. Scientists using expressive hand gestures to explain scientific concepts to students.

This process was deeply influenced by Donald Crafton's concept of the "Hand of the Artist", outlined in his essay on early animation (Crafton, 1991). Crafton describes how, in the early days of animation, the animator's hand served as a bridge between the audience and the artwork. The animator's hand was a tool to signal the "special magical properties" of the animated film. By showing the animator at work, the hands became the mediator between the spectator and the drawings that "come to life". Similarly, in Arcadias's work, the scientists' hand gestures were used to connect abstract scientific ideas with the audience, transforming these invisible forces of the universe into tangible, visual experiences. This approach informed many of the creative decisions made during the production of the film.

5.3. The Movements of the Universe – Process and Insights

Building on the initial observations of scientists' hand gestures, it was sought to further explore how these physical movements could serve as visual metaphors in the animation process. Arcadias began by sketching ideas on how various astronomical phenomena move, letting curiosity guide the process. Whenever a particular concept intrigued the author, she attempted to make sense of it through these sketches.

To bring these ideas to life, Arcadias collaborated with NASA scientists, focusing on their use of hand gestures to explain complex topics such as the Big Bang, the Sun, dark matter, pulsars, gravitational waves, black holes, and binary stars. By observing their gestures, the author could capture the essence of their explanations and translate these physical movements into visual metaphors through animation.

5.4. Case Studies: The Role of Hand Gestures in Astro-Animation

The interviews with the seven scientists provided invaluable insights into how their hand gestures convey complex ideas. From these observations, Arcadias was able to develop animations that visually captured these physical movements, transforming abstract concepts into tangible visual metaphors. Two case studies from *The Movements of the Universe* highlight how hand gestures can serve as powerful tools for visual storytelling.

5.4.1. Case Study 1: The Black Hole Dance

In Arcadias's animation film, one scientist explained black holes, describing how they spin and wobble around each other, likening the motion to a dance. His hands moved in a fluid, almost playful way, which was represented in the animation as two juggling hands with black holes spinning overhead. His feedback highlighted that the animation mirrored the mathematical shift of black holes from theoretical to observable entities, bridging the gap between abstract theory and physical observation. Hand gestures were able to communicate the speaker's excitement about their topic, and it may help memorise concepts. He also mentioned that he does not usually use his hands when he talks, as it is not part of his culture, and he had to integrate that later into his communication tools.

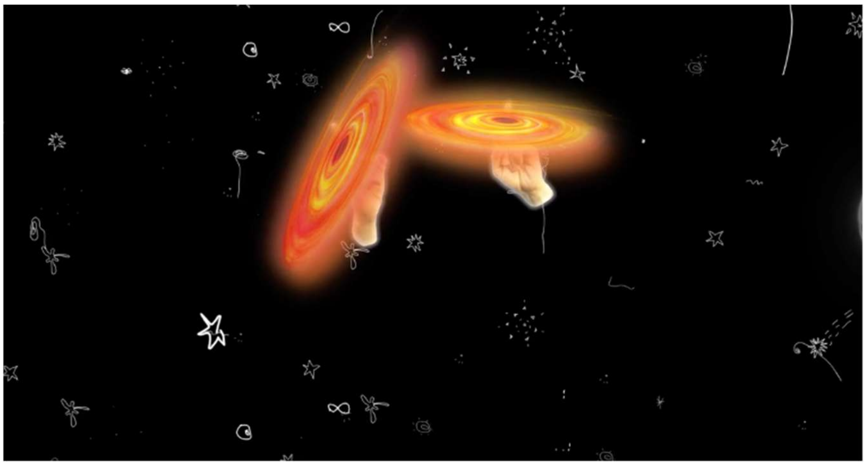

Figure 6. The black hole dance. The animation builds on the scientist's hands to convey the notion of dance[3]

5.4.2. Case Study 2: Dark Matter and Galaxy Formation

In contrast, Scientist #2 used her hands more frequently and dramatically, influenced by her cultural background. In *The Movements of the Universe*, when discussing how dark matter holds galaxies together, she mimicked the act of holding and squeezing a galaxy. This gesture inspired a playful animation where her hands control the galaxy's movements, set

[3] https://vimeo.com/839895776/5a6d6cb5bb

against abstract, fairy-tale-like visuals. Her feedback emphasised how gestures helped her intuitively carry both scientific meaning and emotional expression, showing that gestures can convey both emotion and scientific content and serve as powerful tools for communication. It was a way to liberate energy, be more expressive, and to connect with the audience.

Figure 7. Scientist controlling a galaxy's movements with her hands.[4]

These case studies reveal how hand gestures, which are often disregarded in scientific communication, can actually be crucial in making complex astronomical concepts more relatable and engaging. The author's goal in integrating these gestures into animations is to convert abstract scientific ideas into visual concepts that encourage further exploration and curiosity.

5.5. Astro-Animation with Scientists and Artists

After exploring how animation can visualise abstract astronomical concepts in *The Movements of the Universe*, we decided to apply these techniques in a series of public workshops to reach broader audiences. The science collaborator and Arcadias launched a series of Astro-Animation workshops, bringing together both scientists and artists. These workshops served as a testbed for engaging new audiences, specifically youth from underrepresented communities. Participants from both fields engaged with the process, further highlighting the potential of animation as a tool for scientific communication This collaborative effort between art and science enriched the project and helped establish a foundation for future public workshops.

5.6. Participatory Astro-Animation Experience

A key aim of the Astro-Animation project is to engage broader audiences—particularly teenagers with limited exposure to science education—by making complex astronomical concepts accessible through a creative, hands-on approach. (Bullock, 2017). These workshops demystify scientific concepts, making them more approachable and fostering curiosity

[4] https://vimeo.com/manage/videos/543315132/45fc2d5c10

in both science and art. The workshops are continuously evolving as we gather feedback and refine our methods to better engage diverse audiences.

Key areas of focus include evaluating whether the workshops spark curiosity and engagement, determining if participants can creatively express and communicate complex astronomical ideas through animation, and assessing whether the workshops make astronomy more approachable, especially for those who may feel intimidated by science. Ultimately, we aim to see if this creative process breaks down barriers to understanding and participation in science.

Each session begins with a brief, accessible lecture by an astronomer who introduces a particular astronomical phenomenon—such as Pluto or Solar Eclipses—followed by a short lecture on the principles of animation. Participants then engage in the hands-on animation phase. To gather insights, we will use surveys and interviews. Participants complete short surveys at the beginning and the end of the workshop. These surveys will measure changes in interest, understanding, and attitudes toward science and art over the course of the workshop. Additionally, we are conducting brief interviews with the participants during the workshop to capture their experiences and reflections

5.7. Astro-Animation Workshops: Public Engagement in Practice

The Astro-Animation workshops, initially developed in collaboration with scientists, have since been adapted for broader public engagement, including local communities and teenagers. By using animation to simplify complex astronomical concepts, these workshops inspire curiosity and foster interest in both science and art. They have become a key tool for making scientific learning more accessible and engaging for all participants.

5.7.1. The New York DOT Astronomy Conference

Building on the success of these workshops, Arcadias proposed an Astro-Animation workshop at the New York City DOT Astronomy Conference[5] during the unconference phase, which garnered significant interest and was approved to proceed. The primary goal of this workshop was to engage both scientists and astronomy enthusiasts in a novel method of visualising complex astronomical phenomena, using animation to demystify concepts such as NASA's New Horizons flyby of Pluto (Olkin et al., 2017). The unconference format—flexible and participant-driven—proved to be an ideal environment for this type of collaborative, hands-on experimentation, fostering open dialogue and creative exploration.

This workshop was particularly significant as it invited attendees, many of whom had little to no prior experience with animation, to actively participate in the creative process. By combining scientific insights with artistic techniques, participants were encouraged to explore astronomical phenomena through both visual and imaginative lenses. This hands-on experience not only allowed them to engage more deeply with the subject matter but also reinforced one of the core goals of the Astro-Animation project: making astronomy more accessible and engaging through artistic expression.

5.7.2. Workshop Structure and Execution

The session began with a brief, accessible introduction to NASA's New Horizons mission and its flyby of Pluto, which served as the scientific foundation for the animation activity. Participants were then given the

[5] https://www.dotastronomy.com/twelve

opportunity to create their own animated sequences, using printed images from the flyby as a starting point. By encouraging participants to stylise and enhance these frames with their own imagination, the workshop emphasised the intersection of science and art, demonstrating how creative approaches can demystify abstract and complex scientific concepts.

Incorporating animation into educational settings has been shown to engage participants emotionally while also enhancing their cognitive understanding of complex topics (Schwan & Buder, 2015). This approach promotes "active learning", where participants construct knowledge through hands-on processes, such as animation creation. As a result, scientific topics like astronomy become more accessible and engaging to a diverse audience, making it easier for participants to grasp and retain complex ideas (Miller & Fahy, 2009).

5.7.3. Post-Workshop Film Creation

On the final day of the conference, Arcadias gathered the participants' drawings and shot them using an IPEVO camera. The footage was then imported into Premiere for editing, and the animations were compiled into a short film. This final film, showcasing the participants' work, was presented to the conference attendees on the last day. Watching their drawings come to life through animation was a thrilling and rewarding experience for many participants. It not only provided a sense of accomplishment but also allowed them to see how their individual contributions could be transformed into a cohesive visual narrative, further reinforcing the workshop's goal of merging science with creative expression.

5.7.4. Survey and Reflection

To assess the effectiveness of the workshop, participants were invited to complete a survey at the end of the session. Many of the responses indicated that the activity offered a unique and enjoyable way to engage with scientific concepts. Some of the key feedback included:

"Very fun! As someone who loves space and art, this is an amazing idea to get people more involved and engaged in astronomy."

"Colouring was very therapeutic, but I kept feeling like I was going to do it wrong..."

"It was fun and engaging – looking forward to the results!"

This feedback not only validated the workshop's approach but also provided insights into how participants engaged with science through a creative, hands-on process. For many, the act of creating animated sequences allowed them to explore scientific concepts in a new and accessible way, underscoring the importance of integrating artistic expression into science communication. Furthermore, the therapeutic effect of the activity, as mentioned by several participants, suggests that animation can serve as both an educational and emotional tool for engagement.

Figure 8. Participant during an astro-animation workshop at the Dot.Astronomy conference.

5.7.5. Workshop Takeaways and Improvements

The DOT Astronomy workshop provided valuable insights and served as a blueprint for refining the Astro-Animation method. Several key takeaways emerged:

Clearer Explanation of Animation Principles – While participants enjoyed the activity, some felt uncertain about the basic principles of animation. To address this, future workshops now include a brief introductory segment on animation fundamentals, ensuring that all participants feel comfortable and confident in the process. Providing more detailed guides on animation techniques and clearer instructions during the workshop helps participants feel more secure in their artistic choices.

Improved Technical Setup – Capturing the drawings proved time-consuming and could be streamlined by scanning the images instead of shooting them with a camera. This change will result in a faster turnaround and higher quality.

Adding participants' interviews – I have received feedback indicating that many participants have interesting stories to share about their drawings and their thoughts on Pluto. Some of the drawings feature abstract geometrical shapes, while others are purely fantastical. For example, one participant drew a flying saucer with an alien emerging from it, showcasing her creativity. As a result, I have decided to conduct interviews with the participants to have them explain their drawings.

With these improvements, subsequent workshops—such as one conducted at the American Astronomical Society meeting in Texas — were even more successful. During the solar eclipse, participants created animations that were both scientifically informed and artistically engaging. The resulting film was selected for two festivals. Based on these results, more workshops will be conducted in the future, with a particular focus on engaging teenagers.

5.8. Broader Impact: Expanding Public Engagement

The Astro-Animation project serves as both a creative and educational tool, providing a unique way to connect the public with astronomy. By focusing on underserved teenagers and communities, the project aims to make astronomy more accessible, exciting, and approachable. Hands-on workshops, such as those conducted at the DOT Astronomy Conference, continue to be refined to ensure they effectively engage diverse audiences.

From an artist's perspective, this project highlights the power of visual storytelling in communicating complex scientific ideas. By integrating artistic techniques, such as metaphor, abstraction, and imaginative interpretation, audiences can engage with science on an emotional level. This creative approach makes astronomy more tangible and relatable to participants. Astro-Animation bridges the gap between the factual and the emotional, sparking curiosity and wonder in ways that traditional methods may not.

By merging art and science, Astro-Animation not only brings the universe to life but also fosters a greater interest in STEM fields, offering participants an opportunity to explore the wonders of the universe in an imaginative and meaningful way.

6. How an artist and animation student perceives the universe: a case study

As this essay has posited, artists and scientists have very different views of the universe. Scientists can chart the universe and, from data, can visualise the workings of a vast and complicated universe. Conversely, author Emma Booth believe that artists see the universe and its beauty and, in their own way, try to seek pattern and narrative in its chaos. They are two somewhat opposite ways of seeing but are not necessarily opposing. Scientists and artists may perceive the universe differently, but they are both trying to see. They all look up at the sky to see and categorise and relate to what they find.

As an artist, author Booth never focused on science all that much. In school, she was always fairly interested in learning about science, but then focused more on artistic education.

She was introduced to the world of Astro-Animation as a university student, by taking the aforementioned Astro-Animation class in the spring semester of 2023. Booth was able to participate in the class that the other authors worked so hard to bring to life and see firsthand how the worlds of science and art can interact. Booth has since graduated with a BFA in Animation with a Sequential Art minor; her experiences in this class shaped the trajectory of the rest of her college career.

Astro-Animation is ultimately an attempt to connect and unify the views of the artist and the views of the scientist and it was her first foray back into working with science. It has not only helped to connect to science in a way that is creatively fulfilling, but has also helped shape Booth's art in many ways going forward. Since she was introduced to Astro-Animation, the throughline of her work has been finding the emotional core behind scientific initiatives and utilising science as a narrative tool.

6.1. Applying art and narrative to research

As described above, the Astro-Animation class was a course where a small team of animation students would work with a NASA scientist and create an animated short based on the current project they were engaged with. In this instance, our scientist was working on a project concerning the Lunar Flashlight- a satellite, now decommissioned, meant to orbit and scan the lunar south pole for traces of exposed water ice (Cohen et al., 2020).

The goal was to take that premise and create just about anything the students wanted with it. But how does one take such a specific and complicated scientific topic and make it artistic? How do the animators create something that both they and the scientists can be excited about? Will the science have to be compromised for the sake of the art or vice versa? These are all questions that the Astro-Animation class evokes and Booth and her team handled it a few ways.

6.2. Understanding the reason the research is being done

The first step was to try and understand why the Lunar Flashlight mission existed to begin with. It was easy to understand the mechanics of the mission and its scanning of the lunar surface, but it was necessary to understand the reason that research was being done. Why it was created and what purpose that research was going to serve moving forward were important context clues to start shaping an animation.

In essence, the purpose of the mission was to scan the lunar south pole craters for traces of ice. Any data recovered therein would determine the most appropriate places to land and recover samples from in future missions. Eventually, these samples of ancient ice deep in the southern craters of the Moon, undisturbed by the Sun or anything else for that matter, could uncover information from potentially as far back as the formation of the Earth itself. And that little nugget of curiosity and undisturbed secrets is what artists can latch onto when creating an animated short.

6.3. Translating research into narrative

The next step in taking broad scientific research and creating something that reflects both parties was finding a narrative that conveyed the mission accurately enough without fully devolving into a simple documentary style exposition. Creating an emotional throughline in the animated piece was a priority.

What the team ended up with was a small story about a crew of scientists (who were simply personified versions of the four lasers used to scan the lunar surface) as they search the southern crater. In the end, they happen upon a figure trapped in ice who, once released, tells the crew the story of how life on Earth came to be. In doing so, the team was able to use the characters and the structure of the story not just to showcase what the Lunar Flashlight was for, but as more of a metaphor for the true purpose of its mission.

6.4. The results of bridging art and science

So, how does one take science and turn it into animation in a way that both honours the work of the NASA scientists and engages the creativity and passion of the animators? Can it be done? In the discussed case, the team found the most success when trying to compromise between the science and the art. We didn't want to fully do away with our narrative tendencies, so instead we used them to enhance and highlight the actual motivation behind the Lunar Flashlight project.

This approach was the most successful that the group saw and it was one that satisfied both parties in the end. The group enjoyed bringing a story to life that was loved by the team members and that also honoured the scientists they were working with. In turn, the scientists felt much less precious about the particulars of their work (which was not the case for every team) because they felt assured that their intentions were being accurately reflected.

The Astro-Animation class was a great study in working across fields and was Booth's first real step into using art and narrative as a tool to convey science to an audience. By focusing on the intentions behind the Lunar Flashlight mission as an emotional throughline for the final animation, the team was able to handle the balance of art and science in a way that successfully honoured both.

7. NASA Internship/Astro-Animation Exhibition

7.1. Making science and animation accessible

During the summer of 2023, Booth was an intern at the NASA Goddard Space Flight Center. She worked in part as graphics support for Goddard and the other half of the time she worked directly to assist with the Astro-Animation exhibition development. Her job was to ideate and prototype different hands-on activities related to animation that could potentially be used for the exhibition. However, animation is complicated and time-consuming work, so the issue became finding activities that could be short enough, simple enough, and fun enough for all ages.

What types of activities could fit these criteria and even then, would they be effective in also teaching science on top of that?

7.2. Creating hands-on activities for the exhibition

Short, simple, and fun was the guiding principle to find the right activities for the exhibition. The first steps were to make a list of each potential project, then log the materials required to make them, and finally prototype each option and time how long it would take to create. By doing so, it was possible to weed out activities that were either too complicated or too lengthy to complete. By the end, there was actually a very interesting trend to the remaining activities.

All of the most successful prototypes stemmed from very early forms of animation, such as old optical illusions and crafts. Activities like flipbooks, zoetropes, and phenakistoscopes, well known milestones in the development of animation, all fit the qualifiers of short, simple, and fun projects. This made them perfect candidates for the exhibition.

7.3. Accessibility of animation

It made sense that all of the most successful prototypes were the ones based on well-established forms of animation, because those are all the ones that came about before our modern techniques and technologies. The reason for this is a matter of accessibility. Early animation was very limited in its scope, and so in turn was very accessible in terms of its materials and its simplicity. They were essentially toys and optical illusions, which made them perfect activities for people of all ages and perfect for the activities I was seeking.

Almost all the participants of the Astro-Animation workshop have never tried animating before and so finding accessible activities was crucial, not just for the enjoyment of the participants, but also to not detract from the scientific topics being discussed in the workshop. After all, the exhibition was meant to foster a dialogue between art and science. Either one becoming too complicated would pull focus away from the true purpose of the exhibition- bringing art and science together.

7.4. The results of creating Astro-Animation activities

By the end of the internship, Booth found that the main issue about creating activities for the exhibition all came down to the matter of accessibility. Was the animation accessible? Was the science? All these things were important to balance.

Science and animation are both very complex processes, and it was very important that these activities were the perfect balance of engaging and educating. An exhibition like this one can only succeed if the participants are immersed and interested, so by simplifying the kinds of art being made it was possible to create the best atmosphere possible, one where the science and the art uplift each other and create one unified experience.

7.5. Senior Thesis Project

7.5.1. Using science as narrative

A substantial testing ground to engage with science through animation was found in Booth's senior thesis project. It was developed over a whole year, from the fall semester of 2023 to the spring semester of 2024. It was a fully self-produced animated short. The piece was to use the knowledge gained from working with the concepts of Astro-Animation; however, Booth wanted to take it in a completely new direction than before. But what other ways could science and art be employed?

The work in the Astro-Animation class had been focused on translating science into art and the work for the exhibition had been focused on making science and art accessible to all audiences. All of this served well for the kind of work being done, but a thesis project is not necessarily meant to teach or even necessarily meant to be accessible. It is meant to be a reflection of the animator's interests and goals, and the culmination of all they have learned up to that point. So, this specific thesis project experimented with using science not as an inspiration for narrative, but as narrative itself.

7.5.2. Thesis Project

"*Twin Suns*", the four-and-a-half-minute animated thesis, is about a young woman's journey through feelings of grief at the loss of her sister as well as her isolation in the depths of space. This piece not only utilises space as its setting, but also as a visual metaphor for the main character's emotional journey throughout the film. Using colour and texture, the character's arc is paralleled in the environment around her.

For example, in the film, the use of the colour blue is meant to represent the main character and so, in the first half of the piece, she is often surrounded by blue and other cool, muted colours. Orange is shown to represent the twin character, a ghost that haunts her, and so we see orange and other warm colours start to seep into the woman's world as she learns to accept and live with her grief.

The science that is used along with these colour themes is related to the climax of the animation, where the main character comes across two suns orbiting each other until they finally collide and unite into a brilliant supernova. The suns parallel the relationship between the main character and the twin whom they carry around with them. By coming to terms with the loss of her twin and the acceptance of this grief, so too do the suns unite and create something beautiful.

7.5.3. The results of using science as narrative

The thesis was intended to create a meaningful story and use science as a way to enhance and broaden out that same story.

In October of 2024, *Twin Suns* won for Best Animated Short at the Subtropic Film Festival in Palm Beach, Florida. This might might be a testimony to how animation can create an environment that makes science accessible and emotionally moving to broader audiences.

However, that does not mean it is necessarily a universal thing. Science as narrative is simply another clever tool to add to the toolbelt of anyone who wishes to explore science and art. In this instance, narrative science just so happened to perfectly fit the needs this project. However, this way of exploring narrative, along with the other ways of working with science and animation, can all be successful if used in their own appropriate contexts.

7.5.4. Closing Thoughts to A Student's View

The case of Booth's work illustrated how, after being introduced to Astro-Animation, the throughline of an artist's work could be able to find an emotional core behind scientific initiatives and utilising science as a narrative tool. For students and artists, working with science can be a fulfilling pursuit and inspire and enhance narrative in animated works, to the point of shifting one's way to see the world while reconnecting with scientific concepts through an artistic lens.

This experience showed also how science and art can be connected to make them accessible to an audience, by blending them together in a way that is narratively satisfying and also accessible to a broad audience. By creating an atmosphere of fun and learning, Astro-Animation can help simplify and humanise what are otherwise rather complex pursuits.

Artists and scientists have different ways of seeing the universe. Yet they are connected in so many ways. Art and science both see and categorise and relate and tell stories. Astro-Animation is an approach that eases those connections.

8. Educational and Public Engagement Outcomes

Astro-animation reframes science communication as an embodied, collaborative, and emotionally resonant process. By leveraging metaphor, gesture, and participatory design, it transforms abstract astrophysical ideas into accessible and memorable experiences.

The approach challenges the boundary between scientific fact and creative interpretation, demonstrating that narrative and aesthetics can coexist with scientific rigor. It also foregrounds inclusion by offering a multimodal entry point into astronomy—particularly impactful for underrepresented groups with limited access to STEM.

These findings suggest several broader implications for the fields of science communication and interdisciplinary education. First, they invite a reconsideration of how science is taught in creative education settings, advocating for approaches that value emotional engagement and narrative exploration alongside factual instruction. Second, they point to the potential of interdisciplinary toolkits—such as the Astro-animation model—for use in informal learning contexts, including libraries, festivals, and public workshops. Finally, they highlight the importance of recognizing emotion, gesture, and metaphor as legitimate and powerful forms of knowledge-making. These elements not only support comprehension but also foster a deeper, more personal connection to scientific content.

9. Conclusion

Astro-Animation has demonstrated the potential of blending art and science to engage the public with complex astronomical ideas in innovative ways. By fostering collaboration between artists, scientists, and students, this project has opened new avenues for science communication, making abstract concepts more approachable and relatable to broader audiences. This interdisciplinary approach not only enriches public understanding but also provides new creative methods for scientific outreach.

The success of Astro-Animation lies in its ability to demystify science through storytelling, turning data into visual experiences that resonate with audiences on both intellectual and emotional levels. As this project continues to evolve, it offers exciting possibilities for engaging new generations in science education, particularly by making STEM fields more inclusive and appealing to diverse communities.

Looking ahead, the integration of artistic expression with scientific research will likely inspire further projects that encourage exploration, curiosity, and creative learning. Astro-Animation exemplifies how collaboration between these fields can inspire not only understanding of the cosmos but also a deeper connection to the world around us. By continuing to build on these foundations, we can expect to see art and science working together to transform public engagement with science in new and meaningful ways.

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ORIGINAL ARTICLE

A Reflection on Doors to Hidden Worlds

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Abstract: The ever-expanding boundaries of visualization fuel discussions about objectivity and subjectivity in imaging techniques. This paper aims to introduce practical examples from the University of Applied Arts Vienna‘s Science Visualization Lab and spark discussions about the representation, presentation, and translation of humanity's scientific knowledge. Historically rooted in science communication through documentary films, the lab has expanded its creative field to engage recipients more directly. In recent years, the metaphorical 'fourth wall' has been broken down, introducing a wider range of artistic strategies to present essential and universally significant topics for humanity. With these strategies, the lab seeks to bring the world of science closer to various audiences. These visual and other sensory translations of scientific data open up debates in both art and science about the didactic, subjective, or objective nature of art-science presentations. The discussion about the context in which scientific data is presented to audiences is essential for research and development in visualising science.

Keywords: scientific; visualisation; visual effects; documentary films; animation

1. Introduction

The Science Visualization Lab at the University of Applied Arts Vienna practices the tradition of immersing audiences in scientific phenomena through visual and spatial means, as an active, exploratory, and sometimes embodied practice. Media art belongs to a broader genealogy of knowledge production and emerging new media might change how we approach the creation of socially responsible scientific knowledge (Grau, 2007:357). Immersive art-science is beyond abstract representation, it is supposed to be a multi-sensorial experience to increase tacit knowledge (Mancuso, 2011).

There are several contemporary examples of acquiring, and handling data from the “real” world, representing and presenting it in popular TV and web applications (Grau et al., 2015). The Lab embodies both trajectories: it develops visualizations that convey scientific phenomena using authentic scientific data while challenging audiences with perceptual or experiential engagement.

The roots of this visual immersive tradition stretch back centuries. Robert Hooke's *Micrographia* (1665) and Ernst Haeckel's *Kunstformen der Natur* (1904) brought otherwise invisible natural phenomena into perceptible, almost tactile forms, combining precision with aesthetic attention. In the 20th and 21st centuries, scientific documentary films and experimental science filmmaking extended this visual immersive impulse. Early experimental scientific films in France and Italy were technical innovations and artistic avant-garde at the same time (Bernabei, 2025:28).

Later productions such as Jacques Cousteau's *The Silent World* (1956), David Attenborough's BBC series—from *Life on Earth* (1979) to *The Private Life of Plants* (1995)—and National Geographic and IMAX documentaries also employed techniques such as time-lapse, macro- and micro-photography, and immersive soundscapes to allow audiences to inhabit environments otherwise inaccessible.

In this tradition of television for general audiences, the internationally broadcast *Universum* documentary productions *Limits of Perception – Grenzen der Wahrnehmung* (2001), *NatureTech – BIONIK – Das Genie der Natur* (2006), *TimeLimits – Grenzen der Zeit* (2008), *Limits of Light* (2011), and *Planet You – Wir sind Planeten* (2012) were produced. These works constituted the foundational basis for the subsequent establishment of the Science Visualization Lab and were presented at the inaugural edition of the *Figuring the Invisible* conference (Bellano, 2023), where they operated as case studies of immersive TV documentaries, offering concrete material for methodological and theoretical discussion.

Scientific illustrations continue to immerse audiences in the depiction of natural phenomena, as exemplified in works such as *Science Illustration* (Escardó and Wiedemann, 2021). Visual strategies in these illustrations enable complex information to be rendered legible, accessible, and compelling. These works underscore that visualization has not only accompanied but has actively constituted the production and communication of scientific knowledge across historical and contemporary contexts. Similarly, *Science from Sight to Insight* (Gross and Harmon, 2013) emphasizes that visualization has been central to making scientific knowledge intelligible and engaging. Additionally, for instance, Neuroaesthetic studies reinforce this continuity: Researchers (ie Ramachandran and Hirstein, 1999; Gallese and Guerra, 2019) demonstrate that both cinematic and installation-based visualizations engage perceptual, emotional, and empathetic faculties.

Another example shown at the conference's second edition, Peter Galison's science film making is an example for contemporary deepening of this tradition. In works such as *Black Holes: The Edge of All We Know* (2020), which explores the imaging of black holes, he combines live-action footage with animation to visualize abstract concepts and to render the complex, collaborative processes by which scientists construct images from data. His films emphasize points where physicists, experimenters, engineers, and artists interact.

The Science Visualization Lab mirrors and extends these strategies through immersive, interactive installations. For example, the Lab's projects often use 3D visualization, projection mapping, and Augmented Reality to make complex biological, or environmental phenomena tangible. Similar to Galison's animated sequences, the Lab visualizes processes rather than just outcomes, showing the collaborative dimensions of research and prioritize means for audiences to experience science in accurate metaphors.

In the book *Doors to Hidden Worlds—The Power of Visualization in Science, Media, and Art* (Fröschl and Vendl, 2023) a review of the first seven years of the Science Visualization Lab was published. Therein, an expanded discussion on *Computer-Animated Scientific Visualizations* (Fröschl, 2019) was elaborated. The work on the topic of visual effects for documentary films, as well as the recent book presentation led to the invitation as one of the keynote speakers to the conference's second edition *Figuring the Invisible* and chairing a conference track with the title *Science Visualization from Theory to Fiction and Documentary* at the University of Padua. The metaphor to open doors to hidden worlds fit to the main topic of the conference: Visual effects and animations to make invisible elements visible to show them in documentary films. This is also one of the main objectives of the Science Visualization Lab. Starting in the late 1960ies, the founder of the lab, chemist, documentary director and producer Alfred Vendl experimented with *Doors to Reality* (Vendl, 2023) and soon discovered his passion for documentary shots that show something that cannot be seen with the naked eye. A side his career as university professor, he continuously funded new elaborate and expensive visual and special effect shots for his documentary film productions.

In 2016, the Science Visualization Lab was established to advance these initiatives, as the president of the University of Applied Arts Vienna at the time recognized the potential for innovative scholarly inquiry and international visibility for the university. The exploration of human perception through *computer-animated scientific visualizations* has proven valuable in bridging the gap between the arts and sciences.

The Science Visualization Lab has emerged as a hub for such interdisciplinary collaborations, employing advanced scientific imaging techniques in close collaboration with scientific imaging experts to make the microscopic and nanoscopic worlds through authentic visual effects accessible to the public. The visualization of multiple problems humankind faces today is the key to understanding and awareness, therefore the role of visualizations should not be underestimated in addressing global topics such as climate change, genetic engineering, and ecological sustainability. *Computer-animated scientific visualization* represents a hybrid discipline we can describe as a combination of emotional, sensory, subjective, objective, rational, and analytical approaches. Unlike traditional scientific visualizations that prioritize raw data representation, this method allows more creativity, but still with accurate data representation, aesthetic experimentation. The goal is not just to present information but to engage audiences emotionally and intellectually, encouraging even more than conventional scientific visualizations visual thinking.

The lab's methodology integrates authentic scientific imaging with artistic processes. Tools like scanning electron microscopy (SEM), computed tomography (CT), confocal laser scanning microscopy (CLSM), and light microscopy generate high-resolution datasets that are carefully processed into visual models. These visualizations, whether as standalone animation, as sequence in a documentary film or as a part of interactive art installations, serve as *visual doors* to worlds that are not visible for humans otherwise. The presentation at the conference included an overview of relevant projects that were created since the founding of the lab.

2. Project examples and methods of the Science Visualization Lab to make the invisible visible

Productions out of the history of the Science Visualization Lab were chosen as visual examples for making the invisible visible with computer animations and visual effects. The productions shown were excerpts of documentary films and exhibition documentation videos. Several projects highlight the lab's innovative, increasingly immersive and experimental approach. One example is *CRISPR/Cas9-NHEJ: Action in the Nucleus* (2017), a project that visualizes the groundbreaking gene-editing technology CRISPR in colorful detail. Using color-coded animated representations, the project depicts the "dance" of molecular interactions during DNA editing in the nucleus of a cell. The project uses "jelly cloud-like" protein models and philosophical soundscapes to provoke thoughts on the ethical and scientific implications of genetic manipulation. Such facts make attentive recipients admire their own human bodies and the wonder of biological existence. The video was presented in a full-dome environment as a part of the *Future Room* (2017) installation by Ruth Schnell and on several occasions as standalone piece.

Another striking example and the internationally most successful project so far is *NOISE AQUARIUM* (2016) (Figure1) a collaboration with the head of the Art|Sci Center UCLA, Victoria Vesna. For the project, the author transformed tomographically scanned microscopic plankton into immersive, whale-sized computer-animated projections to illustrate the impact of noise and plastic pollution on marine life. Visitors interact in the installation, activating underwater noise and visualizing its effects on plankton. The visitors of the virtual reality interactive installation are invited to metaphorically balance the ecosystem with the impact of their own weight using a custom-made platform as an interaction device. The project's aim is to create a visceral response to the vicious circle to all these destructive techniques related to obtain fossil fuels and humanity's constant noise and plastic pollution of the environment. The project makes not only microscopic plankton species with fascinating shapes visible, but also the tendency to killing our own source of living.

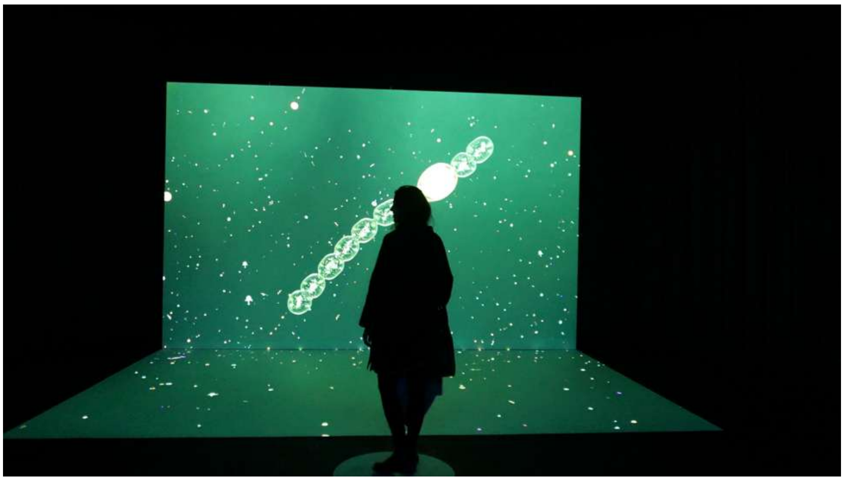

Figure 1. NOISE AQUARIUM in the Barbican Center London (2022). Photo by Martina R. Fröschl.

During the global pandemic of SARS-CoV-2, the project Virus Dice (2020) was created. It uses animations and an interactive board-gameplay performance to explain SARS-CoV-2, its infection pathway, and the probabilistic nature of health and disease. The dice metaphor emphasizes the role of chance and uncertainty, aiming to lower the entry threshold to deal with highly complex topics of biochemistry.

Another project that deals with ecological issues of us humans with our planet is Butterfly}Pieris{Effect (2022) (Figure 2. It highlights the life cycle of the Cabbage White Butterfly (Pieris brassicae) while advocating for biodiversity and that every species, even a pest species is a vital part of the planet's ecosystem. The project challenges the human-centric worldview, encouraging empathy and recognition of the interconnectedness of ecosystems. The art-sci installation tries to question the dichotomy of 'our' (human) gaze and 'their' (insect) point of view.

Figure 2. *Butterfly}Pieris{Effect* (2022) at NTU Singapore. Photo by Martina R. Fröschl.

The creative process and the openness for experimentation is not without challenges, every experiment has no clear outcome and therefore it might need more time, for processing and reflection. The polysemic reception of visualizations depends on the culture in which recipients grew up and are an often underestimated issue (D'Ignazio and Klein, 2020).

The field of cultural studies widely discusses the encoding and decoding of meaning (Ross, 2011), visualizations might be particularly encoded and decoded individually and interpreted subjectively.

Additionally, the environment and the location in which the computer animations and installations are presented have a huge influence on the general reception of the projects. Misinterpretation might happen, like in every form of presentation. However, this ambiguity might also be a strength, allowing various audiences to find personal meaning.

The lab's commitment to experimentation is evident in its openness to *happy accidents* such as rendering errors and glitches, which often reveal new artistic possibilities. These *happened pieces* are celebrated as documents of the creative process, demonstrating the interplay between technology and human creativity.

Looking ahead, the Science Visualization Lab seeks to deepen its interdisciplinary collaborations, blending artistic and scientific processes and skills to inspire curiosity and critical thinking. The lab emphasizes the importance of local and personal engagement, echoing Donna Haraway's call for situated knowledge, we should not think that objectivity is about disembodied detachment (Haraway, 1988).

Therefore, interested artists and researchers of all disciplines are invited to collaborate with the lab. For instance, the collaborative project *Boundaries of Visualization* (2023) (Figure 3) was started within this format including artist and biochemist Mehrta Shirzadian, and computer scientist and artist Peter Mindek. The project discusses advanced imaging techniques in molecular biology, emphasizing how conventional methods produce unclear results without enhanced lighting and data analysis. The project uses data from the innovative MINFLUX microscopy method to create a musical and 3D visualization of protein distributions related to Alzheimer's and Parkinson's diseases in mitochondria. Mitochondria are highlighted for their unique origin through symbiogenesis, where they were absorbed by single-celled organisms to enable complex life. This concept challenges traditional evolutionary models of competition and is creatively explored through collaborative visualizations of human skin.

Figure 3. *Boundaries of Visualization* at Schmiede Hallein 2023 by Mehrta Shirzadian, Peter Mindek, and Martina R. Fröschl. Photo by Martina R. Fröschl

The participation in conferences is a crucial part in starting new topics or new projects in the Science Visualization Lab. The topics and collaboration possibilities are probably almost unlimited. By fostering empathy, embracing ambiguity, and visualizing complexity, the lab hopes to inspire action on global challenges while cultivating a deeper appreciation for the invisible worlds that sustain life.

We might not predict the future but there might be visionary ideas, often formulated long before their time, that should guide humanity. In an era where science often struggles to communicate its value to a skeptical public, the work of the Science Visualization Lab represents a vital bridge, turning abstract data into tangible, emotional, and inspiring experiences.

3. Discussion

Imaging techniques and scientific communication are inherently tied to the tension between objectivity and subjectivity. This interplay influences not only the creation and interpretation of scientific imagery but also the broader context in which scientific knowledge is represented, presented, and translated for general and professional audiences. As art and science converge in these efforts, debates arise concerning the objective nature of these presentations.

Scientific imaging aims to provide accurate, objective representations of phenomena. However, the tools and processes used often involve subjective decisions. For instance, choices regarding color schemes, data thresholds, and image enhancements introduce interpretative layers. These subjective elements are necessary for making abstract or complex data comprehensible but can lead to misconceptions if not carefully managed (Tufte, 1997:24). This carefulness as part of integrity is essential to both scientific and artistic research.

The translation of scientific knowledge into accessible formats involves representational strategies that resonate with a variety of audiences. Traditional methods often favor didactic approaches, presenting facts in an authoritative manner, especially in TV documentary films. However, the increasing use of immersive technologies, such as virtual and augmented reality, challenges these norms, enabling audiences to experience phenomena more directly (Drucker, 2021:13).

In this context, interdisciplinarity emerges as a crucial factor. For example, collaborative efforts between scientists and artists can result in hybrid works that capture both empirical precision and humanistic insight. Such projects redefine how science communicates its narratives, emphasizing emotional and experiential dimensions (Wilson, 2010).

In artistic presentations, the "fourth wall" refers to the implicit barrier between the audience and the creators. Breaking this wall transforms passive observation into active participation, encouraging a more personal connection with the content (Schlütz et al., 2020).

Immersion, to "step inside" scientific phenomena, might democratize knowledge but also challenge perceptions of science as detached or inaccessible. Artistic strategies, such as metaphor and narrative, further enhance these experiences, translating abstract concepts into relatable terms. Art installations as well as TV documentaries can help these democratization approaches.

Proponents of a didactic approach assert that maintaining objectivity is essential for credibility, particularly in a post-truth era where misinformation is an issue. Conversely, advocates for subjective or hybrid methods argue that emotional engagement is critical for motivating action and fostering empathy, especially on complex, large-scale problems (Nisbet, 2009).

The context in which scientific data is presented might significantly shape its impact. A medical imaging study displayed in a clinical journal serves a markedly different purpose than the same data exhibited in a public art installation. Context influences the choice of visual language, the intended narrative, and the expected audience response.

Such initiatives highlight the role of storytelling in scientific communication, demonstrating how context-sensitive approaches can make complex data more accessible and meaningful, especially in embracing pluralism the most complete knowledge comes from synthesizing multiple perspectives, with priority given to local, indigenous, and experiential ways of knowing (D'Ignazio and Klein, 2020).

The interplay of objectivity and subjectivity in imaging and communication challenges traditional paradigms in both science and art. As the metaphorical "fourth wall" dissolves, art-science collaborations adopt innovative strategies to represent humanity's scientific endeavors, sparking debate over their didactic, subjective, or objective nature. Ultimately, the presentation of scientific knowledge must balance precision with accessibility, tailoring its approach to diverse audiences and contexts to maximize its impact.

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ORIGINAL ARTICLE

Languages of Visual Arts: from Venetian Bas-reliefs to Nucleosynthesis, Pulsars, and Beyond

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Abstract: Can researchers use honest, beautiful, and accurate visual strategies to communicate something that is not visible? Especially with phenomena that are just theoretical concepts, or that are too small or too distant in time or space. Art related to science can be much more than divulgation (in the sense of conveying "second-hand", or "cold", research content). Art can bring the general public straight into the core of state-of-the-art research; in some respects, art can become first-hand research in itself (but, at the same time, verge on the edge of fiction), when striving to convey something that science is still trying to define, or to evoke things from an almost obliterated past. We present here some considerations on the above themes, from two different points of view: by an art-historical researcher and art curator, and by an artist active in science communication. In the first part of this article, Gloria Vallese describes the experience of two art and science exhibitions organized by the Accademia di Belle Arti in Venice, Italy. One of the artworks featured was by Alessia Lorenzi, the other author of this article; her experience in that context, together with other considerations from inside her current scientific visualization practice, is analyzed in the second part of this text. The second part of this article will cover some critical points and strengths of visual communication in science applied to the invisible. Practical examples and solutions will be provided to address the critical points and to reflect on opportunities and responsibilities in these fields.

Keywords: Edutainment, science communication, Venice St. Mark's Basilica main portal, public engagement, anima-tion, astronomical knowledge in 13th-century Venice, imagery in nuclear physics, immersive experiences, outreach

1. Introduction (GV)

Stars and Travels (2016 and 2021) was an art and science exhibition in two parts, ideated by Alessia Lorenzi (second author of this text), and entirely created by professors and students of the Accademia di Belle Arti di Venezia.

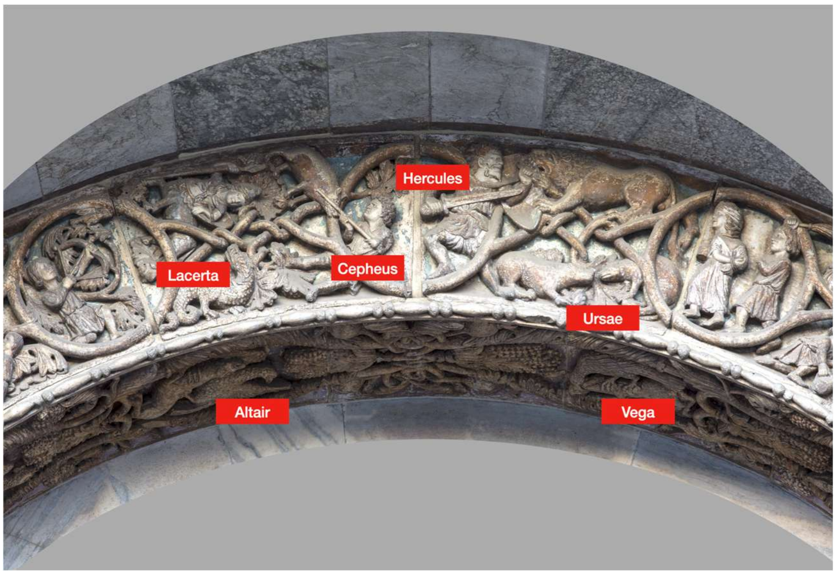

Figure 1. Venice, St. Mark's Basilica, main portal, detail of the lesser archivolt: some of the stars and constellations first observed in 2014. The original polychrome and metallic applications are lost. HD photo composition by students Riccardo Bortolotti and Stefano Leoni for the exhibition *Stars and Travels*, 2016.

It stemmed from the discovery that the sculpted archivolts of the main portal of St. Mark's Basilica in Venice (half of the 13th century), that for a long time were believed to be merely ornamental, contain an early, extraordinary sculptural representation of the celestial sphere: they depict stars and constellations, disposed not randomly, but as to compose a soli-lunar calendar. (Vallese 2014; 2015; 2017). Stars and constellations are represented not only according to the Western iconography, but to a vast range of visual languages from Northern Europe to India and China: this in connection with long-distance travels, which were the basis of the Venetian mercantile social system in that age.

Figure 2. Stars and Travels, 2016 at the Magazzino del Sale 3, exhibition venue of the Accademia di Belle Arti di Venezia. Photo: Shovupa Ainur Rahman, 2016.

The main portal of St. Mark's is daily under the eye of the Venetians and of thousands of visitors from all over the world, yet it had never been actually 'seen', because, in its present condition, it cannot be: the original polychromies which once covered the bas-reliefs, helping the observer to distinguish the figures and their interactions from several meters below, has now gone, exposing the uniform yellow-grey of the underlying marble (Lazzarini 1995; Piana 1995). Consequently, the human and animal interactions represented high on the portal archivolts have become hardly readable from ground level. The first objective of the Stars and Travels exhibition project, therefore, was to bring the bar reliefs at the level of the visitors' eye and to make them 'visible' again, in various ways. The first step was a series of high-definition photographs expressly taken by an équipe of students and professors of the Accademia di Belle Arti di Venezia, which organized the exhibition, and hosted it in its institutional venue, the Magazzino del Sale 3. Each portion of the bas-relief could be observed for the first time in close-up and at length; the panels with the enlarged HD photos were accompanied by illustrations from ancient manuscripts, celestial maps, photographs of the night sky, everything that made the stars and constellations recognizable in the tiny, bizarre figures of the bas-reliefs. The walls of the venue were painted in dark blue, and the light modulated as to evoke the ambience of the night and of the starry sky, to keep this idea constantly in the background. As the title Stars and Travels suggests, in the 13th century the travellers practiced celestial navigation, i.e., oriented themselves by the stars; the deep astronomical knowledge exhibited by St. Mark's portal was directly connected with the long-distance commercial travels which were at the basis of the Venetian economy and politics in that age. Moreover, along the route of the visitor were placed original works of art, created by the students of the Accademia di Belle Arti di Venezia, with the intent of suggesting vividly, and with great and immediate sensorial impact, some of the most complex ideas underlying the research.

2. Art and ongoing research: a frontier (GV)

Not many theoretical discussions about art installations for new museum narratives were available in 2016, at the time of the *first Stars and Travels* exhibition, except for the groundbreaking activity of the Studio Azzurro group (Studio Azzurro 2011; 2016).

Figure 3. Shovupa Ainur Rahman and John Volpato, Phainomena, interactive installation, 2016. Photo: Shovupa Ainur Rahman.

In the last decade, the experiences involving art in museum narratives have quickly multiplied; and so have the analyses, the comparisons, the critical evaluations (Mandarano, 2019).

The consensus is now that for the general public the approach to scientific content through art is not, and cannot be, as minute and detailed as through the reading of a technical text. What art can do is rather to ignite interest and involvement, moving the public to further spontaneous exploration. This, in turn, increases general awareness, which can make a crucial difference, not least in terms of political choices and financial decisions.

On the other hand, art can go beyond the simple divulgation, meant as the sharing of already assessed contents. It can bring the general public straight in the middle of very new paths of investigation. Yet, this poses some problems. To share with the general public ongoing research, means to share results that are still partial, hypothetical, and/or not yet completely verified. Is this advisable? Is it ethically correct? The answer is very much a matter of choice. As an art-historical researcher and an art curator, I am for bringing the general public, as far as possible, where the research is still ongoing. This, because the alternative does not appear very safe either. Should we wait, for example, that the debate on global warming is settled, to involve the public?

And then, there is another task that the artist can do in connection with science: with his visualizations, he can manipulate already known symbols in an original way, to anticipate the scientist's vision, to push his effort for a mental synthesis one step forward. Chris Impey describes vividly the interaction between art, science, and science fiction, in his history of the notion of 'black hole' (Impey 2023).

3. Viaggi riflessi (2021), installation by Alessia Lorenzi (GV)

At the time of the second *Stars and Travels* exhibition (2021), our ongoing art-historical investigation had evidenced that originally the bas-reliefs of St. Mark's portal were not only clad in polychromies but had also metallic asterisks of different sizes applied to the stone, to highlight the stars and constellations. These metallic applications are no longer present, as the surface has been eroded over the centuries by exposure to atmospheric phenomena. Yet, where they once stood, tiny regular patterns of holes on the stone are still visible. Hi-res photographs treated with experimental software, such as D-Stretch, can bring these tiny holes back into clear visibility (Vallese, Campanile, 2021). Every day, at dusk, there was a moment in which the stone carvings became invisible in the increasing darkness, but the metallic applications would have glistened a little longer, evidencing the outline of the constellations; at dawn, the effect would repeat in reverse.

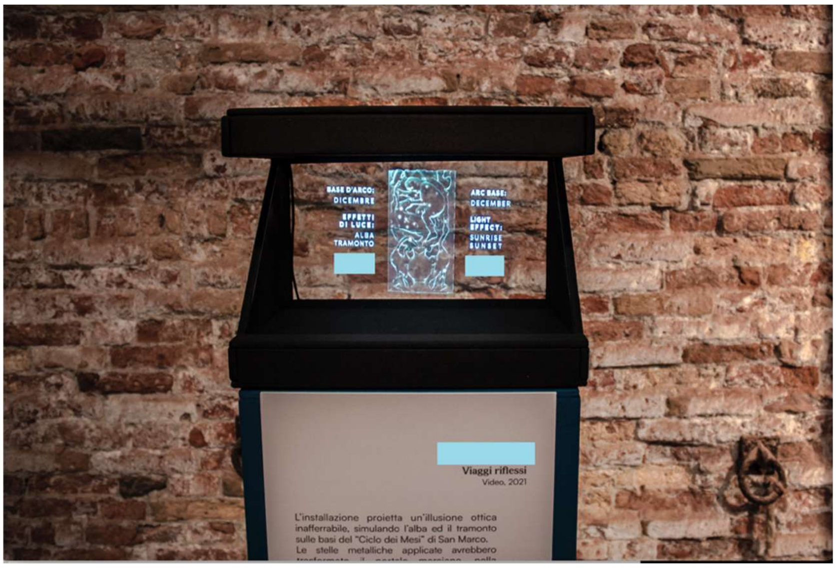

Figure 4. Alessia Lorenzi, *Viaggi Riflessi*, installation for the exhibition *Stars and Travels* 2021. Own Work. Photo: by the author.

In her installation *Viaggi riflessi*, Lorenzi created a holographic box with an animation movie, in which the public actually could see the bas-reliefs fading into dark, leaving place to the shining outlines of the constellations, and vice versa (Lorenzi, 2021).

Thanks to this artwork, what would have been only a description on a written page became alive and present for the exhibition visitors, impacting them in a deeply different way. The ancient glimmer on St. Mark's facade was revived in a vivid sensorial experience, which caught also its delicate, transient nature: the visitor was invited to 'touch' the light effect, inserting their hand in the opening of the holobox, thus experiencing (literally, 'grasping'), the immateriality of the figures drawn by the quickly fading ray light.

It is important to note, however, that the maps of the stars once present on the bas-reliefs were at the time (and still are) under construction; their completion will probably take many more years from now. The star maps used for Lorenzi's holograms were preliminary, which means they could prove incomplete or even incorrect in some details in the future. Does this make our operation wrong, deceptive, or ethically incorrect? Again, personally, I think not. At that time (2021), we chose the option to share with the general public the basic idea, i.e., the rediscovery of the metallic outlines of the constellations on the bas-reliefs, rather than to wait many more years for an accurate and detailed reconstruction of the star maps.

The experience of *Viaggi riflessi* within the *Stars and Travels* 2021 exhibition was a step on the path that Lorenzi is now pursuing, in a most interesting and crucial field, art applied to the representation of something that is not visible: either because science is still trying to grasp it, or because it can be represented only in symbolical way, since, being infinitesimally little, it is not, and never will be, accessible to the human eye.

Figure 5. Viaggi riflessi: two stills from the holographic video. Own work.
Photo: by the author.

4. Visual communication and data storytelling in science (AL)

There are many ways of transposing science into a visual message. The point of departure could just be a huge amount of raw data stored in a common csv or excel file. Experts and researchers might understand a sequence of recorded data, but in most cases, this is not enough to communicate hypotheses and to read the results in a clear and effective way.

Researchers in nuclear physics use graphs to read data; this method allows them to see beyond the visible. The fact that researchers themselves need specific visualization methods to be able to read what they are doing highlights how much visual communication and its architecture are of the essence in this field. There are many different types of charts: bar chart, line graph, tree map chart, scatter plot, waterfall chart, bubble chart, field line diagrams, and others. A specific graphical representation can influence the reading of the data, and this means that it can also influence how researchers think about the phenomenon investigated by themselves. A graph imposes a specific point of view of the phenomenon and also requires the ability to compare certain values represented in the chart (Padilla, Creem Regehr, Hegarty et al., 2018).

The communication possibilities expand incredibly when, from the internal communication and data visualization methods used during research, we move on to external communication, to public engagement (Pitrelli, 2003). The general public may not be familiar with the above-mentioned visual ways of reading data. Some graphs, certainly effective in the world of research, are difficult to understand in other contexts.

For these reasons, to explain scientific data to the general public, science communicators use other types of languages derived from common symbolic systems, including the use of metaphors recalling familiar concepts.

This is very evident when talking to a general audience: spoken language has a great influence in the way in which we read reality, but visual language can reach both the researchers and the general public (Lupi, 2017).

There are many cases of the influence on reality through language: reading errors, interpretation errors, and a wide variety of biases related to perception (for example cognitive biases about the comparison of values, but also psychological and social biases like the linguistic intergroup bias). An in-depth knowledge of perception processes can help communicators in designing more effective tools and communication strategies.

Concerning internal communication within the research groups, there are conventions established in the academic environment. Learning to read and use a certain type of graph can require study, so it is realistic to think that most of these charts are not suitable for the general public.

There are cognitive studies regarding the ease of reading certain graphs rather than others (Vandemeulebroecke, Baillie, Margolskee et al., 2019; Cleveland, McGill, 1948). Concerning the general public, the visual possibilities are much wider, even if new challenges arise correlated to the need to balance between over-simplification and the accuracy of complex information. Rather than using specific high-accuracy data tables and graphs, researchers can use intuitive pictures and symbols inserted inside the graphs (an example: the bars of a chart-bar could be replaced with stacks of coins to indicate investments over the years. This solution could be quite intuitive and attractive, and suitable for social media, both as motion graphics animations, and as a static image). Such graphs, however, can be so inaccurate that they could be considered rather as mere illustrations inspired by the original graph. Their purpose, on the other hand, is not to present the entire data set, but rather to suggest what the researchers want to communicate.

Data storytelling may be meant to tell or represent a phenomenon with data, or just starting from data (Manovich, 2002). A data storyteller must make decisions to design solutions that are creative but also useful for the purpose: if the purpose is to accurately present a set of data, the creative solution will probably be a more complex and more conventional communication system; otherwise, the risk is to fall into oversimplification or to increase the probability of interpretation errors. Sacrificing accuracy for engagement is as risky as producing content that is rich in technical content, but too complex or boring to be understood and consequently remembered. Too difficult descriptions can push people away and not be listened to; on the other hand, simplistic descriptions can even undermine credibility. Trust in science and institutions is also influenced by how the information that they produce is presented (Gregory, Miller, 1998). Despite it all, memorable experiences and engaging explanations are not necessarily condemned to oversimplification and unreliability; finding the balance for the right target in the right context appears to be the core of the challenge for scientific communicators.

To sum up, there can be different types of data representation: data tables, exact scientific graphs, accurate graphs with a simple visual language, data storytelling, and art in its various forms (which can become completely new artworks inspired by the original data, and by the considerations that can be drawn from that data) (Mancuso, 2020). It is important to clarify to the public that inaccurate kinds of engaging content cannot replace the original data, because the information could be oversimplified. Clarity and honesty not only determine credibility but also the effectiveness of communication projects, by reducing the effect of cognitive biases.

5. Engagement, accuracy, misleading communications (AL)

The style chosen for a communication project can make concepts appear more complicated (or simpler) than they actually are. Communicators can decide whether to create accurate or approximate content based on their purpose (it usually depends on the context and on the target audience). There are delicate balances between accuracy and approximation (in favour of engagement) that cannot coexist in the same project; therefore it is necessary to discard one maintaining honesty and allow the other to find a dedicated space in another place (for example a QR code with the sources, explanations and insights or a volunteer present during an event to answer questions). A well-known example of a balance difficult to find is the representation of the Solar System: very often, even in books used in schools, the planets are represented with the wrong scale and wrong distances (Masters, Park Rogers, Vanashri, 2011): this because the illustrations would result ugly, with the planets appearing just like tiny dots very distant from each other (the mass of the Sun is the 99.9% of the mass of the Solar System, the Earth is only about 0.1% of the mass that is left). There are scientifically correct methods, such as the use of a logarithmic scale to represent the planets with an aesthetically good aspect yet maintaining the correct scale and distance; but this mathematical method can cause many errors of perception. The logarithmic scale is not intuitive for us humans; in this way, the students would remember the planets as much bigger and much closer than they actually are (even inserting a ruler into your drawing or animation, to make the use of the logarithmic scale evident). In this case, an appropriate solution could be to place a pleasurable image on a logarithmic scale next to an image in the real scale (with distant tiny planets instead of huge ones). This is an example of how a problem can hide its solution inside: this honest and clear solution would produce amazement, which in turn would help to memorize the concept. The problem of representing quantities of this scale (astronomical distances and sizes), is also typical of nuclear physics and quantum science. Atom pictures can also cause several misunderstandings (Kaya, 2023); one of these concerns the atomic void (which is considered by many chemists to be a kind of hoax). In numerous science communication contents, atoms appear "empty", due to how they are represented (the volume of the atomic nucleus is only 0.01% of the atom). The question becomes quite complicated if we think about the laws of quantum mechanics and the dual nature of particles: it appears very difficult to identify a single way of representing all these concepts in a simple and engaging way. Even just talking about volume: the volume of the atomic nucleus is the region of space where all the nuclear charge and neutrons are substantially enclosed, the electron cloud is the region of space where there is a high probability of finding electrons. "Volume" can concern different things (specific physical properties and probabilities); but actually we are talking here about regions of space. The scheme of an atom, even if it may seem so usual and easy, is a very difficult thing to design without oversimplifications (Türk, Nur Tüzün, 2018; Albanese, Vicentini, 1997).

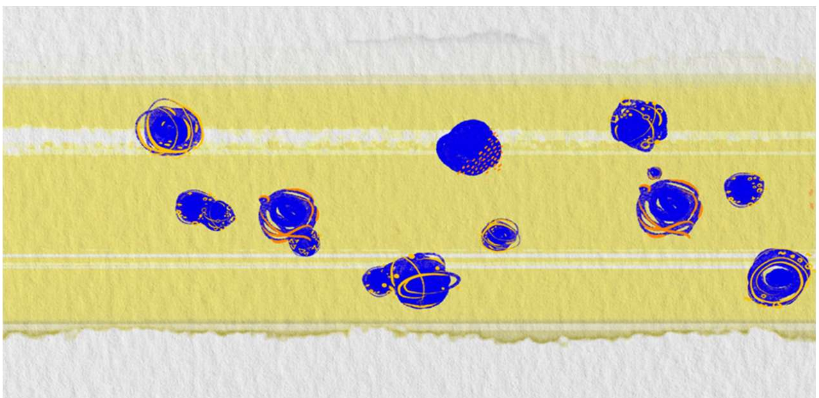

Figure 6. INFN-LNL Introductory Video, 2023. Still from the video. Own work.

There are many images (whether photographs, or graphical interpretations of data) that come directly from scientific instruments; and yet, although they may be considered real, and so rich in detail that they can be studied to discover new physical laws, they can generate misunderstandings. It is not enough to see something “real” to read it correctly (in this article there will be an example about photos of atoms and common misconceptions about atomic structure).

Although even "real" images can lead to misunderstandings, it may be urgent and necessary today, in the information age (or in the generative age), to teach how to distinguish between photos, simulation, interpretation and artwork inspired by a scientific concept (for science engagement purposes, or science fiction). This urgency arises from the fact that all these areas and contents, different from each other, share the same visual languages and can be mistakenly exchanged, causing problems in trust, and misunderstandings (completely different things that speak the same language, blurring the boundaries of contexts). It is also useful to learn about cognitive biases and to develop good digital literacy, in this way it is easier to avoid the spread of fake news, and to reduce information pollution. Communicators can play an important role in teaching this, by highlighting what they mean by clarity and honesty when designing scientific content for the public (Orecchia, Preatoni, 2022).

Generative AI will produce further pollution. Not only this becomes a problem when searching for information a polluted web; it will also become a problem for the generators themselves, as a sort of death spiral that causes the generation of nonsensical AI contents. Communicators could make a difference, by raising public awareness on this topic, and by teaching how to recognize the reliable sources. The public should get used to scrutinize their sources, to be informed about the type of content they are seeing.

At the beginning of the generative era, since generators have become so popular and so easy to use, the generated images can represent our common idea of a certain topic (but only if the dataset used for the training has been sufficiently large and varied). To visualize the common visual idea that people have about atoms, black holes and dinosaurs, a researcher could simply ask some AI to generate images of them. The result might seem very familiar to most people, nevertheless those images derive mostly from fictional images, from art and simulations. The web is so full of images of black holes and dinosaurs that even an image generator could create new ones, and they would be recognizable as such, even if no one saw them in real life. AI will only reinforce these visual images of invisible things, but it can do so because these images were already common in our imagination. The fact that people believe them to be true, may indicate a failure of science communicators to clarify how and why these pictures were made. A common example is the use of the term "photo" for scientific images that are not actually photos. Researchers and communicators should clarify these terms or use different terms because they convey important concepts about the identity of the content. The term "photo", like the term "simulation", can generate presumptions, and it should be accompanied by a certain explanation. Researchers have been using certain images of dinosaurs for so long that it would be difficult to imagine them being different. Movies have certainly contributed extensively to the creation of the collective imaginary about them, but these images have long been confirmed by scientific communication projects. The language of cinema and the language of science can collaborate by exchanging suggestions and images, the important thing is to help to keep truth separate from imagination. Just as a dinosaur can ‘seem’ real, an effect of general relativity in the distortion of space-time can seem like cinematic absurdity, conveying distrust to the scientific world that supports it. It's not the job of science fiction to explain science accurately. Like other film genres, science fiction movies can take advantage of technologies to make their footage realistic or even hyper realistic. These seductive images will certainly continue to compete with images that come from the scientific world (it means that imagination and fake news may seem more interesting than real images and, in a certain sense, more worthy of attention from a general public); yet, it would be simplistic to think of limiting art and creativity, in the field of science communication, imposing a range of homogeneous styles reserved for scientific communication (in order to visually distinguish scientific content from one that is the product of the imagination).

Real science pictures are usually rich in information. Artistic interpretations may visually convey ideas and make us feel something, but we can't discover and measure reality based on them in a scientific and objective way.

We could say that artistic interpretations are "empty" due to the lack of information about reality (but we can conventionally say this only from this perspective and for this specific purpose, without underestimating the epistemology related to art and philosophy).

A simple way to explain the difference between an image from the scientific world and a fictional artwork based on the same topic could be spectroscopy.

Spectroscopy allows scientists to analyse "light", unveiling valuable information about the composition, the temperature, the velocity of celestial bodies, and the identity of particular atomic nuclei.

Redshift and Blueshift are very well-known examples from astrophysics (the increase or decrease in the frequency of electromagnetic radiation). This data about the frequency and energy of photons, visible using scientific equipment, can indicate to astronomers that a star is moving away (it appears red because its light is shifting to lower frequencies on the colour spectrum), or approaching (tends to blue). This effect is also called the Doppler Effect (Schilling, 2023), which is what we experience when an ambulance passes near us, and the sound perceived during its approach is different than when it is moving away). Colour, in this case, has nothing to do with style, with a personal subjective choice dictated by taste or emotion; it is the necessary result of a process, and allows researchers to read reality objectively.

The second example concerns nuclear physics applied to cultural heritage: it is possible to visually distinguish different materials by reading the light via spectroscopy; in this way, it is also possible to carry out dating and discover any false findings (Lo Giudice, Re, Angelici et al., 2017).

These data and the types of images we produce through them allow us to delve into physical phenomena with scientific rigor. This is not valid for artistic interpretations and for excessive simplifications.

It is important to note that an accurate simulation and an artistic work can appear similar to reality, indeed, sometimes they can seem more real than the original data that was collected in the lab, as often happens with images of celestial bodies and of extreme physical phenomena. It's a difficult competition to win on the aesthetic level: images of a truly scientific nature are not created to entertain. It is now known that the idea of realism is a convention and the culture we have regarding these areas can be refined, allowing more effective cognitive distinctions regarding the meaning and the nature of what is observed (Bate, 2017).

To facilitate the distinction between different types of visual solutions, a research organisation could use this distinction as a standard for their communication projects: original data usable for research purposes, accurate simulations intended as predictions based on theories, content designed to communicate something, and artistic interpretations.

In this four-level simplification, the original data could consist of raw data, tables, graphs, if it is accurate enough to be usable to discover or understand something with scientific rigor. Contents designed as a product created with the aim of explaining something in a certain way can hide many risks, so it is good to specify what it is and how it was done. For example, a project could be oversimplified and therefore could require support material for in-depth analysis, this type of material can be exploited for unpredictable purposes, such as the generation of plausible fake news through decontextualization, thanks to the interpretability levels. On the other hand, works of art can be completely free from the purposes and responsibilities of the communicators, just promoting interest and involvement.

6. Case studies: Visual solutions to show the invisible. (AL)

New Media Art, interactive installations, and science documentaries can effectively bridge the gap between technical information and captivating communication designed for the general public.

One of the key principles in creating these visual solutions is striving for a balanced subtlety between accuracy and engagement. As mentioned earlier, trading off accuracy for engagement or vice versa has risks built into it, in this case perhaps resulting in oversimplification, or in lack of comprehension and remembrance. Thus, communicators are tasked with making deliberate creative choices, often with the use of symbolic systems and metaphors referring to known notions, thus however holding true to scientific intent. In an age of information overload, and of artificial intelligence capable of generating both images and texts, it is essential that these technologies also encourage truthfulness and clarity. What this means is making it clear to the public how to distinguish among photographs, simulations, interpretations, and works of art based on scientific phenomena, thus encouraging digital literacy as well as preventing disinformation. This openness and transparency might be necessary in building trust in science and its institutions in this society of information (increasingly characterized by digital information pollution).

These following case studies –*Nucleosynthesis VR Experience*, *Pulsars, A Tale of Cosmic Clocks*, *INFN-LNL Introductory Video*, and *Viaggi Riflessi* – are practical demonstrations of the different visual styles in use. All the projects demonstrate creative ways of rendering the invisible visible, presenting difficult-to-understand scientific substance in a form that is both accessible and engaging, and gets to work on the precarious balance between scientific accuracy and artistic freedom.

Nucleosynthesis VR Experience is an interactive VR project which has been used for several years by the Legnaro National Laboratory of the National Institute of Nuclear Physics (INFN-LNL). The user, taking on the role of a researcher, embarks on a fantastic and metaphorical journey in a virtual world (literally virtual and fantastic: there is a “virtualization” of the user at the starting scene and teleportation between various scenarios). In this fantastical voyage, users encounter reconstructions of real concepts, places, and experimental tools installed at INFN-LNL. It is an example of artistic and extreme blend of reality, fiction, and wonder. It is so extreme, metaphorical and science-fiction-like that it declares itself to be a world of false engaging images blended with the truth. The purpose of this experience is to allow general users to familiarize with the topics of particle astrophysics and nuclear physics by acting on people's intrinsic motivations.

Thanks to intrinsic motivation, a student can be much more inclined to search for more information, to ask questions, and to remember concepts linked to exciting memories (Csikszentmihalyi, 2014). This Virtual Reality experience can be enjoyed during local outreach events where a researcher can answer visitors' questions or encourage them to reflect on what they have seen.

To carry out this project, a lot of User Experience Design and User Interface Design work was done to make the experience comfortable and prevent episodes of motion sickness. Furthermore, careful planning was made for the symbolic systems and to choose the style used in this project.

The main scene consists of a nuclear physics experiment. In the daily life of nuclear physics laboratories these phenomena are not visible to the human eyes, and the experimental rooms are not accessible during experiments with accelerated particle beams. These phenomena are often not visible even with special cameras. Physicists observe graphs and study data to understand what is happening during the experiment. In this VR experience, however, the users find themselves very small and located inside a real particle detector (AGATA). Witness fireworks represent particle collisions. When the fireworks disappear, 3D information on the passage of photons appear (to explain a feature of this specific scientific instrument that consists in advanced tracking) and a constellation of formulas surrounds the user, symbolizing the work of the researchers who think and interpret these phenomena.

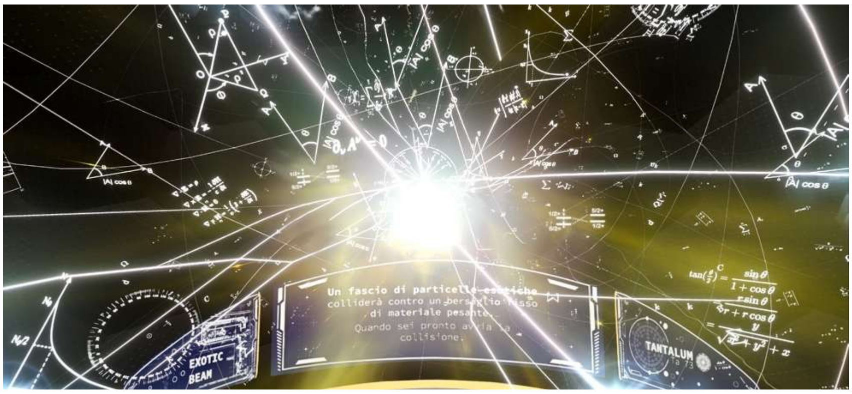

Figure 7. Nucleosynthesis VR Experience, 2021. Still of the collision event. Own work.

It would be completely incorrect to represent a nuclear physics experiment in this way, as an explosion of sparkling fireworks or as formulas suspended in the air like ghosts. But the artistic nature of this project is so evident that the metaphorical exaggerations are made acceptable and useful. One of the scenes in this VR experience even features a sun with a lock (as if it were a door), to represent the mystery of stellar nucleosynthesis that can be unlocked with the data recorded during the experiments. Users should understand that stars do not have locks, but it is still very exciting to see your key finally reach the sun.

The second example, *Pulsars, A Tale of Cosmic Clocks*, produced by Virtual Immersions in Science (VIS) and 15L FILMS, is a short film aimed at young viewers that combines live action and animation: Alma, a young girl, embarks on an unexpected journey into space, led by a mysterious scientist. What was supposed to be a simple trip to the museum turns into her life-changing adventure. At the centre of the journey there are pulsar stars and the surprising story of the young scientist that discovered them. The animation style is very far from realistic representations of astronomical phenomena: it is stylized but full of careful details such as lively brushstrokes, but above all it is scientifically accurate.

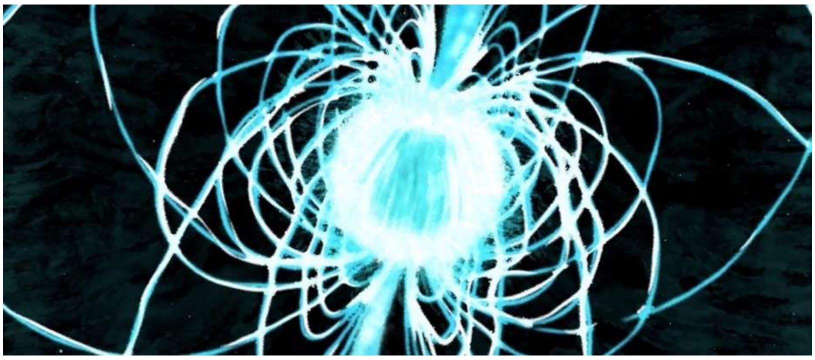

Figure 8. Pulsars, A Tale of Cosmic Clocks, 2022. Still from the film. Own work.

'Pulsar is an unprecedented film project that brings together storytellers and scientists.

We asked ourselves, how can we tell a captivating story about the cosmos without losing sight of the accuracy of scientific information? The result is a short film aimed at young viewers that combines live action and animation.

We also wanted to deal with the issue of girls' access to the study of science and the gregarious role that women still have in the sector today. It seems important to us to state that today any young person can take an interest in astrophysics.

Cinema can also be an artistic and informative tool at the same time.'

(Bruna, Guerra, 2022: *www.vis-sns.com/products/video/pulsars-a-tale-of-cosmic-clocks/*)

This movie is the winner at the Ciencia en Acción 2022 and at the Raw Science Film Festival 2022. Products of this kind are achievable thanks to teamwork, involving experts, artists and scientists. A multidisciplinary team can encourage the adoption of different points of view and the exploration of wider problem spaces to design solutions suitable for the general public.

The third example, *INFN-LNL Introductory Video*, is a short documentary video that describes the history and activities of the National Laboratories of Legnaro of the National Institute for Nuclear Physics (INFN-LNL). This video features a mix of stylized and abstract animations, special effects with holographic overlays of 3D models (from original CAD files) on real footage, collages of photos, motion graphics and unaltered normal shots.

The presentations of the Laboratory in this video include the use of 3D maps of the floor plans and sectional views, which, though impossible in reality, aid in understanding the complexity of the scientific apparatus often interconnected underground between different buildings.

In some scenes, the animations are drawn with a pencil line and painted on paper to give the idea of being something simple to understand, as if it were a product suitable for an audience of very young people.

Both the paper-looking animations and the holographic special effects are drawn in a way not to be misunderstood: the drawn illustrations can be overly simplified, which is what you can expect from a drawing that seems more artistic than scientific. The 3D technical CAD models are inserted into the videos with holographic precise and detailed style because these contents are real, they are simply inserted into a different context: instead of being on the PC screens they are inserted on the real images to allow the public to see what is inside the objects. This style is in clear visual contrast with the paper style and is also in contrast in terms of meaning to avoid misunderstandings and to strengthen communication.

Animation was used with the purpose to simplify complex concepts about nuclear physics and to encourage the public to listen to explanations of these complex topics.

The last example is *Viaggi Riflessi, holograms and simulations,* an installation exhibited in *Stars and Travels* 2021 in Venice. The installation consists of a pair of looping videos presenting a 3D simulation with light effects based on photogrammetry of two bas-reliefs from the Cycle of the Months in the St. Mark's Basilica in Venice. The bas-reliefs have been virtually enhanced with metallic stars. The simulation showcases holograms of the relief panels with the applied stars. The bas-relief with the stars becomes a starry sky revealing the corresponding constellations. Artistic concept for a hypothesis in archeoastronomy.

In this case the holograms represent something impalpable: a theory, a virtual simulation. In fact, the artistic installation envisages that someone can try to touch these transparent 3D models by crossing them with their hand, because even if this theory on metallic stars was real today it would not be palpable as we would like to do.

The simulation may still seem real enough to give a good idea of what this theory predicts but, to be honest, it does not show it in a too real or too concrete way, exploiting this problem in a poetic artistic solution that allows you to reflect on the topic.

Reflection is a key concept in this project because these metallic stars, inserted into the bas-reliefs, could have shown the sparkle of the star map during sunrise and sunset, when the sun reflects its first and last light in a particular way onto the Cycle of the Months of the Basilica of San Marco.

7. Conclusions (AL)

To create the holograms for *Viaggi Riflessi* there was a style design phase that attempted to create something accurate but at the same time responsible. It is not obligatory, today, to set linguistic or symbolic limits when representing scientific concepts. There are conventions that can be overcome. Communication teams often do not consider the impact that misinterpretations could cause and how to prevent them.

It is difficult to compete with the aesthetics of fake images that have potentially no limits, and that are designed to capture people's attention.

Speaking of aesthetic advantages and engagement, it may be necessary to consider that cinematographic visuals, that can be extremely powerful and captivating, are suitable for various contexts, not just for entertainment contents that are competing against scientific images making them more boring and confusing the meanings. A long time has passed since the term edutainment was coined to classify those entertainment products suitable to education (Zhu Feiyue, 2022) but the old challenges still remain open: balancing accuracy and engagement; the coexistence of competing contents made with similar languages but used by different domains about the same topics; the confusion and misunderstandings that can arise from blending boundaries and decontextualization.

Today there are many visual competitors to science products and many bad sources of information. Artificial intelligence, fast information designed to work with short attention spans, pictures inflation, fake news, unethical neuromarketing, hyper realistic contents for entertainment are competing against authentic scientific visual contents (Szabo, 2014; Quaranta, 2020). How should we do good visual communication for science? Should we establish guidelines to clarify meanings and to moderate expectations regarding certain visual content? Should we divide the different domains that deal with the same topics, clearly differentiating them in style even with science fiction?

An effective solution could be to define a multi-level framework to be specified every time to distinguish the nature of the image shared, including the purpose for which it was created and where to find the sources. A research organization could use this framework as a standard for their communication projects: original data usable for research purposes, accurate simulations intended as predictions based on theories, content designed to communicate something, artistic interpretations. It is not just about freeing journalists from this responsibility by applying labels, it's about providing tools to distinguish media content and purposes and, at the same time, training people on train to distinguish and evaluate what they are seeing to avoid unexpected exploitation and misunderstandings.

In the absence of a clear and unequivocal framework and in the absence of a common culture in which people expect to be informed about what is proposed to them (as has happened in Europe with information regarding privacy and as is happening with the products generated by generative artificial intelligence), it is still possible to create honest but at the same time attractive, exciting and effective communication projects, considering the complexity and importance of this topic already in the very early planning stages.

This arises from the urgency of teaching people to distinguish types of images from each other even when they may seem very similar and support them in seeking clarification regarding what they are seeing. This strategy would also lighten the work of debunkers and allow this kind of culture to flourish in support of the digital literacy that is necessary today to live in the information society and web 2.0, a collaborative web that can increase the amount of knowledge available but also pollute and confuse information. Science communicators and researchers operate in this information system, and they can make a difference in the evolution of information pollution by supporting their audience and, circularly, themselves.

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ORIGINAL ARTICLE

The Wonderful, Fluorescent, Massive World of Tiny Invisible Things: Creating transformative science stories for children. A collaboration between science and creative arts

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Abstract: This article is a case study of a creative practice research project which aims to address the lack of representative science content for children by creating animated hybrid documentary science stories for ages 10-12 featuring a diversity of scientists (especially women) as protagonists which can in turn influence STEM career choices. The case study is in two parts, first the development and research methodology of the pilot and second, the plans for a larger-scale research project. The project expects to generate new knowledge pioneering a novel model of science communication translating complex contemporary scientific research visual data into engaging animated narratives, enhancing diversity and scientific visual literacy for children. Outcomes are an education-focused series and associated teaching assets for broadcast and use in the classroom.

Keywords: Science; Animation; Documentary; Children; Hybrid; STEM

1. Introduction

This creative practice research project brought together award-winning filmmakers and animators and some of Australia's most ground-breaking research scientists working within the Microbial Imaging Facility (MIF) at the University of Technology, Sydney (UTS). The work of the scientists involves high-resolution 3D imaging of micro-organisms, of reef coral fluorescent tissues, and of spheroids, organoids and organ-on-a-chip systems that mimic human tissues. These microscopic organisms, cells and engineered miniature tissues – while scientifically world changing - remain to the public, both unknown and unseen.

The case study is in two parts. The first part focuses on the research, development, presentation and an evaluation of the pilot and the second part details research plans for a larger scale project.

2. Background

The origin of this creative practice research enterprise emerged out of a cross-faculty grant opportunity between academics from Media Arts and Production and Animation Production in the Faculty of Arts and Social Science and MIF scientists working in the Faculties of Science (FoS) and Engineering and IT (FEIT) at the University of Technology, Sydney (UTS). In addition to the academic team, the project involved a dozen creative industry-based practitioners, as well as schoolteachers and students, working to co-design a unique and transformative way of communicating science to children.

The pilot project set out to explore how combining hybrid documentary techniques and 2D and 3D animation could bring to life the imaging data generated by research scientists using advanced microscopy technology. The goal was to craft compelling narratives about the extraordinary innovations of contemporary Australian science that could captivate the public's attention, especially young people and particularly young women, to inspire their interest in Australian Science and encourage them to consider careers in STEM (Science, Technology, Engineering, Mathematics) fields. Collaboratively, we created a research driven, user tested, pilot as the proof of concept for a suite of innovative education audio-visual content with learning assets for STEM 3 learners (10-12) about the 'invisible' world of microscopy, using a hybrid documentary framework that combined three elements: narrative, animation, and anthropomorphisation in inventive ways. This was based on evidence that narrative was more effective than information-only approaches in communicating science, and that character animation, performance and world-building were particularly impactful to children. Uniquely, we used anthropomorphisation to give real scientists the form of the phenomena they were researching. For example, Dr Anya Salih took the form of a fluorescent coral protein (Figure 1) and Dr Yan Liao that of an archaea (Figure 2). Using this tripartite hybrid framework, we were able to illuminate the fascinating world of microscopy – without which, as former chief scientist of Australia, Dr Alan Finkel, said, "there is no modern science" (Microscopy Australia, 2018). Working with scientists who use advanced microscopes and their imaging-data to tackle fundamental questions (e.g. about the origin of life) and real-world problems (from cancer to climate change), we sought to make this research accessible to children, to showcase the diversity of scientists undertaking it, and to reveal the often-unrecognised passion for inquiry that drives them.

2.1. Under-representation of women in STEM

Both the pilot and the anticipated larger scale project address a significant problem and an important gap in knowledge. The under-representation of women in STEM fields is an ongoing problem in Australia. In 2024 there were just 15% in STEM-qualified occupations and only 29% in the research workforce in STEM fields (Australian Government, 2024, July 26: 4.). These concerning statistics appear intractable, having barely shifted over the last two decades despite substantial funding being channeled into 'hundreds of Women in STEM programs across Australia' as stated in the *Catalyst Report: From Insight to Action: Strategies for Cultivating Equity and Empowering Women in Industry* (Devis, 2023: 4). This report also noted that there is an 'overwhelming lack of positive role models' (5) and that,

> *'the participation of women and people of diverse gender in the STEM fields is essential for innovation and productivity. However, the barrier of gender inequity still stands in the way. As identified, there are many drivers behind this barrier,*

however a major driver of workplace gender inequity are the cultural norms and beliefs that perpetuate and underpin harmful biases and stereotypes (26)'.

A major role in perpetuating these cultural norms and beliefs, particularly for children, is played by media and popular entertainment, in which female scientists are barely visible as protagonists. These problems in Australia are mirrored in international statistics about gender inequity in STEM careers, see Stem Women UK (2023, Aug 30), the American Association of University Women (2024) and in media representation, *Representations of Women STEM characters In Media* (2023) and *See Jane* (2023). Propagating gender stereotypes of scientists, this underrepresentation – which extends to a lack of socio-economic and ethnic diversity – has negative repercussions for both girls and boys in their experiences of, and potential careers in, STEM. The Geena Davis Institute on Gender in Media demonstrated in *The Scully Effect* (2018) that strong positive female STEM role models in entertainment have measurable impact on women entering these professions.

> *'The findings of this study confirm what previous research has established, that entertainment media is influential in shaping life choices. It is easy to dismiss entertainment media as simply entertaining, but half a century of social science research reveals that the characters, images, and storylines in media shape our everyday lives in profound ways. They provide subtle and not-so-subtle cues about what we should prioritize in our lives, how we should spend our time, how we should spend our income, who we should love, how we should love, how to overcome hardships, etc. In the case of the "Scully Effect," entertainment media influences what career options girls and women can envision for themselves'.*
>
> *(Davis, 2018: 6)*

A major question for the team was how to replicate the Scully effect in much younger audiences, using techniques that were engaging and age appropriate. This was a significant challenge about which scant research had been conducted against a backdrop where much science content that boys and girls receive is negative or catastrophising (media), skewed male (screen entertainment) and/or information-only (school), which can entrench behaviour and bias. This collective evidence demonstrated that rather than simply address the symptoms (a lack of diversity in STEM), we needed to radically tackle the root of the issue, starting with how science is traditionally communicated to children. Our project addressees this challenge via two specific aims:

1. create a multi-part short-form hybrid animated science series (together with associated learning assets) suitable for education-focused streaming and for use in the classroom, that encourages girls to participate in STEM careers;
2. develop an innovative co-design framework that embeds scientists, students and teachers into the research methodology to generate new, inclusive, and diverse ways to communicate science to children, to enhance their scientific visual literacy and to foster their passion for, and engagement and participation in, science.

2.2. Hybrid Documentary

Hybrid documentary was the innovative conceptual framework from which this pilot project was forged. Hybrid documentaries are bold explorations of cinematic language combining two or more (sometimes disparate or antithetical) ideas/styles/traits to make a new form with which to articulate complex intellectual, visual, and emotional ideas through metaphor, reflection, refraction and nuance that challenge entrenched, conventional and predetermined ways of seeing (*The Act of Killing*, Oppenheimer, 2012). Hybridization synthesizes disparate characteristics (like Mendel's genetic hybrid scientific tests) creating a distinct new entity. While there are 20th Century antecedents of the form (Morin, Rouch, 1961), it is recognized in international documentary theory and practice as a 21st Century cinematic frontier (Moody, 2013; Sellors, 2014; Stam 2016; Heeney, 2021). Lead Chief Investigator of the pilot and the larger scale project, Professor Rachel Landers, was commissioned by Routledge in to write the first international monograph on hybrid documentary (published 2024), which provided evidence of the form's ability to challenge documentary theoretical orthodoxy, positively impact audience perception, foster inclusivity, and provide subjects with authority and authorship. ***Uniquely, the project applied this conceptual framework to children's science content.*** Our intended audience was the underserved age group 10-12 (*STEM 3 NSW curriculum*), where there is demonstrable attrition in STEM engagement from girls (Angeleni, 2024). Each character animation in the pilot series anthropomorphizes one scientist, fusing their identity with the microscopic object of their research so that they inhabit the invisible forms they are investigating, bringing to life the vivid, fluorescent 3D images they produce during their research (Figure 1).

Figure 1. Dr Anya Salih, one of Australia's leading coral fluorescence and biomedical imaging scientists, as an animated, anthropomorphized fluorescent protein from corals. These proteins are revolutionizing cell biology, cancer and neurological research. Image Deborah Cameron, Design Aki Clayton and Alyssa Mullen.

These fun, authentic, animated characters will also convey the wonder and personal passion that drive scientists yet are so often neglected in science screen content and science communication. As H. Holden Thorp, the Editor in Chief of Science stated in 2023:

> *'Scientific research is a social process that occurs over time with many minds contributing. But the public has been taught that scientific insight occurs when old white guys with facial hair get hit on the head with an apple or go running out of bathtubs shouting "Eureka!" That's not how it works, and it never has been. Rather, scientists work in teams, and those teams share findings with other scientists who often disagree, and then make more refinements. Then those findings are placed in the scientific record for even more scientists to examine and produce further adjustments. Eventually, theories become knowledge. All along the way, these scientists are conspicuously and magnificently human—with all the assets and flaws that humans possess. And that means that who those individuals are, and the backgrounds they bring to their work, have a profound influence on the quality of the end result'.*
>
> *(Thorp, 11 May, 2023:1)*

There is abundant international research demonstrating the extraordinary impact of animated content on children's reception, development, cognition and bias – particularly about gender roles (Pillar León González, et al, 2020; Turkmen, 2020; Alehpour & Abdollahyan, 2022;

Praveen & Srinivasan, 2022). There is also leading contemporary research from neuroscientists charting the critical cognitive impact of narrative and storytelling on behaviour (Gallese, et al, 2011; Davidson, 2017; Suzuki, et al, 2018). Information-only science content and learning has been associated with a pattern of disengagement from children (Kahan, 2016) and can reinforce gender bias (Gleeson, J, et al, 2022; Gapminder.org 2024). There is also much evidence that girls respond far better to visual learning in science (Bian et al, 2017) and to positive media role models (See Jane 2023). Much of the STEM 3 (Aged 10- 12 years) curriculum in Australia, however, is nonvisual, devoid of narrative and not focused on female protagonists (NSW Department of Education, 2024).

2.3. Research driven audio visual content for children's education

Both the pilot and the larger project offer the first research-driven science content for STEM 3 Australian primary school curriculum in a children's popular education format (10-12 year-olds). Prior research-driven children's popular education content is focused on early learners (3-7 year-olds) – Sesame Street, The Magic School Bus, Bluey, The Wiggles (Cingel, 2024). Even recent international documentary programming committed to addressing the lack of diverse and female STEM subjects (Portray Her, Geena Davis Institute, 2024) tends to be information-based, focused exclusively on inserting female scientists into traditional hitherto male dominated spaces; or it presents 'specials' that focus only on female-led science and do not normalize diverse workforces. Our project's innovations go further, challenging conventions, stereotypes and bias by using animated character performance in hybrid documentary to highlight a diversity of scientists (which includes men) inhabiting a visual research universe (e.g. inside a coral reef, a heart, a placenta) they generate and investigate, not one they are 'allowed' or are invited to enter.

Our team of Chief Investigators and Partner Investigators piloted this hybrid tripartite framework in 2023/24. We co-designed four-character prototypes using 3D, 2D and amalgams of 2D/3D animation, and trialed different narratives, and evaluated them over several iterations. This work, which involved six research scientists as well as teachers and 110 students (ages 10-12, Stage 3 STEM) from Ultimo Public School in Sydney, highlighted the value of embedding scientists, children and teachers into the research methodology.

2.4 Methodology

The collaboration produced four short hybrid animated documentary films for children 10/12 Hearts, Lost, Extreme and Coral, metamorphosing a scientist's innovative research, point of view, passion, identity and impact with the microscopic object of their investigations. anthropomorphizing the microscopic life forms using animation.

The Microbial Imaging Facility (MIF) where we sourced the scientist protagonists is headed by Associate Professor Louise Cole who was also the director of the Australian Institute of Microbiology and Infection (AIMI). It was she, along with fellow MIF scientist Dr Amy Bottomley who were responsible of the 'casting' of the scientists for the pilot'. MIF is an open access core imaging facility that supports ~130 researchers annually from the UTS faculty of science and engineering. Research areas are predominantly focused on biological and biomedical applications. Researchers are trained independently on MIF microscopes to produce high resolution data that will progress their research on a global scale. Confocal laser scanning microscopy is a powerful technique used to produce high resolution 3D images of living samples. The technique allows scientists to see into and reconstruct individual micro-organisms, larger invertebrates such as corals and healthy or diseased or damaged tissues such as cancer tumours.

> *'The laser penetrates the sample surface, "seeing inside it" and creating optical sections, which are then digitally reconstructed to create highly resolved volumes in 3D. The impact of this research is not always accessible and understandable by the public, meaning the understanding of how research impacts people's lives can be lost'.*
>
> *(Cole 2023).*

By transforming the way this research data was communicated, the collaborative team wanted to expand its national and international visibility and reputation both within academic settings by showcasing its research and imaging capabilities, but also to through outreach activities that are public facing, thereby pushing the boundaries of open access to improve visibility, education and science communication for all.

Four MIF Research Scientists collaborated with the FASS animation team transforming their research into narrative animated form for the pilot project. The four scientists involved were : Dr Anya Salih (Coral) who investigates cellular processes in reef corals and other organisms, exploring such questions as the function of coral fluorescent proteins in light optimization, in resilience of corals to climate change and in biomedical applications in diseases and cancer. Two: Dr Carmine Gentile (Hearts) whose research focuses on recreating heart tissues by mixing cells and gels in a test tube. These so called "mini-hearts" can be made from patient's cells to create personalized testing tools with drugs, as well as transplantable heart tissues when printed using a "3D bioprinter". Mini-hearts have the potential to be a new hope to prevent and treat cardiovascular disease, the number one killer in Australia. Three: Dr Yan Liao (Extreme) whose research work focuses on understanding the molecular mechanisms that archaeal cells ("extremophiles") use for survival, adaptation, and division under extreme environmental conditions. Her research anticipates future harnessing of Archaea in tackling climate change, waste management, agriculture, and biotechnology. Four: Dr Claire Richards (Lost) who investigates, preeclampsia - a leading cause of death in pregnant women and their babies. Claire has been growing cells from the placenta in three-dimensional cultures ('mini placentas' or organoids) to understand how preeclampsia develops and might be treated.

The Media arts and Animation and Microbial Imaging Facility teams collaborated translating the research image data into narrative/animated form through three phases of preproduction, production and post-production. The 6 scientists and 3 filmmakers built a shared online site collating scientific images, PowerPoints and public facing science communication presentations. This was shared and discussed at multiple workshops in August/September 2023 in which scientists and filmmakers worked on ways to translate, storyboard, integrate, hybridize, animate and narrativize MIF research data. We conducted a series of filmed workshops with the scientists in the FASS/MAP film studio to form the basis of the scripts for the animated hybrid documentaries. Prof. Rachel Landers, head of Media Arts and Production worked closely with AP Louise Cole and the Microbial Imaging Facility team workshopping content with scientists, creating narrative scripts overseeing editing and guiding the delivery of creative production milestones. Longform audio interviews between 60 to 90 minutes were conducted where the scientist were invited to communicate their work as vividly, visually and viscerally as they could through metaphor, narrative and descriptions of their personal motivations and passions driving their work. These interviews were iteratively edited down to 3 to 5 minute audio cuts. MAP FASS Animation academics Matthew Gidney and Deborah Cameron were responsible for overseeing the anthropomorphisation, visualization methodology and development of the generation of authentic animated characters from the 3D microscopic image data, as well as the building of story worlds in which they exist. The 4 professional animators hired to execute the designs worked with the scientists in MIF laboratory co-designing and translating data into narrative form. The professional animators were all recent graduates of the UTS Animation Production degree so were familiar to the academic animation team and importantly the workflow protocols that had been set up at the university.

Each animator was paired with a specific scientist. They spent time together in the Microbial Imaging Facility working side by side with the scientists observing and translating their work and the imaging data they were producing and analysing. It was critical that the animators not only understood the science but that the merging, morphing and anthropomorphizing of the scientific research data; a hearts stem cell, an organoid 'mini' placenta, an archaea with the character of the actual scientist was authentic and the result of a vigorous research trajectory (Figure 2).

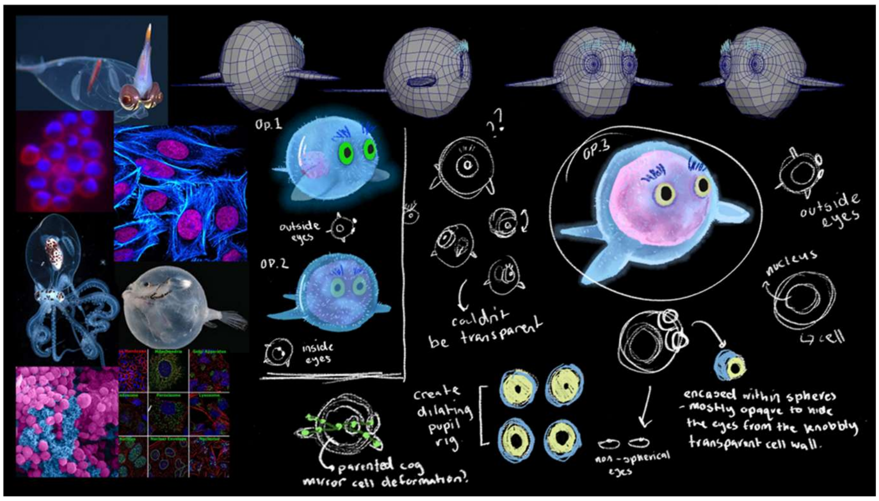

Figure 2. Dr Yan Liao as Archaea. Images by animator Amelia Farrell.

The animators created first looks for character design and story worlds which the academic team – scientist and animators gave critical feedback. Revisions were made and the first animatics were created. The animations while personality driven, brightly coloured and narrative driven they were also robustly fact checked – the task at hand was ensure the complexity of the scientific data and research retained its integrity and impact. It was also always envisioned that these works would act as 'snackable' launching pads to help students enhance their scientific literacy and the work would lead to and complement the actual scientific visualizations and work conducted by the scientists (Figure 3).

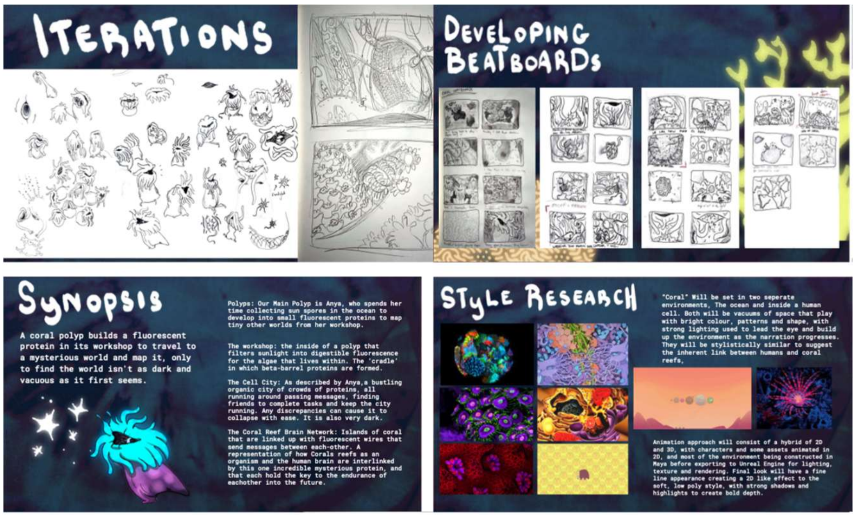

Figure 3. Images by animators Aki Clayton and Alyssa Mullen.

d. **Work in progress. Testing the pilot**

Early in the project we approached a local primary school (based next to the University) to seek the opportunity to test the pilot animations at the animatic stage with the target audience – students aged 10 to 12 years old studying Stage 3 STEM curriculum. We had a 90-minute session with 110 students and their science teachers presenting the works in progress. Most of the scientists were able to attend with their respective animators. We screened each short animatic film individually and then asked for feedback from the students. We first asked if someone could volunteer to 'tell' the scientific story they had heard back to their fellow students. We wanted to ensure that the narrative arc and science had been communicated clearly. We then invited students to ask open ended questions (to the scientists and/or animators) about what they had seen. We also handed out feedback forms asking then to give written feedback to three questions 1. What did you like? 2. What didn't you understand? 3. What did you want to see/hear more of?

Analysis of (over 440) students' written responses to the four prototypes revealed promising results but identified areas requiring investigation. Specifically, we needed to determine the most effective ways to visualise, humanise, narrativise and translate the science and scientists (Thorp 2023), and find more rigorous ways to connect content to the curriculum and to shift the biases that present barriers to diverse participation in STEM learning and careers. The feedback helped us identify what we would do differently for larger project such as involve student users at an earlier stage of character design and world building.

We were selected to present our work in progress pilot and ongoing research at CILECT (International Association of Cinema, Audiovisual and Media schools) World Congress, representing 180 leading international tertiary film schools, in Rome November 2023. Even at the development stage, the pilot project connected strongly to the Congress' theme: 'In times when the audiovisual (AV) medium dominates human lives since birth… the task is to develop projects that build the AV literacy of all types of audiences, but especially ones oriented to children… as well as to people in minorities and deprived environments. It is crucial to challenge established knowledge and beliefs about the AV language' (CILECT 2023).

The pilot work in progress was then presented at the Figuring the Invisible Interdisciplinary Conference in December 2023 at the Lucerne

School of Applied Sciences in collaboration with the Marie Sklodowska-Curie Global Research Project FICTA SciO. This conference showcased the leading global research innovations in 'Conventions and Tactics in Animation for Science' for the 'representation of invisible objects – too big, too small, too far away in space and time' (Bellano, 2023). Participating in the conference enabled us to begin to envision the work as a potentially larger project which could synthesize into a single project - research interrogations from the fields of animated documentary, scientific visualisation, useful animation studies, diversity and gender inequity studies in STEM professions, the measurable impact of animation content on children's cognitive development, bias and behaviour, and the impact of research-driven children's television. Much of the recent international research showcased at the conference demonstrated innovations in data visualization (e.g. Astro Animation NASA/MICA) and social impact mostly involved health and medical information (e.g. Visualising medical information for edutainment, Nayang. SG) demonstrated the potential of popular educational engagement with children with a focus on challenging bias through innovative visualisation - a powerful way to bridge pure scientific data visualization and popular art- and education-oriented animation by seeking a shared visual language through which to create more authentic and transformative relationships between them. (Curtis, 2023).

The team worked on the project iteratively through to mid 2024 and debuted the work at the VIVID festival June 1st 2024. The VIVID festival is the largest arts festival in the southern hemisphere and is an annual celebration of creativity, innovation and technology. To engage the target audience (broadened for the festival to include children from ages 8 – 12) in an immersive, engaging, educative and interactive experience, the works were presented within the context of a large-scale hands-on science and animation workshop entitled Superheroes of Science. The event sold out within days and the demographic of participants skewed female. The children were taken through the same scientific/creative process that the team had gone through in researching and developing the pilot with the intention of exploring dynamic ways of translating and visualizing complex science. We sourced ninety university teaching confocal microscopes and set up twenty tables for eight children each with microscopes, slide samples, pens, pencils and coloured drawing paper. Each table had a student volunteer to assist participants with using the microscopes and to help guide the workshop. We were in a large hall that could accommodate over one hundred and fifty children (along with their parents/guardians). We also had a stage and large screen at the front of the hall. We began by gathering the children at the front and with animators and scientists took them through the development of two of the animated works Lost and Hearts and then screened the completed films. The children were then taken to the tables to start using the microscopes and looking at sample slides. While they were doing these activities, we had a state-of-the-art confocal microscope (from MIF) on stage in which the science team demonstrated looking at samples while two of the animators did a 'live' demonstration of turning the microscopic data into character animation.

After the students had looked at and identified several slide samples (plants cells, insect cells, blood cells etc.) – one of the animators took the students through a short animation character workshop getting them to anthropomorphise what they were looking at (Figure 4).

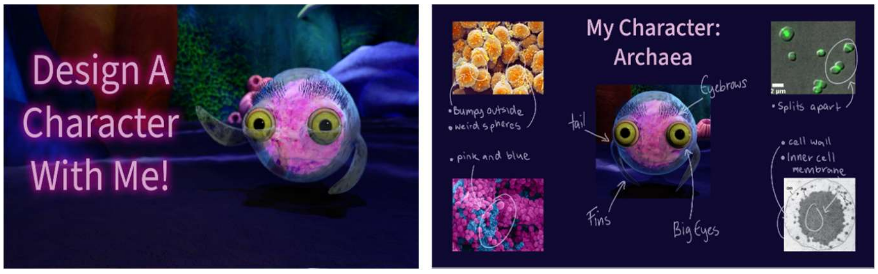

Figure 4. Images by animator Amelia Farrell

The children worked with the microscopes and created their own characters with pilot project scientists and animators on hand to answer questions and assist. We then screened the completed version of the archaea film Extreme on which the development workshop images above were derived.

We brought the children together at the end screened the final animation Coral and gave each participant a foldscope kit (a portable paper microscope with smart phone accessories, samples and instructions), to take home to further explore the microscopic world in their own environments.

The success of the workshop and debut of the animated pilot films gave the team scope to develop the research into a larger scale more comprehensively and rigorously tested research project.

Larger scale research project 2025 - 2027

The major research questions raised in the pilot project were:

1. which hybrid documentary methodologies (with novel combinations of animation, narrative and anthropomorphism) produce the most impactful ways to communicate contemporary science, represent the diversity of scientists, and encourage participation in STEM education among children?
2. Can our deeply integrated co-design approach involving research scientists working with visual 3D-imaging data, screen researchers in documentary/animation, and end-users (i.e. teachers and students) generate a new model of research communication that promotes diversity and inclusion and improves scientific visual literacy with measurable impact?
3. What are the most impactful and engaging education learning assets prototypes (that complement the hybrid animated series) to build into the STEM 3 curriculum that promote engagement, participation, and diversity in science education for children and shift bias?

This proposed 3-year project will involve chief and partner Investigators - scientists from the pilot, a documentary academic, animation academic, a screenwriter, a curriculum learning designer, a graphic novelist, research assistants, support staff from the UTS Microbial Imaging Facility (MIF), the UTS Media Lab (ML) (staff, facilities, equipment) and 2 PhD students. The entire 3-year project co-design methodology is intended to be captured in observational behind-the-scenes film creating a powerful document of innovative science communication.

The project team will work with the University of Technology, Sydney Women in STEM outreach team WiEIT (women in science, engineering and IT) led by Maryam Kauser, Georgia McCarthy and Dr Faezeh Karimi. WiEIT are working with 14 NSW public schools (including Ultimo PS) through their

STEMxPlay program with focus on STEM 3 curriculum. The UTS outreach team who won the 2024 Cygnet (Science in Australia Gender Equity – SAGE) award, have been working with NSW public school students and teachers for four years collecting, collating data and measuring student STEM engagement, bias, disengagement, reception. They will work with the team and learning designer to develop and deploy an integrated and participatory, evaluation methodology.

The project will address the creative research practice aims and questions via three principal stages:

1. development (year 1);
2. production (year 1 and 2);
3. post, prepare publications (year 3).

Each of these three stages will be guided by our hybrid documentary conceptual framework (AIM 1, Research Q 1,2,3). At each stage of the project, we will iteratively screen, workshop and collect feedback of Works in Progress (WIPS) of the hybrid animated series and associated learning assets/ prototypes from; participant scientists and STEM 3 students and teachers at both holiday workshops held on the UTS campus and at in-school WiEIT programs at a cross section of NSW primary schools. Written and verbal feedback (via methodology below) from students and scientists will be collected at each iteration and incorporated back into the research. Finally, the team will test prototypes of related science-focused screen content/activities that could be linked to the primary curriculum, such as graphic narrative science books, merchandise connected to science websites, and models of co-design between schools, students and universities.

The methodology and evaluation design (led by CI Cole with the learning designer and DP and WiEIT teams) uses a multi-method approach combining qualitative and quantitative data to examine how the developing project and associated learning assets impact student's scientific engagement and inclusivity, particularly focusing on girls. Teachers, students and participating scientists will also be interviewed to gather feedback and data. Quantitative data will be collected through open-ended questions, focus group discussions, and semi-structured interviews. The teams will create curriculum-specific tests, focusing on higher-level cognitive skills. Students will complete these at designated points to measure changes in knowledge, motivation, and engagement. Ethical standards will be maintained throughout. This comprehensive methodology will provide robust data on the effectiveness of the projects aims in enhancing scientific literacy, engagement and promoting diversity in STEM, aligning with Australian Government STEM priorities. The project design, methodology and findings will be published in a scholarly monograph.

3. Conclusion.

Successful collaboration between early education academic researchers and children's television content is well established both internationally Sesame Street and nationally The Wiggles and Bluey. Despite this, currently there are no national Australian research driven collaborations between children's TV industry, education and the academy explicitly focused on generating narrative driven STEM diversity content for older children. By default, this means there are no research driven collaborations between industry and the academy with the aim of encouraging girls into STEM careers linked to the education curriculum. This project has the rare potential to break down silos that foster bias and exclusion and instead address critical gaps in Australian Federal and State Government initiatives/institutions that are currently working at odds with each other and in contradiction to established Government priorities outlined below. An example of this is that - despite overwhelming evidence of the efficacy of research-driven education- focused children's AV content on cognition, bias and development – neither Screen Australia (the national screen finance fund), nor the Australian Broadcast Corporation (Australia's public broadcaster) will fund educational television content. Another example is that ABC Education will acquire finished AV content but will not fund its research or development. Where then will this research driven user tested content for Australia's children emerge from? This project delivers a co-design model that powerfully answers this question.

The animated science series for children (pilot teaser password WON24) will be showcased at international animation and children's film festivals and conferences broadcast on television through education focused free to air and/or streaming services. Curriculum study guides for Stage 3 STEM education integrated with science animated shorts and published through the Australian Teachers of Media (ATOM) site along with graphic novel like lesson plans developed by scientist and animators/artists/ STEM stage 3 teachers and a learning designer. A long form documentary of the making of the Wonder project collaboration showcasing the co-design and methodology released on science communication platforms. International book publication of the process, methodology, design, collaboration, and findings (e.g Advances in Film Studies Routledge). Product development of animated science characters – e.g. toys, apparel, school lunch boxes. All products will be QR coded to link to broad public facing open access website featuring the science and scientists.

The project aligns strongly with the following three Australian Government Priorities.

1. Pathway to Diversity in STEM Review. Final recommendation report (February 13, 2024): This policy initiative aims to improve diversity in STEM fields through strategic actions aimed at removing barriers and fostering inclusivity across the STEM workforce.
2. National Science and Research Priorities (August 12, 2024): 'The Australian Government's vision is for an Australian society engaged in and enriched by science'.
3. Priority for international collaboration on science and research.

All the new focus priorities directly relate to this project. This project has long-term benefits for Australian industry investment in innovation and digital technologies by cultivating a diverse and inclusive future workforce adept in STEM fields. It also promotes gender equity initiatives by inspiring young girls to pursue STEM careers; the project addresses the gender imbalance and enriches the talent pool, which is essential for driving innovation. It responds as well to the actuation of a nationwide engagement with the sciences. The hybrid documentary framework combining animation, narrative, and anthropomorphism aligns with the Australian government's priority for international collaboration on science and research. By utilizing innovative storytelling methods to communicate complex scientific concepts, this project opens avenues for partnerships with global institutions focused on similar educational and scientific goals. Such collaborations can lead to the sharing of best practices, co-development of educational content, and joint research initiatives, thereby enhancing Australia's reputation as a leader in science communication and aligns with The National STEM School Education Strategy 2016 – 2026 focusing on 'strategic approaches to school-based partnerships with business and industry to develop the engagement, aspiration, capability and attainment of students in STEM'.

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ORIGINAL ARTICLE

The End of the Image

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Abstract: Digitization has made nearly every aspect of human life computable, and specifically, by way of computation and increasingly clever algorithms, the creation of any image is possible. The application of this technology towards any image and sonic media, combined with speed and mass communications could lead to a form of totalitarianism, the loss of history, and the end of truth.

Keywords: Computation, Machine Learning, Image, Mass Media, Speed

1. Computability

One can look to the invention of the transistor in the 1940's as the dawn of early computation. Since that time, transistors have become an inseparable part of our daily life, finding their way into all micro-electronic devices. The affordances of transistors are broad, but the focus here is computability, and the digitization of data, including sound, image, and text into a universally computable digital binary format for algorithmic operations. Furthermore, while digitization is the process of converting information to a digital format, the highest concern is regarding the generation, parthenogenesis so to speak, of digital data that resembles sound, image, and text.

Let's quickly refresh how digitization, sometimes called encoding, works. Computers operate on binary data represented by long sequences or strings of zero's and one's, called bits. Bits are the universally computable binary format that computers use. These bits are chunked together in groups of eight, called bytes. Bytes are handy containers, able to hold a base-10 number from 0-255. Modern text representation uses the Unicode Transformation Format 8-bit (UTF-8). This means each letter, number, and symbol is held in one byte. When referring to an UTF-8 chart, an upper case "A" has a value of 40, while lower case "a" has a value of 61 (Köllerwirth, 2015). With an UTF-8 chart we have a digitization process from text to byte (number) and back from byte to text for all manner of text in a Romanized language that can be digitized.

To digitize an image there are two primary properties: colour depth and resolution. Regarding colour depth, most digitized images are 24-bit images, meaning one pixel needs one byte for red, one byte for green, and one byte for blue. Some cameras can capture at a higher bit-depth, representing more than 24-bits per pixel, but for simplicity's sake we'll set that information aside as an exception. Nearly every display device is limited to 24-bit colour, which is greater than sixteen million colours. Human colour perception is measured at ten million colours, so it's easy to see why more colour depth isn't necessarily required. Image resolution refers how many samples are needed within the physical dimensions of an image. Resolution is often represented as Dots Per Inch (DPI) or Points Per Inch (PPI). Suppose an image is being scanned, one can choose to sample or scan at 72, 150, or 300 DPI. Thus, a 100 x 100 pixel image on the screen represents 240,000 bits or 30,000 bytes, which is slightly less than 30-kilobytes.

In the next section we will reverse the process and generate data to decode (de-digitize) into images.

2. Application of Computability

In the previous section we examined how media can be captured and digitized in a universally computable binary format. In this section we will reverse the process by generating data and decoding it back out to human relate-able formats.

For the first example we will look at taking digital colour gradient information and decoding, representing, it into the physical world. Tauba Auerbach's *RGB Colour Space* book is a representation of all sixteen million colours from the computer RGB palette (2011). Red, Green, and Blue are each representing one dimension of this book in physical space: width, height, and depth. The pages of the book become a perfect cube because each dimension has equal bit depth. One corner of the book is white where all three colours have a value of 255. And the opposite corner of the book is black, where all three colours have a value of 0. The title is the exact description of the contents of the book.

An algorithm could quickly compute the pages necessary for this book. Since the binary representation of a colour is one byte, each page will be 256 pixels by 256 pixels, and the book will have 256 pages.[6] Simply increment each red value by one as each colour dot is drawn horizontally, increment each green value by one as we draw each colour dot vertically, and lastly increase each page's blue colour by one as we complete each page.

This type of computation is referred to as *brute force* because each value is computed sequentially as opposed to randomly or by using a more complex algorithm. The brute force approach will generate all possible outcomes, whereas other approaches may not. Continuing with brute force, let's examine more image-based examples that exist only on screen.

The first image example is John F. Simon Jr's *Every Icon* (1996). Icons are the small images one often sees on a computer's desktop or smartphone and generally represent a file, folder, or application. Early icons on Apple's operating system were black and white with dimensions of 32 x 32 pixels, and *Every Icon* references these 1980's early icons and runs on a wall hanging screen where each grid pixel is sequentially updated one-by-one until all possible black and white icons are generated. While this sounds reasonable, the total number of unique possible icons is 1.7×10^{308}. In Simon's own words about how long *Every Icon* runs:

> *Although it takes only 1.36 years to display all the variations along the first line, it takes an exponentially longer 5.85 billion years to complete the second line. Even in this limited visual space, there are more images than the human mind can experience in many lifetimes. (1996)*

[6] Yes, this is more than 255, the computer starts counting at 0 instead of 1.

Simon only mentions how much time it would take to complete all possible icon combinations with only two rows of pixels. And yet, there are thirty more rows remaining.

The second image example is Jim Campbell's *The End*, not-with-standing prescient to this paper. Similar to Simon's *Every Icon*, Campbell's piece sequentially changes each pixel in 8-bit grey space instead of black and white (1996). While his image resolution is not specified, lets imagine a 2 x 2-pixel image; arguably very small to see anything, but this is more for the demonstration of human-scaled math. Each pixel has 256 grey values possible. If we update the pixel grey value at sixty updates per second, we have to wait slightly over 2.25 years to see all possible 2 x 2-pixel images. With a 32 x 32-pixel icon, the number of possibilities is 256^{1024} or roughly 10^{2466} This number is long enough to almost fill an entire page. While that's already an unreasonable number of possibilities, we can appreciate that the heat death of the universe, estimated at rough 10^{106}, will have completed long before we get even near to seeing anything in this greyscale icon. In fact, the universe would cycle from big bang to death 24 times before we see all possible variations of this icon. Using red, green, blue colour instead of grey, exponentially increases these timespans.

Clearly, from the technical brute force standpoint, a sequential approach to generating every icon or all possible images is more a conceptual contemplation than realizable artifact. Within that conceptual space, for a moment, just consider that in the reverse order of computation, data into image, if one creates an algorithm to compute the desired data in-place, then it is possible to generate the images one wants within an acceptable human timescale. If every image possible could be generated, then we could, for example, create the image of our death. And not only that, but we could also create that image from any camera angle, any time of day, at any setting, and so forth. All images exist in this potential data image space, regardless of whether they are computed. In the next section, we discuss how machine learning approaches image generation and gets closer to that goal.

3. Learnt Computability

Machine Learning (ML) or as it is more popularly known as Artificial Intelligence (AI) is just another generative algorithm based on statistics. Humans have created ML as a style of algorithm that learns to regurgitate what it has accumulated to the best of its design with parameters, controls, to find patterns, variability, or compute difficult problems. The modern-day ML algorithm, linear regression, has been around for almost 50 years; although, affordable computation capacity hasn't emerged until more recently. Supercomputers could equally perform the task, but not everyone has access to a supercomputer. When parallel processing on a graphics card for machine learning was discovered, there was a sudden and significant drop in cost and higher degree accessibility.

Have you ever asked ChatGPT a question? Your question to ChatGPT is a prompt, prompting the ML to give a response. If you have tried one of these systems, you may have discovered that how the prompt is written, or the addition of keywords will trigger desired results. David Rokeby writes in *Transforming Mirrors* about interactive art interfaces, but the analogy can be applied to any interface - in this case we use Rokeby's model to frame the ML prompt (1996). The basic premise is that humans are amazing and will fill in the gaps for a lack of interface quality, control, and so on just to make something work. In this way, we, humans are trained by the interface or algorithm to conform to it, rather than it becoming better and conforming to us, in fact, humans may be learning and adapting faster than the ML they use. Rather than continue to improve the quality of the ML, humans adapt. Shouldn't prompt writing become better for humans and who is really benefiting? Is this really good for human society?

Aside from the common ML stories about chatbots learning to be racist (Schwartz, 2019) or suggesting glue in a pizza recipe (Ovide, 2024), there are other areas of concern. Take for example Joy Buolamwini. They, at the time a graduate student at MIT, were trying to use ML face tracking technology, but Buolamwini discovered that the ML couldn't find them. Why? Because they're a person of colour, and the data set used to train the face tracking technology was of primarily White and Asian men. Buolamwini was successful at using the algorithm after putting on a white mask. The algorithm, literally, could not see them. This demonstrates the perpetual and systemic technology industry's: lack of diversity, compassion, and equity to just name a few issues. This ML face tracker, in a way, was saying that unless you're white or Asian, then you don't exist in technology. Buolamwini took this experience and founded the Algorithmic Justice League, "to illuminate the social implications and harms of AI" (n.d.).

Another example is Kate Crawford and Trevor Paglen's *ImageNet Roulette* (n.d.). ImageNet is a Stanford Machine Learning algorithm that was trained to quickly recognize the contents of an image, for example if a human was in the image or if an animal and what type of animal. For this to work, a person must analyze and label each image so that a training dataset of labels is associated to the image dataset when the ML trains. Stanford used Amazon's crowd-sourcing mechanism Mechanical Turk to complete this task.[7] Crawford and Paglen's research revealed the results of this process in their article *Excavating AI The Politics of Images in Machine Learning Training Sets*:

> *You open up a database of pictures used to train artificial intelligence systems. At first, things seem straightforward. You're met with thousands of images: apples and oranges, birds, dogs, horses, mountains, clouds, houses, and street signs. But as you probe further into the dataset, people begin to appear: cheerleaders, scuba divers, welders, Boy Scouts, fire walkers, and flower girls. Things get strange: A photograph of a woman smiling in a bikini is labeled a "slattern, slut, slovenly woman, trollop." A young man drinking beer is categorized as an "alcoholic, alky, dipsomaniac, boozer, lush, soaker, souse." A child wearing sunglasses is classified as a "failure, loser, non-starter, unsuccessful person." You're looking at the "person" category in a dataset called ImageNet, one of the most widely used training sets for machine learning (2019).*

The dark underbelly of machine learning is exposed and on display for all to witness as one delves further and further into the ImageNet database. The labeled images become more derogatory and racist. Because the ImageNet database was free to download and use, these labels become the perpetuated and passively accepted norm. With a name recognition and educational pedigree like Stanford, who of equivalent techno-prowess could question their decision? The image to label association must be acceptable if Stanford stands behind it. Moreover, who is a turker? What is their background, why did they decided to label things as they did, what was their motivation for labeling images in this way? Why did the ImageNet researchers find this acceptable, or did they not look or care? Only after Crawford and Paglen created and published this work, garnering angry public opinion about Stanford, did the ImageNet researchers examine their

[7] Amazon's Mechanical Turk, this is an online crowd-sourced work force as a service. Humans, or turkers as Amazon calls them, are paid a rate per task they are assigned. Frequently the tasks are fast and pay only a few cents. Since the researchers at Stanford needed hundreds of thousands of images labeled, this was a fast and cheap approach to solve the solution.

data and take responsibility. Why did it have to get this far? Sofian Aubry's begins to answer questions like these with a relation to art:

> *Machine learning offers a unique challenge to art because of its historical entanglements with an engineering culture that idealizes optimization and problem-solving over open-endedness and diversity. Traditional engineering approaches to art making within computer science and artificial intelligence rest on false premises as they focus on techniques and outcomes rather than on processes and contexts. (2021: 75)*

From this, we can start to piece together a picture of techno-culture that is less concerned about implications and methods and more concerned about solutions and results.

With ImageNet and other examples in mind, Catherine D'Ignazio and Luren F. Klein tackle the source of the problem with their book *Data Feminism*. Their book suggests seven principles for Data Science or as we have been discussing, machine learning: examine power, challenge power, elevate emotion and embodiment, rethinking binaries and hierarchies, embrace pluralism, consider context, and make labor visible (D'Ignazio and Klein, 2020).

On the surface, it's clear that the status quo of computer/data science is a hidden, omnipotent monoculture that does not always want to consider ethics or impacts. When researchers are called out, as previously demonstrated by Crawford and Paglen, then they back-peddle and attempt to correct their errors. We ask, why not start that way from the beginning?

Training sets for machine learning are vast collections or databases. In the case of ImageNet for content recognition or a machine learning algorithm designed to generate images, the data is preexisting images. Taking Mcluhan's proposition that the media is the message, then our media is a data collection or a database. With this framing the intent of Catherine D'Ignazio, Lauren F. Klein, Kate Crawford, and Trevor Paglen is clear: whomever creates or curates the data is the person who intentionally or unintentionally creates the message.

Through this section we have been critical of machine learning, and clearly for good reason. Whether intentional or not, ML can have wide ranging negative effects that build more systemic racism. It's appropriate to know what it is we're working with and the potential consequences before doing so. Technology CEOs frequently tell society that ML is the future and that it will magically solve our day-to-day problems. Politicians and society should trust them to do the right thing, self-regulate because only they understand it, and their technology is for the greater good. Regardless, Frieder Nake stated things clearly with regards to technology over 50 years ago and it still holds true today with regards to machine learning:

"The big machinery, still surrounded by mystic clouds, is used to frighten artists and convince the public that its products are good and beautiful. Quite frankly, I find this use of the computer ridiculous" (1971: 18). Machine learning is often used to try and impress and show how a company will save money, a person will save time, or a task will become easier with a ML assistant. From the examples and critique in this section, there is able evidence to the contrary.

To quickly review, this paper has described how to capture and represent images as computable data, and how to use brute force methods of generating images, albeit over exceptionally unreasonable time frames for humans. The next section will focus on a specific ML algorithm used to generate images quickly without using the aforementioned brute force method.

4. Image Computability

The ML algorithm we're going to focus on is the Generative Adversarial Network (GAN). In the previous section, ImageNet was used as the example, because that ML is successful and finding content within an image. This ML algorithm, the GAN, is very good at learning images, recalling, and generating new images from its latent space. For an example, the website *This Person Does Not Exist* is a near infinite number of human faces that can be generated. Each page reload creates a new face (n.d.). When we consider the mere 24-year time frame between Campbell's *The End* and the website *This Person Does Not Exist*, it's quite incredible.[8]

To quickly explain how a GAN works, there are two agents that are *competing*: one agent is referred to as the artist and the other as the critic. The artist agent is trained by feeding it inspiration noise data, not unlike real life[9], and asking it to generate masterpieces. The critic agent is trained on known masterpieces and the ML artist agent masterpieces. The adversarial/competition component happens when the critic is asked to determine if the artist agent's masterpiece is as good as or look similar to, a known masterpiece. Depending on that result, adjustments are made to the artist agent and as well as the critic agent. Ideally, both adjustments are made equally, so that both artist and critic slowly improve. Over time, the artist agent should become better at generating images of similar fashion to the known masterpiece samples. How well the artist agent does then determines how harsh the critic agent is in its assessments. The training phase is complete when the margin of error falls below the accepted threshold, meaning good enough. Sometimes the margin of error never reaches the desired threshold which is an interesting topic although beyond the scope of this article.

Let's instead, review two artists, Sophia Crespo and Memo Akten, with their approach and usage of GANs in their artistic practices. Starting with Sophia Crespo and Entangled Others' website *This Jellyfish Does Not Exist* is like *This Person Does Not Exist,* because the website regenerates a new jellyfish image each time the page is loaded (2020). Crespo's *Neural Zoo* does not specify the machine learning algorithm, although they recognize and comment, "These images resemble nature, but an imagined nature that has been rearranged. Our visual cortex recognizes the textures, but the brain is simultaneously aware that those elements don't belong to any arrangement of reality that it has access to" (n.d.). Crespo here reflects on the technology as an algorithm and that humans are responsible for the interpretation of the images. Images shouldn't be taken at face-value, they should be looked at and analyzed to find meaning.

Memo Akten's *Learning to See: Gloomy Sunday*, is one of their earliest GAN based artworks in a lineage of technological similar work up through *Embodied Simulation*, (2017; 2024). What is unique about this body of work is how the GAN is utilized. Akten trains a specific GAN algorithm, pix2pix, to be used like a filter or translator from one image to another. One sees this most clearly in the side-by-side documentation of *Learning to See: Gloomy Sunday*. On the left is the input image of fabric and power cords, while on the right is the output image of Turner-like waves crashing, or other examples of fire, clouds, and flowers.

[8] Not-withstanding Moore's Law to accelerate this reality.
[9] In computer terms, noise means a smooth, continuous randomness rather than jumping from random number to number. Metaphorically, this is further implied to be background information, life events that has impact on the artist.

Memo Akten and Katie Peyton Hofstadter's *Embodied Simulation* uses video images of the human body or video recordings of a dancer to produce sea creatures, butterflies, and flowers that are then projected into imagery of outer space. The human form is most recognizable near the end of the sample video on the documentation page. What's notable about this oeuvre of artistic production is Akten's motivation for using ML as explained in a 2019 SIGGRAPH paper: "The second motivation behind the work is more practical and is driven by the desire to create visual instruments, real-time, interactive systems for creative expression, with continuous, meaningful human control" (2019: 3). It's worth reiterating that Akten recognizes machine learning as a tool to be used rather than falling into an artificial intelligence category.

When comparing the brute force method to the above machine learning method of image generation, after the training phase, the machine learning method of image generation can be quite fast. Although, we ought to recognize that as of 2025, the training phase represents a non-negligible amount of time. Without getting too far afield, desired quality could be achieved within a range of days to weeks.[10] On the output standpoint, the image generation phase decreased from a wholly unreasonable amount of human scale time of Campbell's *The End*, to now, a few seconds to fractions of a second with Akten's *Learning to See: Gloomy Sunday*. Prompt-based image generation is not quite as fast, but the results are still quite acceptable when considering one can receive results in under a minute. With the ability to create any image, very quickly, we rely on media theorists to help examine the implications when media distribution is folded in.

5. Computability of Distribution

Mass media communication is not a new concept, as newsprint, radio, television, and the internet are now commonplace, and although each of these methods is faster and more experiential than the previous, the transmission of information is at their core. And yet, during this span of mass media communication methods there is a change of how fast news/information can be disseminated and whether information is sought after or unavoidable. Vilém Flusser theorizes in *Into the Universe of Technical Images*, about media communication and the idea of technical images: "The difference between traditional and technical images, then, would be this: the first are observations of objects, the second computations of concepts. The first arise through depiction, the second through a peculiar hallucinatory power that has lost its faith in rules" (2011: 10). We can break this down in two ways. First, with help for Roland Barthes' *Rhetoric of the Image*, we can determine that traditional images are denoted - meaning the literal what is seen in the image-ness, depicted. In Barthes' example image of pasta, onion, and tomato, the denoted meaning is literally what is seen: pasta, onion, and tomato. Then technical images are connoted - meaning the implied intent/message of the image. Using Barthes' example again, pasta, onion, and tomato imply a meal, hunger, or Italian cuisine – these ideas are connoted. A second approach to unpacking Flusser's definition of the technical image is by focusing on the "computation of concepts." Put another way, image ideas formed though computed descriptions and algorithms rather than an unaltered photo of the object, person, or place. When focusing solely on the most recent method of information dissemination, the internet, remember the concepts of digitization (encoding information as bits) and

[10] Environmental resource cost of machine learning image generation should be made noted. Kyle McDonald created *Nvidia-CO2*, (2020) an extension to the NVidia tools for machine learning that provides statistics on how much carbon dioxide is created or cubic meters of polar sea ice is melted while the machine learning is in the training phase.

computability (universally computable binary data). Prior forms of information dissemination hints at its next instantiation, and Flusser predicts internet culture:

> *Producers of technical images, those who envision (photographers, cameramen, video makers [influencers, tiktokers, etc.]), are literally at the end of history. And in the future, everyone will envision. Everyone will be able to use keys that will permit them, together with everyone else, to synthesize images on the computer screen. They will all be, strictly speaking, at the end of history. The world in which they find themselves can no longer be counted and explained: it has disintegrated into particles—photons, quanta, electromagnetic particles. It has become intangible, inconceivable, incomprehensible, a mass that can be calculated. Even their own consciousness, their thoughts, desires, and values, have disintegrated into particles, into bits of information, a mass that can be calculated. This mass must be computed to make the world tangible, conceivable, comprehensible again, and to make consciousness aware of itself once more. That is to say, the whirring particles [bits or bytes] around us and in us must be gathered onto surfaces; they must be envisioned. (2011: 31)*

When Flusser says, 'the end of history' what's suggested is that there will no longer be traditional images or observation of life to record the present day for posterity. From this point forward only producers and their ideas, the algorithms they use, and consumers with their decoding devices will be relevant. What is happening in the present will not be observed and captured into traditional images. Rather, the producer's ideas will be created and distributed as technical images. If we extend the metaphor a little more: a producer, a ML prompt writer/engineer, or could be anyone with an idea who creates a technical image with a machine learning algorithm. On a superficial level, the creation of images from text or ideas sounds like fun, but in the next section we will discover what happens at the intersection of a producer's ideas and machine learning level of algorithmic image computability.

6. Computability of Truthiness

Photography was, at one point, considered as Flusser may label, a traditional image. It didn't take long until the first fake photo was created using in the photographic darkroom. Photography darkroom techniques evolved to create more elaborate faked images for use in the film industry. One of the best-known visual effects companies, Industrial Light and Magic (ILM), was well known for creating visual effects for analog, celluloid film. Under the leadership of George Lucas, it pushed these film techniques into the digital/computable realm through significant investment and demands from realism from directors (Light & Magic, 2022). Industrial Light and Magic wasn't the only company at the time or the first, but they are the most widely recognized as championing the use of computers for creating the appearance of an imagined reality. ILM's visual effects are probably best known for *Star Wars* (1977), *Jurassic Park* (1993), and *Terminator 2* (1991); although perhaps more relevant to the topic of this article is the use of image manipulation in *Forrest Gump* (1994), where the Forrest Gump character is inserted into previously captured *real* historical events, often well-known black and white film. These comical re-enactments provided an alternative historical record for the purposes of the narrative. The whimsical and often aloof Forrest Gump character makes these fabricated vignettes fun and nostalgic.

What if we create our own historical events? One of the first believable attempts at this was created by the faculty at the University of Washington in 2017. In a demonstration they recreated a video former President Barack Obama (Suwajanakorn, et. al, 2017; BBC News, 2018). The researchers were able to create the appearance of him saying anything they wanted, while only using fourteen hours of training data to create the machine learning algorithms. This is an entertaining technological achievement, yet history has demonstrated that many that advanced technologies find themselves quickly in socio-political questionable area, for example the Manhattan Project. The researcher in the video even admits that the technology will be reverse engineered, which it now has, and for the purposes of propaganda and disinformation as seen in the Deepfake video of President Zelenskyy (Allyn, 2022). Most world leaders have significant hours of audiovisual content online, and to build a machine learning system to create a leader making any proclamation becomes a trivial exercise of downloading the already available online content. The United States' Department of Homeland Security has written an extensive document outlining the history, techniques, potential scenarios, and mitigation strategies, in which they briefly discuss real-time, puppeteering methods (U. S. Department of Homeland Security, 2023).

It's easy to see how impersonating someone else is a significant issue when the intent moves out of the entertainment context, but the extent of the issue is much larger. Oliver Lass writes in his English translation of *Computational Creativity and its Cultural Impacts* that, "applications of creative AI may bring about an epistemic crisis with respect to evidential status of audio and visual recordings" (2022: 89). Laas is suggesting that faked or impersonated AI generated material may be passed on as facts. He further comments:

> *Because of limitations in cognitive ability and resources, most of our knowledge about the world comes from the testimony of others. … Since the invention of film, photography and other recording technologies, various kinds of recordings have become the means for testing testimonial evidence in our culture. This is shown by the fact that we tend to correct testimonies on the basis of recordings and not vice versa. (2022: 99)*

When presented with testimony/narrative in comparison to image/audio recordings, we place more epistemic truth in the recordings, "specifically, they regulate our testimonial practices providing what I'll call an *epistemic backstop*" (Rini 2020: 1). Regina Rini invents this term to describe how audiovisual recordings have historically demonstrated factual information counter to verbal testimony. In Rini's example they use Nixon's Watergate denials and the countering epistemic backstop of Oval Office audio recordings.

Machine Learning generated audiovisuals are creating a condition where the validity of an audiovisual recording, the epistemic backstop, can no longer be considered true. Image, video, and audio recordings/evidence can be brushed off as generated by machine learning – not factual. Rini continues:

> *Imagine, for example, that Richard Nixon had said: "Look, that wasn't me on the smoking gun tape. They used that VoCo technology to make it sound like me ordering CIA interference. But it wasn't!" This would not have been a very plausible claim in 1974. But now imagine that late in the 2020 US presidential campaign. (2020: 7)*

Considering the ML technology of 2020, the plausible deniability of an item of audiovisual media is becoming a reality. We return to the epistemic crises. If testimony has been known to have inaccuracies and the epistemic backstop of media recordings are questionable, as media consumers, in Flusser's standpoint, are we relying on producers to provide what is considered fact? Which producers' technical image envisioning will muscle in as an accepted epistemic backstop - Fox News, MSNBC, Al Jazeera, or another?

Having addressed distribution and truth, we pay more attention to speed in the next section.

7. Computed Totalitarianism

Paul Virilio establishes the concept of speed in his book, *Speed and Politics* in 1977. He and Sylvère Lotringer further discuss the idea of speed in their 1983 edition of *Pure War*, where Virilio states that, "Speed is violence. The most obvious example is my fist… I can make a fist into the slightest caress. But if I project it at great sped, I can give you a bloody nose" (1997: 37 [1983]). While the example is trivial, Virilio makes the point and starts to build the frame for the danger of real-time from the previous section. Real-time in computation, specifically in computer graphics, means that the images being drawn to the screen are occurring at the speed of what is believably real to human cognition and interaction. One could think of live broadcast television or sporting events as near real-time. For Virilio this would be at the speed of light, the fastest something can happen, and that speed is what becomes dangerous, as described below with puppeteering.

Puppeteering in ML is when a person acts or performs as someone else, and the technology changes their appearance and voice into that other impersonated person. Historical, non-real-time puppeteering (performance capture) is used frequently in visual effects where an actor will be motion captured and turned into another character. This performance capture, or sometimes called motion capture (mocap), has been a physical and algorithmic process for many decades, involving a dedicated room, lights, dozens of cameras, technicians, animators, and so on. Gollum from *Lord of the Rings* (2001-2003) is a perfect example. The Gollum character is performed by Andy Serkis, and it's his motion (performance capture) that is used in the film. This process is still used today, but the speed and quality has improved substantially to be achievable in real-time, but with significant expense. Machine Learning, on the other hand, like the Obama example is significantly cheaper and able to deliver believable results in real-time. Real-time meaning that as the performer/impersonator acts, the results are instantly created. A slightly less complex version of real-time puppeteering methods of this would be a live streamer using avatars or *vtubers*, a virtual YouTuber.[11] For an example of one person impersonating another with machine learning, we look at Jordan Peele's performance of former President Barack Obama in 2018. The interviewees in the video state this is achievable in a few days. Five years later, the Department of Homeland Security stated the technology can provide this impersonation in real-time. In the situation we are addressing, anyone could pretend to be a world leader in a video interview, conference call, or mass communication press release. For example, in 2022 a puppeteering video call attempt was made between an impersonator of a Kyiv Mayor and several European leaders (Oltermann, 2022). With "projects like Deep-Live-Cam, it's becoming easier for anyone to use this technology at home with a regular PC and free software" for puppeteering Vice Presidential Candidate JD Vance, Elon Musk, or anyone (Edwards, 2024).

Knowing that we can create a historical record of global leader saying what we wish, with real-time puppeteering, we begin to question authority, or can we? There is incredible danger, that Flusser points out,

[11] Vtubers live stream themselves and have their computer convert their video image feed into a virtual avatar.

Taking contemporary technical images as a starting point, we find two divergent trends. One moves towards a centrally programmed, totalitarian society of image receivers and image administrators, the other toward a dialogic, telematic society of image producers and image collectors. (2011: 4)

We can think of these as state-run authoritarian media. If the ruling technocratic class could create any image or sequence of images instantaneously, it means that the historical record as the producer decides to create it will be consumed by the image consumers. A global gaslighting of image consumers who are duped to engage with the producer's ideas as reality is something Orson Welles explored as early as 1938 yet current manifestations are far more sophisticated. Meta's AI has been found to report inaccurate historical events of then former President Donald Trump's shooting (Brodkin, 2024). And Elon Musk was found releasing AI generated video of then Vice President and Presidential Candidate Kamala Harris saying and doing things that did not happen (Tandanpolie, 2024). Speed is the most important feature here - speed of ML creating the video and speed of media distribution. There is clear danger from not being able to counter the false narratives as fast as they are generated and distributed.

Speculating on the future, how far are we away from Orwell's vision of a Ministry of Truth[12] in his *1984* novel? If we're inventing the history today, why not invent the history of yesterday to match? This article has demonstrated that rewriting image and video can be done as fast as someone can act it out or write the prompt. With an army of people, like a Ministry of Truth, this previously fictional reality comes closer to plausible. Science fiction has played out several scenarios for us – mostly dystopian futures: alien attacks, zombie apocalypse, and governmental totalitarianism to name a few. The value lies in knowing what could happen and navigating around those speculative endgames.

With the speed of computation, mass communication, and access to digital historical records, this future is possible.

8. Socially Computed Spectacles

Let's reflect on this brief overview of the impact digitization, algorithms, distribution, and speed has had on the image. In Guy Debord's book, *The Society of the Spectacle*, a portion of his critique is how a ruling class uses images to create a spectacle as a means of control on working classes. Debord writes how spectacles are used to create a desired illusion or way of living that the working class strives for. This media attempts to influence the working classes for that which they don't have expensive cars, larger houses, or fashionable lifestyle. In other words, the spectacle is the common life-narrative that the ruling class imposes. This "spectacle" is both an economic engine and method of systemic control. Consider Guy Debord's statements about images: "The spectacle is not a collection of images; rather it is a social relationship between people that is mediated by images" (1995: 12). Unpacking this statement, one finds that images are merely a mechanism for idea distribution, and that what is important is to push those ideas into a social sphere where desire, competition, and distraction can occur. A ruling class using images to control a populous through crafted social relationships. Images have transcended their function of depiction/denotation, "Images detached from every aspect of life merge into a common stream, and the former unity of life is lost forever" (Debord, 1995: 12).

[12] The Ministry of Truth was responsible for Newspeak, the creation of truth and updating all historical documents to conform to the new "truth" so that anyone research a past event would discover the new "truth" rather than an original truth.

Every image in this world of spectacle is encoded with a connoted rhetoric. This connotation supersedes the denotation, meaning that what the image implies, and its influence is more important that what the image depicts. For example, consider the ML generated images of then former President Donald Trump protecting cats and dogs that emerged after the U.S. Presidential debate (Rashid, 2024). These images are created for the intent of generating a spectacle - not the same kind of working-class control, but one of political control to bolster the social dialog around the idea of Donald Trump protecting the cats and dogs for his political gain. Analyzing the depiction of these images is to question the validity of the idea and the former president himself. In another case, remember the Elon Musk example of falsified Kamala Harris video from the previous section, clearly the wealthiest technocrat on earth and owner of the fastest and widest mass media distribution in the world, X formerly known as Twitter, would have political and economic reasons for generating spectacle for his own benefit.

Taking into consideration the computability of instant image generation and dissemination, it's becoming clear that society is moving into an age of pure ideas and spectacle – at least for those willing or not knowing there are alternative options. Any desired reality can be fabricated and socially constructed to become the reality. "In a world that has *really* been turned on its head, truth is a moment of falsehood" (Debord, 1995: 14).

9. A Computed Conclusion

At the beginning of this article, whence the digital generation of any imagined image was impossible within reasonable human lifespan, now we arrive at the end of this article where the results are nearing instant gratification. Those images can be shared by anyone, globally and instantaneously into a social mass media stream and disrupt out epistemic backstop of truth. At this point, producers are only creating simulacrum for the consumers. (Baudrillard, 1983)

Therefore, the image is dead, long live the image.

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