THEATRE ABOUT SCIENCE. THEORY AND PRACTICE

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Theatre About Science. Theory and Practice

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INTRODUCTION

This volume is a direct result of the Theatre About Science Conference, held in November 2021 in Coimbra, Portugal. Most of the articles build upon presentations given at the conference, but some were written specifically for this publication.

Some of the objectives of the conference were to map theatre and science intersections around the world, to promote exchange and expand knowledge on this field, to identify new types of intersections and to integrate non-anglophone initiatives.

In fact, some of the main academic contributions and events to that date in this area of research still had a strong anglophone-world bias. Kirsten Shepherd-Barr's "Science on Stage: From Doctor Faustus to Copenhagen"[1], in 2006, stands out as the first tour de force trying to study and organise a set of what became known as science plays, followed by Eva-Sabine Zehelein's "Science: Dramatic: Science Plays in America and Great Britain 1990–2007"[2] in 2009. After that, the Interdisciplinary Science Reviews published a set of two special volumes, in 2013 and 2014, under the title "New Directions in Theatre and Science"[3] and guest edited by Shepherd-Barr and Carina Bartleet (following a groundbreaking special issue in 2002 in the same magazine[4]), that gathered a collection of articles reflecting the liveliness and diversity of this area, and pointed out some future trends for science-related performance. These publications, along with several meetings on the subject starting with the primordial "Theatres of Science" conference (Wales / UK, 2004), the "Communicating Science to the Public through the Performing Arts" conference (New York / USA, 2010) and the "Performing Science: Dialogues Across Cultures" conference (Lincoln / UK, 2014), stand as important landmarks in the study and reflection upon the field.

More recently, "The Cambridge Companion to Theatre and Science"[5] (2022), edited by Shepherd-Barr, compiled a series of articles that added some new perspectives in this field, and "Science & Theatre: Communicating Science and Technology with Performing Arts"[6] (2022), edited by Emma Weitkamp & Carla Almeida, configures an important step towards mapping the diversity of practices of cross-pollination of theatre with science.

1 Science on Stage: From Doctor Faustus to Copenhagen Science on Stage: From Doctor Faustus to Copenhagen, Kirsten Shepherd-Barr, Princeton U. Press, Princeton, NJ, 2006.

2 Science:Dramatic: Science Plays in America and Great Britain 1990–2007, Eva-Sabine Zehelein, Heidelberg: Winter, 2009.

3 Interdisciplinary Science Reviews, Volume 38, Issue 4, 2013 & Interdisciplinary Science Reviews, Volume 39, Issue 3, 2014.

4 Interdisciplinary Science Reviews, Volume 27, Issue 3, 2002.

5 The Cambridge Companion to Theatre and Science, Kirsten Shepherd-Barr (Ed.), Cambridge: Cambridge University Press, 2022.

6 Science & Theatre: Communicating Science and Technology with Performing Arts, Emma Weitkamp & Carla Almeida (Eds.), Emerald Publishing, 2022.

The forthcoming edition of the Theatre about Science Conference, which will take place in 2023, builds upon all the above to continue to enrich the knowledge and exchange in this fertile field. This volume reflects the great diversity and different perspectives related to the connections between theatre and the sciences, both regarding the performative practice and the academic thought upon that practice. It also gathers contributions from Literary Studies, Theatre and Performance Studies and Science Communication. It reveals a diverse group of practices, varied stages, different formats, different sized productions and diverse target audiences, that suggest a common quality or characteristic in these intersections that can be activated in varied contexts and with different levels of production.

Finally, the diversity of voices and experiences present in this volume also carries with it a strong geographical perspective, with reports of practices in different regions of the globe, sketching a wider panorama of theatre and sciences intersections.

One additional goal guiding the Theatre About Science Conference, which is reflected in this volume, is the promotion of dialogue between the artistic and the science communication worlds. The connections between these two fields have been quickly expanding in recent decades. Science communication is becoming more and more essential in academic and research environments and theatre has been one of the most engaging artistic languages used in this endeavour. The contents of this volume give us a glimpse on some fruitful interactions between artistic practice and science communication.

The volume is organised in two main sections, Reflections and Reports on Practice. The first section contains a group of manuscripts of a more reflective nature, that analyse several theatre plays and performances from an academic perspective and/or question the nature and discuss possibilities for theatre and science liaisons. The second part of the volume presents several engaged reports on practical cases of interactions between theatre and the sciences, which are very diverse in nature, form, theme and working processes, and display a rich ecosystem that defies the establishment of boundaries for what can be defined as theatre about science.

Along with the diversity they portray, the manuscripts in this volume also dialogue with each other. There are shared themes, like for instance Physics and metaphors in the texts of Canals and Hagenaars, discussions on the lecture-performance format in Delbecke and Brunello, the anthropogenic impact on the planet is present in the manuscripts of Albernaz, Hamilton and Simpson & Shepherd-Barr, or considerations on ethical perspectives in Health Sciences, in the works of Townsend and Zehelein.

Several texts describe different creative processes, with a variety of perspectives, like the one of a dramaturg (Tretter), the one of the writer in his individual endeavour (Marques), the collaborative

writing of several playwrights (Erice), a one-woman show (Hagenaar), the collaboration between artists and scientists (Albernaz, Rodrigues et al., Spiga, Bowman, Erice), writing plays with Artificial Intelligence (Rosa), or the interaction human-AI machine on stage (Mirowski). On the other hand, we also have some philosophical reflections on theatre and topology (Jerpe) and on the very meaning of theatre about science (Mendes).

Although we can trace science in theatre at least to the beginnings of modern science itself[7], the scholarship on this intersection started essentially in this century. It has been an academic subject for roughly two decades. This volume stands as an additional contribution to the knowledge on this field, displaying its diversity in terms of themes, geographies, presentation formats, target audiences, and creative contexts, processes and tools.

7 The Emergence of Modern Science and its Representation in Dramatic Text, PhD Thesis, University of Coimbra, 2017.

I. REFLECTIONS

STUFFED BEARS AND CANNED TUNA: STAGING ANIMAL EXTINCTION THROUGH THE MATERIAL PROP

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Introduction

Our Anthropocene epoch, also termed the "Sixth Extinction" period, is one of the six major extinction periods of the Earth's existence.[8] We are witnessing catastrophic rates of multiple flora and fauna species extinction, overwhelmingly due to human activity that has resulted in habitat loss, overexploitation, invasive organisms, pollution, and climate disruption (Ceballos, Ehrlich and Dirzo, 2017). Current scientific estimates place us on a trajectory towards "a mega-mass extinction of populations", losing between one-third and two-thirds of all currently living species (Myers and Knoll 2001). It is easy to forget that extinction – whether the mass-species extinction event, or the total extinction of any single species – was once conceived of as a normal process of nature. In Charles Darwin's writings, for example, extinction is not described as tragic loss, but instead as an inevitable, even necessary part of the cycle of the natural world and illustrative of the workings of natural selection.[9] Now, as human beings have sped the rate of species extinction up to disastrous and unprecedented levels, animal extinction has become a nearly inconceivable tragedy, posing a challenge to our attempts to conceptualise or comprehend the sheer magnitude of climate crisis, "the new kind of incommensurability that is being forced on us by our ecological predicament" (Chaudhuri 2016, 305). The immense number of individual deaths encompassed by this collective annihilation, the ongoing consequences for the associated ecosystem, and the sheer finality of that creature's now-total non-existence: extinction strains at the boundaries of our cognitive or emotional comprehension.

There are two entwined representational challenges for theatre that attempts to grapple with the fact or threat of animal extinction, in order to render the phenomenon both cognitively and affectively legible to the audience: the difficulty of translating the fact of *loss* onstage, of absence rather than presence, and the difficulty of translating such an inconceivable *scale* of this loss on the bounded space of the stage. An entire species or species of animals gone forever: how to stage such massive loss, or its looming threat? In a previous discussion of theatrical engagement with global climate disaster (Shepherd-Barr and Simpson 2022), we focused on the staging of landscapes, ecosystems, and envisioned catastrophes that extended far beyond and below the scale of the traditional theatre stage (and, indeed, any easy human conceptualising), surveying how contemporary theatre has sought to move us into a more-than-human scope of thought. Here, we narrow our focus to consider instances of animal extinction depicted onstage as small, inert material props, drawing together Timothy Morton's ecological hyperobject (2013) and Andrew Sofer's "dark matter" of the stage (2012) into a new theorising of the non-living theatre prop as a means of conveying on the stage the near-incomprehensible scope of the lost life entailed by animal extinction.

8 The previous five major extinction events, which saw losses of more than 75% of the Earth's living species, have been the Ordovician-Silurian, the Late Devonian, the Permian-Triassic, the Triassic-Jurassic, and the Cretaceous-Paleogene (Raup and Sepkoski Jr., 1982).

9 See Beer 2009 for further exploration of Darwin's depiction of extinction and our altered valuation of extinction today.

Tanya Ronder's *Fuck the Polar Bears* (2015) and Marek Horn's *Yellowfin* (2021) both turn to a non-living but uncannily adjacent-to-life prop in order to communicate the vast loss of extinction on stage: a cuddly stuffed polar bear in *Fuck the Polar Bears*, and a tin of tuna in *Yellowfin*.[10] In both plays, the "discrete, material, inanimate object", as theatre scholar Andrew Sofer defines the stage prop (2003, 14), is invested with a simultaneous and mutually cancelling sense of liveness and non-liveness – an adjacency-to-life that is never permitted to spill into actual liveness – in order to evoke the ungraspable scale of the *lost* life encompassed by animal extinction. It is precisely the twinning of an adjacency-to-life with the crucial *absence* of actual animal life onstage that most effectively conjures the sense of unfathomable loss entailed by species – and of the dispiritingly small individual human action in the face of the vast scope of the climate crisis. Each prop is comically tiny within the stage space, straining under the weight of the characters' sustained attention. This imbalance echoes the dispiriting clash evoked in both plays between the minute scale of individual action against the immense scope of the climate crisis – and of corporate environmental damage caused by mass-scale corporate and governmental action. The central props of teddy bear and tuna can thus operate as crucial points of slippage on stage: a slippage that sits at the heart of our current ecological despair.

Animal Extinction and the Stage Prop

Environmental philosopher and anthropologist Thom Van Dooren has observed that, in order to render species extinction legible, many Western accounts have focused on the death of the very last individual of its kind. Here, the instance of death stands simultaneously for the death of an individual creature *and* for the collective death of an entire species; the bounded moment of death also stands in for the broader *absence* that follows, the collective *non-being* of that species stretching out infinitely across time. Van Dooren criticises this representational tactic as overly reductive, arguing that "the immensity and significance of extinction cannot be captured within these singular events" (2014, 11):

> [T]he loss, the change and disruption – often accompanied by violence and suffering – that occurs in extinction must not be reduced to this one event. Instead, the deaths of these last individuals must be understood as singular losses in the midst of the tangled and ongoing patterns of loss that an extinction is. […] When species are understood as vast intergenerational lineages, interwoven in rich patterns of co-becoming with others, then their departure from the world cannot help but be felt in a range of complex and drawn-out ways. (2014, 12)

To Van Dooren, the synecdochic representation of animal extinction via the death of one creature occludes the large-scale "violence and suffering" encompassed by a species extinction and the

10 *Fuck the Polar Bears* was first staged at the Bush Theatre in London in September 2015, directed by Caroline Byrne. *Yellowfin* was first staged at Southwark Playhouse in London in October 2021, directed by Ed Madden.

"ongoing patterns of loss" that follow that moment of death; this representational strategy fails to capture the intricate vastness of the entangled consequences of one species death for the ecosystem as a whole. The problem, again, is one of scale: death is not the same as extinction, and a single death is not the same as species loss.

Yet theatre as a medium very often works at precisely this level of synecdochic representation, materialising the small, singular, temporally specific instance onstage in order to represent the larger, multiple, or ongoing offstage phenomenon. As Una Chaudhuri points out, "a certain kind of incommensurability is in fact *constitutive* of theatricality", whereby "immense horror" can arise from "a modest structure" of the characters, items and settings that will fit on the bounded stage space (2016, 304). Deke Weaver's *The Unreliable Bestiary* follows precisely this tactic, using the singular titles "Bear", "Wolf", "Tiger", "Elephant" and so on to signify entire species endangerment. Central to Weaver's approach is the fluidity of the stage space, which encompasses site-specific natural settings suggesting or recreating habitats, simulating encounters between elusive animal species and humans and, most importantly, enabling the audience to feel like the intruder into the animal's space — rather than a spectator watching an animal perform.

The stage prop's most common function, Sofer argues, is to act as a "*visual shorthand*", signalling a larger abstract or concrete entity as it exists beyond the stage space: "Theatre continually encourages us to take parts for wholes" (2003, 20, 332; original emphasis). Within this context, we suggest, the stage prop in the climate crisis-engaged play might be more productively understood as a "theatrical hyperobject", following environmental philosopher Timothy Morton's concept of the environmental hyperobject. The hyperobject is the nonlocal, the incomprehensibly vast phenomenon that disorients the human scope of understanding, massively distributed in time and space relative to humans, and which the human consciousness can directly experience only in part via specific, local manifestations: the raindrop that is part of "the climate", the city flood that is part of "global warming", the plastic bag that is one instance of the incalculable accumulation of nondegradable petroleum products in existence.[11] The bounded local and material manifestation or consequence both is and is not 'the hyperobject': the hyperobject is simultaneously both itself as individual material object, and an immense nonlocal phenomenon that cannot, in its vast totality across time and space, be directly experienced. There is a secondary parallel here with Sofer's theorising of the stage prop as not only synecdochic of its broader existence in the offstage world, but also as part of the system of "dark matter" that Sofer theorises as central to theatrical representation, "the invisible dimension of theatre that usually escapes detection, even though its effects are felt everywhere" (2012, 330).

This is how the central inanimate props operate in *Fuck the Polar Bears* and *Yellowfin*. The *Yellowfin* tuna can is spectrally linked to all the lost fish of the world's oceans, as well as to the main character's

11 See Morton 2010 and 2013.

own murdered brother and the drowned people of England; the cuddly toy polar bears of *Fuck the Polar Bears* evoke the actual living polar bears menaced with extinction, as well the future generations of children the play imbricates in the threat of climate crisis-induced mass annihilation. Both props are unsettlingly *adjacent* to life: the stuffed polar bears are recognisable miniature replicas of a living bear, and the tin of tuna holds the flesh of an animal that was once alive. Nevertheless, both props are 'dead', inanimate objects, and so a central animal *absence* remains embodied in their onstage presence, for all their extended associations with various form of animal life. Both the tuna can and the stuffed polar bear prop, then, materialise a certain 'presence of absence' to denote animal extinction. The material *not-quite*-animality of each prop evokes the threat of the more abstract *no-longer*-animality represented by species extinction. Both the polar bear and the tuna become what Sofer terms "enlivened props", props that "take on a life of their own in performance" and "haunt the spectator's imagination" – and, we might add, the imagination of the plays' characters as well, imbricated in the catastrophe of animal extinction evoked by these haunting, enlivened props (2003, 29). The specific qualities of these terms "enlivened" and "haunting" are crucial to how these props function to connote animal extinction: they are "enlivened" but not 'alive', they "haunt" rather than 'live'. These props are associated with an animate form of death, lost life or not-living rather than straightforward 'life'. Thus the small, individual, non-living prop in these plays can translate onto the stage a sense of the vast *lost* life of animal extinction, of haunting absence rather than presence, entwined with a 'dark matter', 'hyperobject' sense of the ungraspable, materially unrepresentable scale of that loss.

In both plays, the way the props are handled mimics our collective handling of the earth: roughly, violently, abusively. Horn's can of tuna is eventually punctured by an incongruously large harpoon gun, and then its contents greedily consumed as the play ends. Ronder's toy polar bears are manhandled, kicked across the stage and stuffed beneath furniture; a young actor dons a polar bear costume, blurring the line between subject and object. Is this a model of inter-species empathy, the child's existence overlapping with that of the bear? Or another image of grotesque exploitation in a play full of such instances, animal life (and the rest of the natural world) ravaged for human consumption, clothing, comfort? The vulnerability of these not-quite-animal props resonates across both plays, even though they gain a short-lived – and distinctly malevolent – agency of their own in the course of the drama.

This chapter explores how the central props in Ronder's *Fuck the Polar Bears* and Marek Horn's *Yellowfin* operate within this dark-matter hyperobject dynamic to render animal extinction legible on stage. It also reads these plays as key expressions of a contemporary form of ecological anxiety, in which the scale of the disaster facing the Earth so overwhelms the scope of possible response as to make the individual's action seem futile, tiny, absurdly inconsequential. This is the "crisis of human agency" that Timothy Clark terms "Anthropocene Horror", in which the impossible scale

of environmental catastrophe clashes with "the felt insignificance of any and every single act" that a human being can make in response (2020, 70, 75). "What difference could it make?", Calantini demands in *Yellowfin*, faced with the choice of opening a single tin of tuna. "You know there's only one way this is going to go / And so you know that it doesn't really matter" (2021, 115). In the final section, we explore how the central props of these plays signify doubly on stage. Connoting the larger scale of animal extinction, they also still exist as single material objects on the stage, very literally figuring the tiny, seemingly trivial individual action in the face of vast systemic governmental and corporate negligence and mass-scale ecological catastrophe.

Fuck the Polar Bears: "she's disappeared"

In Ronder's *Fuck the Polar Bears*, the two titular toy polar bear props function as complexly 'alive' yet non-living objects. The stuffed toy bears are potent onstage entities which the human characters invest with imaginative life, and which twice seem momentarily to come to life before the audience's eyes. Yet both are very literally *non*-living (both on the stage and in the fictional stage world), and their uncanny moments of apparent life – as malevolently agential forces intervening in a world that barrels towards their extinction – bespeak a sympoietic mingling of material object, animal and human life, all imbricated in the climate crisis.

In *Fuck the Polar Bears*, Gordon is the Communications Director of "*a big energy company*" (2015, 6), and lives with his wife Serena, his daughter Rachel, and their au pair Blundhilde. Gordon and Serena are an upwardly mobile family, thanks to Gordon's success in the energy industry: their lives are a whirl of yoga, champagne in the kitchen, and expensive home improvements, as well as periodic defences of their complicity in the climate crisis in the face of criticism from the ecowarrior Blundhilde and Gordon's semi-hippy brother Clarence. Nevertheless, intimations of ecological loss and particularly animal death creep through the play. The couple are painting their home in an ominous "bone" shade (2015, 28), and Gordon reminisces about the declining population of the British hedgehog: "Have you ever seen a hedgehog, Blundhilde? […] There used to be thirty-four million on this island. D'you remember the one we found in the park with Dad?" (2015, 59).[12] Evocations of the skeleton, the fossil, and the lost native hedgehog haunt the edges of the play.

However, it is the simultaneous absence-and-presence of daughter Rachel's favourite stuffed toy, a polar bear named Phoebe whom Rachel insists is alive, which most forcefully focalises the play's attention to animal extinction. The beloved Phoebe has "disappeared", we are told early in the play (2015, 14), the word resonant with intimations of species disappearance; we hear Rachel's

12 British hedgehogs were formally classed as "vulnerable to extinction" and added to the "Red List for British Mammals" in July 2020, in recognition of the sharp decline of the species population over the previous two decades: https://www.mammal.org.uk/science-research/red-list/

disembodied voice on the phone calling for her lost animal, and the adults repeatedly ask each other for updates on the vanished Phoebe throughout the first two acts, suffusing the action with a constant reminder of the absent toy. Before she vanished, it seems that Phoebe suffered at the hands of the family's energy-guzzling appliances: "we washed her in the bath and then hung her out to dry, but Rachel wanted her that night in bed so Serena put her in the tumble dryer but the plastic on the eyes melted", Blundhilde tells Clarence (2015, 34). As a non-living object that is absent from the stage for much of the play's action – and indeed, as a non-human object damaged by human technology before her disappearance – Phoebe connotes the gone-life of extinction. (Blundhilde's anecdote that the neighbours thought that Phoebe hanging on the washing line was the body of a dead dog heightens the aura of literal animal death that hangs around the idea of her.) At the same time, however, the very absence of her intensely evoked once-presence invests that idea of extinction with a particular affective force. Phoebe, once convincingly 'alive' to the family by way of the imaginative games they played with Rachel – and, rather more disturbingly, by the fact that her melted plastic eyes made it seem "like she's always looking at you, wherever you are in the room" (2015, 34) – operates as a staging of the lost throughout most of the play, part of what Sofer identifies as the "dark matter" of theatre performance: "*whatever is materially absent onstage but un-ignorable*" (2012, 332, original emphasis). It is in her very absence from the stage that Phoebe can become more effectively 'alive' for the audience – or, more specifically, alive-yet-lost.

If Phoebe the bear is primarily an *absent* adjacent-to-life prop throughout the stage action, a more distinctly *present* material version soon appears onstage: Rachel's uncle Clarence has brought her a new, even smaller cuddly polar bear, "a baby one" (2015, 23; see Figure 1), who appears onstage at the end of Act One and is immediately freighted with a sinister adjacent-to-life stage presence. At moments when Gordon is defending his environmentally destructive lifestyle most vociferously, the cuddly toy trips him up:

> GORDON: Even us rich bastards have our moments. But it won't last long. (*He takes a step backwards and trips over the little bear*.) Aagh! (2015, 24)

> GORDON: Bully for you, with your Help-the-Aged girlfriend and your do-gooding attitude. (*He trips up again*.) Fuck! (2015, 27)

Gordon, as the energy company's CEO and instigator of a new bill to allow UK fracking at a catastrophically destructive level, is the clearest representative in the play of the corporate drive to "to sell and burn and heat the world", as Blundhilde will later accuse him (2015, 66). The tiny polar bear's tripping Gordon up offers a repeated moment of the object's seemingly agential refusal to be forgotten or ignored: a literal instance of the disruptive encounter between human and non-human that forces a new acknowledgment, against what Timothy Clark has identified as our collective

inattention towards climate change and habitat destruction: "we have lived for so long with variously frightening possible futures, that even emerging news on vast swathes of the arctic being in flame has an insidious sense of déjà vu and the inevitable, so its resistance to being felt slides easily into being effectively a form of denial" (2020, 74). Son of Phoebe interrupts this disregard on Ronder's stage.[13]

Figure 1: Phoebe and "Son of Phoebe", *Fuck the Polar Bears* rehearsal, Bush Theatre, London, 2015. Photograph by Helen Murray.

From here, the representation of the polar bear onstage becomes increasingly overlaid with a complex array of seeming-but-not-quite-liveness. The au pair Blundhilde has been secretly keeping a white hamster named Igloo in her room, which escapes: both Gordon and audience members see

13 The rest of the house similarly turns malignly against Gordon and Serna, refusing to submit to their environmentally destructive lifestyle. The kitchen doorknob comes off in Gordon's hand, and his champagne glass shatters as he is holding it; the hot water stops working and the drains flood; light bulbs blow unexpectedly and the tumble dryer starts up at will. Gordon's phone charger and Serena's laptop track pad stop working; the fridge-freezer cuts out, defrosting the food inside; the patio door sticks and refuses to close. A piece of glass somehow makes its way into Serena's slice of pizza, which she only notices when she "crunche[s]" it in her mouth, leading Gordon to advise her to "eat something to bulk it out so it can't cut anything on the way down", "Like my jugular?" she replies (2015, 18).

"*a small white creature scamper*[ing] *across the room*" in the middle of Act Two (2015, 45), and for a moment it seems that the missing Phoebe the polar bear has in fact come to life and invaded the stage. While the attentive audience member quickly realises that this is *not* Phoebe, the moment of perceptual uncertainty lingers, investing our idea of Phoebe with a still more disorienting degree of simultaneous liveness and non-liveness – and Gordon, already struggling with his ambivalent feelings over his fracking plans, descends into a guilt-induced spiral, convinced that Phoebe has come alive and is taunting him. He hunts Phoebe with increasing fervour, charging her absent-presence with a dangerously malevolent aliveness, warning his family, "Polar bears are very, very clever. […] You mustn't underestimate them, we can't afford to do that. […] They're so cunning and vengeful. […] They look all fluffy and pure but have you seen a picture of someone mauled by one? They're dangerous, dangerous animals" (2015, 47-9). He describes a recurrent nightmare in which he is trying in vain to save his daughter Rachel from a heavily polluted river, impeded by Phoebe:

> I try to swim to her but there are things in my way. She can't see through her goggles. The things I'm passing are corpses, humans and bears. With plastic eyes. […] Then I see Rache is holding Phoebe, trying to swim. 'Rache!' I yell, 'drop her, let go of the bear!' She still can't see but Phoebe looks at me. Not caring if she takes her down. (2015, 70)

As the prospect of human and animal extinction becomes increasingly mingled in Gordon's mind, the figure of the toy bear appears again as both living and non-living here: the bears in the river are the "corpses" of presumably once-living bears, and yet have "plastic eyes"; Phoebe herself is still Rachel's toy, small and passive enough for Rachel to hold her while she tries to stay afloat, and yet capable of looking at Gordon and "caring" or not caring about Rachel's death. Although materially absent from the stage – and a non-living entity – Phoebe the stuffed polar bear comes *nearly*-alive, *nearly*-present, everywhere throughout the play: in the family's frantic search for her, in the inanimate-but-agentially-malevolent onstage "Son of Phoebe" toy, in the large white bearskin rug in the middle of the stage, in the briefly glimpsed figure of the white hamster, and in Gordon's recounting of his nightmares. Phoebe is spectrally present, haunting the stage and its characters, in a constant threatening reminder of the threat – in both senses of the word – of animal extinction.

At the climactic moment of Act Three, Gordon finally succeeds in trapping 'Phoebe', exploding in violent anger:

> *Out of the corner of his eye he sess a white figure run into the playroom. Gordon turns, He stalks to the door, pulls it closed and draws the lock*.
> GORDON: Now I've got you, you little bitch!
> *He pulls a chair up against the handle*.
> And I'm not letting you go. You're here till my wife gets home so I can show her who you are, furry

fucking demon. Messing with my head. You're severed from my daughter. Before she ever sets eyes on you again, I'm ripping you up, pinning you down, shaving you bald, then I'm going to get a knife…
He goes to the kitchen, gets a knife.
I'm going to get a knife so I can cut your stupid fucking eyes out, plunge my knife inside your brains and cut them off from their stems, roll your sightless dismembered head in shit, foul it with excrement and then stuff it down your neck […]. You're not taking her with you, you're not taking her with you, you're going alone and you're never coming back, wreurrrrghhhhhhhhhhhh!
He is screaming through the door. (2015, 57-8)

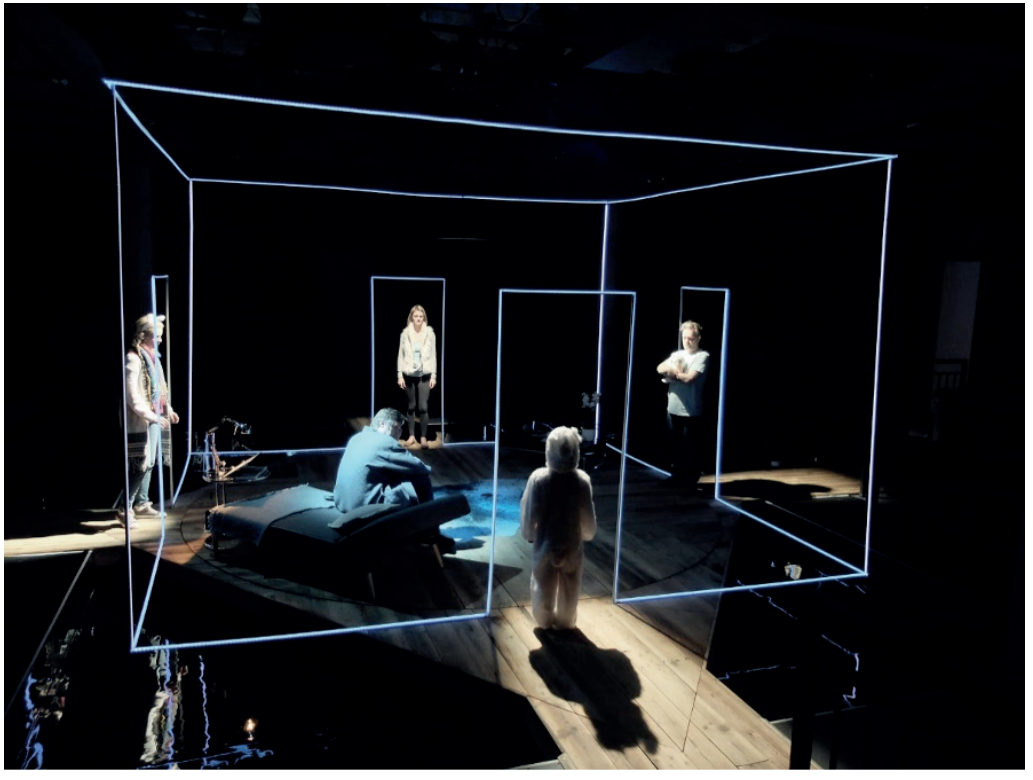

Figure 2: *Fuck the Polar Bears*, Bush Theatre, London, 2015. Photograph by Chiara Stephenson

Figure 3: Susan Stanley as Serena and Eléa Vicas as Rachel in *Fuck the Polar Bears*, Bush Theatre, London, 2015. Photograph by Helen Murray.

Serena and Blundhilde return – Serena wearing a white furry coat, and Blundhilde Rachel's dress-up bear ears – just as Uncle Clarence comes downstairs, clutching the bedraggled body of the stuffed Phoebe, whom he has found underneath the bath. Phoebe has finally arrived onstage in a material (and clearly non-living) form, but her presence is wildly, uncannily multiplied before she can be reduced down into a singular non-living entity: "*the space seems peopled with bears*", the stage directions instruct, as the flashing white lights of the set bounce across the white fur of Serena's coat, Blundhilde's ears, the bearskin rug, and the furry toy in Clarence's hand (2015, 58; see Figure 2). Serena and Blundhilde demand to know if anyone has seen Rachel, who has apparently just

returned from a friend's sleepover dressed in a new costume outfit, "like a little polar bear" (2015, 58) … and it becomes clear that the white furry shape we've been seeing on stage was not Igloo the hamster but Rachel the child, and that Gordon has been screaming threats and obscenities through the door at his daughter, who now finally appears clearly for the first time on stage, dressed as a tiny polar bear (see Figure 3). Gordon cannot in fact "sever" Phoebe from Rachel; he cannot separate the damage his fracking plans will do to the environment from the damage he will do to her future. Just as he inadvertently turns his violent rage on his own child in place of the absent bear, so too the consequences of his ecological destruction are displaced onto her generation – themselves synecdochically embodied in her small, vulnerable figure onstage**.**

The rapid shifts between inanimate prop, seemingly live animal and human figure onstage cognitively and affectively disorient the spectator as well as the hapless Gordon. For all our momentary uncertainty about the living white figure onstage, and for all the family's investing Phoebe and Son of Phoebe with imaginative life (and death), the live animality of the actual polar bear remains absent from the stage – an echoing absence emphasised by these moments of seeming life. Unsettlingly adjacent to life, yet nevertheless non-living, Phoebe and Son of Phoebe evoke a crucial animal absence via their onstage presence: local manifestations of the 'dark matter' of the threat of species extinction beyond the family's domestic world, and the theatre's own stage space. Simultaneously, however, the constant slippage between prop, animal and human muddles the boundaries between the three, refusing the idea of "extinction as something that happens 'over there', 'out in nature' […] as a process that affects other species" (Orozco 2018, 185). The weird potency of the non-living but adjacent-to-life bear prop on Ronder's stage moves beyond established categories of human, animal and object, into a more troubling version of Donna Haraway's sympoietic environment in which all beings exist in contingent contiguity with each other, a multispecies "becoming-with and unbecoming-with" rather than in secure isolation (2016, 40). Following the logic of Morton's hyperobject and Sofer's dark matter, these polar bear props manifest that which is simultaneously unrepresentable yet unignorable on Ronder's stage: the entire life of the polar bear species vanished from existence, along with future generations of children likewise imbricated in the threat of climate crisis-induced mass annihilation.

Yellowfin: "And then there weren't fish"

Horn's *Yellowfin* picks up the thread of imbricated animal extinction in a near future very like our own present day, but in which two large-scale 'species extinctions' have occurred. Mass flooding has drowned all the inhabitants of certain low-lying countries, including England and all the English; and, some thirty years prior to play's action, all the world's fish disappeared. "They went overnight", protagonist Michael Calantini muses:

There was no 'steady decline'
There was no 'just getting used to it'
There were fish,
And then there weren't fish,
Simple as that. (2021, 50)

The play stages a US senate committee hearing in which Calantini is being questioned by the three senators Marianne, Roy, and Stephen on the possible charge of "the illegal handling of rare fish substances" (2021, 46). As in *Fuck the Polar Bears*, the key titular prop – here, a tin of tuna – remains offstage in the early scenes, during which time the characters' discussion invests the object with a potent sense of lost life. Calantini explains to the senators how the taste of "real" fish – unlike the cloned squib-fish now being bred, incapable of swimming or breeding – tastes of "life" when eaten:

It feels like
Power
And
It feels like a thing… that has lived. (2021, 31-2)

The tuna meat within the can is loaded with a powerful sense of not simply death but of indescribable *lost* life: it is "hard to describe what it means" to encounter actual tuna (or even actual tuna meat), Calantini reiterates: "There really is nothing like it" for those, like the younger senator Stephen, who have never known nor eaten fish (2021, 29, 31). Here again, *non*-living animality is used to evoke *no-longer*-living animality, this time via the tin of tuna fish in place of the stuffed toy polar bear.

Indeed, it is not simply the tuna meat but the tin itself that becomes most potently freighted with the sense of lost life. When trading on "the underground wild-fish black-market" that sprang up in the aftermath of the fish's disappearance (2021, 53), Calantini explains, he and his brother would never open a fish can themselves, in order not to rob the customer of this element of the experience:

When it comes to a can like that,
They want the *complete experience* and he *knew* that
They want to *open it*, themselves
They want to drain the oil over a sink like they're bleeding a stuck pig
They want to fucking… *hunt* it (2021, 35)

This imbrication of the can itself in the life-death nexus continues as Calantini's backstory is revealed. When some black-market clients suspected the Calantinis of deceiving them as to the contents of the can they were purchasing, we learn, they enacted a brutally ironic revenge on Michael's brother, dismembering and "chunking" his body before encasing it in the family's own tuna cans:

ROY: Like one of your tuna fish?
CALANTINI: Yeah
Exactly that
That is exactly the analogy that I would use […]
It is that, exactly
That is how they 'Tinned' him
Like a tuna fish.
Pause. Calantini, still away from the mics, double over and screams. Silence. (2021, 48-9)

By the time the tin of tuna itself appears on stage near the end of Act One, it is difficult to dissociate the material object from the idea of death. In turn, this post-fish society's treatment of the remaining tins of meat becomes part of the extended process of extinction, as not only the food consumer market but also the scientific community "hunt" them:

And they needed the information that was inside the old fish
That was inside the meat […]
That they knew must reside…
In each fleck of Fish DNA
And so they pillaged the existing supply
They ripped through it
Churned through it
Like a fucking wood chipper
Can after can with no sense of restraint. (2021, 52)

Figure 4: Joshua James as Calantini in Yellowfin, Southwark Theatre, London, 2021. Photograph by Helen Maybanks/ArenaPal'

Even after the disappearance of living fish, rapacious human consumption continues, and the tins of tuna meat are drawn into the extinction process. The adjacent-to-life but non-living object comes to stand for the idea of lost animal life at a vast, irreversible scale.

Thus, by the time the final remaining can of tuna itself appears onstage, it has already been invested with an intense weight of meaning. Roy produces "*an unmarked can*" from behind the senators' bench (2021, 63). The senators tell Calantini that, according to the tests they have run on this crucially "unlabelled" tin, they believe this to be one of only four remaining cans of bluefin tuna left in the world; they want to open it under controlled conditions to scientifically analyse each shred of the fish flesh in the hope of discovering the reason for the mass species disappearance. The senators don't know for certain what is inside, and need him to confirm the contents in order to get both permission and funding to go ahead with their investigation: "Only if we know that this is Blue can we proceed", Marianne admits (2021, 72). The playscript never confirms if the can holds bluefin tuna, or perhaps yellowfin as the title suggests – or another type of fish entirely. The unknowability of the tin parallels the unknowability of the disappearance of the fish themselves. As Marianne puts it, "How did the fish go? / Where did the fish go? / Why did the fish go? / The three great questions of our age" (2021, 67). These questions are part of a sustained monologue consisting entirely of such questions: urgent, wistful, and unanswerable. The inscrutable presence of the hermetically sealed, unmarked tin offers a material reminder of the unfathomable scale of the extinction of an entire order of animal life.
As with the two miniature bears in *Fuck the Polar Bears*, the tiny tin of tuna on the *Yellowfin* stage by now carries an absurd burden of meaning: the collective existence of the vanished fish, Calantini's murdered brother, the memories of the lost human experience of eating fish, the answers to Marianne's extended monologue of questions about the fish disappearance to which its DNA might reveal the answers, and the dream of a future world full of newly resurrected fish. The comically outsized weighting is emphasised when Calantini produces a huge harpoon gun from offstage and points it at the tin, threatening to pierce its protective seal too early and degrade the precious meat within. The moment heightens the unsettling adjacency-to-life of the tuna can, since the harpoon gun is more typically used to kill a living creature and thus offers a reminder of the "violence and suffering" that occurs in animal extinction, to return to Van Doreen's thinking (2014, 12). More specifically, however, the incongruous size difference between the harpoon and the tiny tin also emphasises the uncanny potency of the hyperobject prop itself, standing in for all the unrepresentable 'dark matter' of mass extinction beyond the bounded stage space – and, indeed, beyond the ready comprehension of the human mind.

The Prop as Individual Object: "IT'S JUST / A FUCKING / FISH!"

The significance of this imbalance runs beyond the clash between visible materiality and unrepresentable magnitude in *Fuck the Polar Bears* and *Yellowfin*. Both plays are concerned not only with the vast extent of the climate crisis and animal extinction, but also with the agonising sense of

the individual's futilely tiny scope for meaningful action within that crisis. The problem is again one of scale. As Clark puts it, "At issue is not the ethical ordeal of being able to reach a decision, but the panic inherent in that decision having no decisiveness" (2020, 73). The individual ecological action – recycling, going vegetarian, walking or cycling to work – needs to be replicated, consistently, across many individuals in order to have any effect. "Because unilateral doesn't work. *If you're not doing anything about it, why should I?*", Gordon despairs in *Fuck the Polar Bears*. "How do you organise multilateral, worldwide self-denial…?" his wife replies hopelessly (2015, 77, original emphasis). The individual action by itself seems vanishingly insignificant, any scale effect invisible quickly eroding any easily comprehensible sense of individual influence. Both plays depict the individual's anxiety as to the futility of their own individual actions in the face of the overwhelming catastrophe of the climate crisis – and the more far-reaching action (or inaction) of larger industrial and governmental bodies. The issue of scale looms large again here: what use recycling my egg carton while multi-national airlines fly hundreds of empty airplanes across the skies in order to maintain governmentally-mandated contractual obligations?[14] What use walking instead of driving when corporation negligence allows disasters like the Deepwater Horizon oil spill to pollute 70,000 square miles of ocean and 600 miles of coastland with 205 million gallons of crude oil?

Both *Fuck the Polar Bears* and *Yellowfin* express this sense of what Clark calls "Anthropocene horror": this feeling of "living in a context of latent environmental violence and feeling personally trapped in its wrongs" – implicated, complicit in its destruction – and yet powerless at an individual level to make any significant change, "a feeling of inadequacy, of being the target of ethical demands that exceed anything one could do in combating global environmental wrongs" (2020, 62, 68). That is, neither play necessarily abjures the logical possibility of cumulative individual action making some difference to the environmental situation – both Ronder and Horn clearly position accelerated animal extinction as the consequence of human activity – but each digs into the affective mismatch of individual gesture against large-scale catastrophe, "the kind of derangement of scale familiar in environmental slogans ('eat less meat and save the planet')" whereby "a sentence about the possible collapse of civilization can end, no less solemnly, with the injunction never to fill the kettle more than necessary when making tea" (Clark 2012, 158, 151). "Make your showers too long and you'll make the world unlivable in", Serena observes wryly in *Fuck the Polar Bears*, adding "Did you know we're killing Peruvians by eating so much quinoa" (2015, 74). The earnest Blundhilde slips between rousing call to action and absurd bathos throughout the play in her determination to cultivate an ecologically friendly way of life:

> BLUNDHILDE: There are no spectators, baby or old man, whatever your problem you cannot not take part, everything you do either saves or cooks the planet. (*Beat*.) Be sure to put your mint wrapper in the right bin – it's the blue one in the kitchen. (2012, 39-40)

14 The term "ghost flights" refers to empty or near-empty planes flown to ensure that airline companies meet their contractual obligation to run 80% of their scheduled flights to retain their airport landing slots. It is estimated that current ghost flight numbers in Europe alone generate up to 2.1 million tons of greenhouse gas emissions per year (Nelsen 2022).

Struck by the agonising mismatch between her own efforts and the extent of new environmental devastation heralded by Gordon's fracking plans, she spirals into frantic small-scale action:

> BLUNDHILDE: I save everything, the tiniest bit of plastic, I save, I have piles of mint wrappers in my room waiting to come down, I pick toilet rolls out from the upstairs bin. I break my brains working out where to put the lunch box when food is stuck to the sides, do coffee cups go in plastic or paper, what do I do with hardback notebooks when the cardboard has that layer of plastic on, receipts with staples, cling film with sticky labels, kitchen roll, padded envelopes…
> *She goes to the kitchen, gets the normal bin*.
> I bet this is full of stuff you've not separated.
> SERENA: Don't get the bins out, Blundhilde…
> BLUNDHILDE: Look, that's pure plastic, these shouldn't be in here, you have to put them in there!
> SERENA: Stop it, Blundhilde, put the bins away.
> BLUNDHILDE: I won't stop.
> *They have an in-out fight over stuff from the bin*. (2015, 66)

The material objects of recyclable waste onstage seem pathetically small in the shadow of the vast destructiveness of Gordon's fracking plans – which are themselves ironically represented onstage by a single sheet of House of Commons-headed paper which could too be placed, carefully, futilely, in the correct recycling bin. "You're not going to save the world with recycling, Blundhilde," Serena snaps; "What am I meant to do?" she responds despairingly (2015, 68). Clark's Anthropocene horror resonates through these scenes: the reality of human responsibility for ecological disaster is coupled uncomfortably with the insignificance of individual human action. Competing scale of representation collide in the props at these moments, to devastatingly disorienting effect. If the prop operates at one level as an onstage material surrogate for vaster offstage species loss or unrepresentably colossal global catastrophe, it can simultaneously also collapse back into exactly what it literally is: a tiny single object, reflecting the smallness (and futility) of the individual action in the face of climate catastrophe.

Similarly, much of *Yellowfin*'s dark humour circles around the absurd weight of significance placed on the tiny onstage tin: opening a single can of tuna will, by itself, likely make little difference to the survival of an entire species. Shifting scales of meaning are superimposed upon the onstage tin throughout the play's final scenes, which revolve around a battle over the ultimate significance or insignificance of the single tin itself in the face of final extinction. Marianne and Stephen, the most determined members of the Senate Committee, retain a dizzying vision of unprecedented insight and possibility emanating from the tuna can before them: they can multiply a tiny "shred" of tinned fish into vast new existence, to "make the great empty blueness *teem* again" (2021, 73). "Maybe we can start anew again", Stephen offers, "Maybe we can start to put things right" (2021, 102-3). Calantini decries their intentions as "meaningless" (2021, 93). In contrast to Blundhilde's

desperate continued attempts to 'make a difference' in *Fuck the Polar Bears*, Calantini is resigned to the inevitable destruction. Having caused the problem, humanity is now helpless to stop it:

> ROY: We should try to make things better!
> We should try to make things… back how they were!
> CALANTINI: It's too late for that
> It's too late for any of that
> It is all too little
> And it is all too late. (2021, 113)

"It is all too little": increasingly across the final moments of the play, the onstage tin on tuna shrinks back down into the trivially tiny object under Calantini's merciless gaze. There is no hidden solution enshrined in the rare flesh of the bluefin tuna, he insists: "IT'S JUST / A FUCKING / FISH!" (2021, 98). At the climax of the final act, in protest against the senators' vision of resurrecting the fish population (and their associated vision of resultant fame and riches), he pierces the one remaining can:

> *He takes the harpoon gun and, holding it like a spear brings it above the can on the table*.
> MARIANNE: No!
> *He brings it down, piercing the can. Pause*.\ (2021, 104)

Yellowfin does not definitively deny all significance of human action in the face of climate disaster. Even when opened, the significance of the tin of tuna remains uncertain: the play leaves open the possibility that salvation *might* in fact have resided in the can, and that Marianne and Stephen's hopes of species renewals might have been viable. As Calantini teases Roy, the answer "could be in this can, couldn't it? In this can / That I've punctured / With this harpoon / And the 'something that is somewhere' that they're still hoping for… / That could be slowly rotting away now" (2021, 110). What the play foregrounds, however, is the feeling of futility faced with the colossal scale of environmental catastrophe, and the seeming finality of ecological decline that cannot be deterred by any individual choice. It is in masochistic expression of this outlook that Calantini goads Roy into the final action of the play: eating the contents of the world's last remaining tin of tuna. "What difference could it make?" Calantini probes the older man, who wistfully remembers the lost taste of fish from his childhood:

> You've seen the way that they behave
> And so you know there's only one way this is going to go
> And so you know that it really doesn't matter. […]
> It's inevitable
> Someone is going to eat this can of tuna
> And it might as well be you.\ (2021, 115-6)

The play closes on the darkly comic-grotesque image of Roy crouched on all fours in the centre of the stage, scooping flakes of fish messily out of the tin and into his mouth with his bare hands, desperately, greedily, delightedly.

Figure 5: Nicholas Day as Senator Roy in the final moments of Yellowfin, Southwark Theatre, London, 2021. Photograph by Helen Maybanks/ArenaPal.

Instead of representing the death of the final animal of the species, we see the consumption of the final tin of animal meat. The tuna thus becomes 'extinct' twice over in *Yellowfin*: first in the disappearing of the fish themselves, and then again in the destruction of the final tin of their flesh. As such, their extinction is evoked in two ways on this stage: in the literal absence of any living fish from the stage space, and still more potently by the presence and eventual consumption of the non-living fish meat, rendered so adjacent-to-life – and indeed adjacent-to-death – throughout the play.

Conclusion

There is another scenographic feature of *Yellowfin* that is central to its ideas but easy to overlook. Horn writes in his staging directions that:

> The most crucial element is the microphones. Each character should have a table-top microphone placed in front of them. The purpose of these in the world of the play is primarily to record, but for our purposes they should also amplify and be very sensitive to changes in intensity and volume. Mediated sound is the play's key aesthetic element. (2021, 6)

This soundscape enhances the already highly metatheatrical, performative tenor of the play: a congressional hearing being recorded, a paradoxically private, sealed discussion which is nonetheless ostensibly geared toward the public and its greater good. Each character is thus consciously performing a historical awareness of their own importance in this public hearing/tribunal play. In place of any comparable soundscape, Ronder's play employs a lighted box that marks out a specific space in which the action takes place. The box in many ways fulfils the purpose of Horn's microphones, amplifying and highlighting movement and setting apart one space on the stage from another. Both scenographic approaches have to do with territory: how we colonise and mark out spaces to possess, whether verbally or physically.

Finally, then, both *Fuck the Polars Bears* and *Yellowfin* capitulate – knowingly, deliberately – to the ecological despair of our contemporary moment. Neither play is geared towards promoting change. This is not Timothy Morton's "ecological collectivity" where reflection and meditation become central to "enacting or experiencing an intrinsic interconnectedness" between human, animal and non-human, and generating a new way of being (2010, 127-8). Instead, both plays project futility, resignation, and anxiety. The problem, as Calantini neatly articulates it, is in the seemingly unchangeable, destructive human attitude towards the co-habitants of their shared environment, and discovering why and how the fish disappeared would make no difference to any future outcome: "We're still us! / Knowing why the fish went won't change that!" (2021, 113). For all its dramatic flair, the ending of *Yellowfin* is as downbeat as that of *Fuck the Polar Bears*: as long as humans are still humans, as long as "we're still us", there seems no hope of change, no solution to the destructive decline of the Anthropocene era.

These two plays thus stand in stark contrast to the ethical investment of earlier environmentalist theatre makers and commentators, wherein "a sense of loss produces an opening for care" (Orozco 2018, 185), or which aim to produce change "not only in the ways we live with animals and the ways we think about them but also by transforming our values more broadly, resetting our priorities, rebooting our sense of what it might mean to be human" (Chaudhuri 2014, 1). As the climate crisis has intensified, it has prompted newly urgent questions about not only what "we" can individually

and collectively do to reverse global warming, but what role the arts can play in that process, as shown by recent studies such as Martin Puchner's 2022 *Literature for a Changing Planet*. Such hopeful works stand in distinct contrast to the lived experience of climate catastrophe, and their enlightened urgency to harness the arts and humanities to fight climate change can sometimes seem more theoretical than practical. *Fuck the Polar Bears* and *Yellowfin* might seem to give up on humanity, but the tough question they ask is necessary: are we really capable of genuine, lasting change on a species level? Both plays operate as attempts to express this *feeling* of inexorable disaster, rather than as performances generated towards prompting new ethical behaviour from its audiences. "It is all too little / And it is all too late", after all. The consumption of the last remaining tinned tuna both matters and does not matter. The fish are already gone.

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SCIENCE IS INCREDIBLE: PERFORMING BODIES, SEARCHING FOR IDENTITIES VIVIENNE FRANZMANN'S BODIES

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When Thomas Eakins presented his vast canvas (ca. 8 by 6.5 feet) with the title *The Gross Clinic* to a Philadelphia public in 1875, people swooned right in front of it. Some also felt seriously sick. Eakins had hoped that this painting would become part of the Centennial Exhibition in 1876, praising progress in science and medicine, celebrating America. But instead, he created a scandal. His contemporaries were just not ready for such explicitness, for such a realistic, aggressive depiction of a surgical procedure, including shining blood on Dr. Gross' hand (Krieg, 1999; Werbel, 2007).

Gross was 'the father of surgery' in America, famous also for his *Manual of Military Surgery* (1861), used by all field surgeons during the Civil War; it introduced new operation methods as well as tools. What Eakins depicts here is a performance of a revolutionary operating procedure invented by Gross – the removal of osteomyelitis of the femur, an infectious disease of the bone marrow. Previous to Gross' innovation, amputation of the infected limb was the only way to try and save the patient's life. Now, thanks to Gross, the infection could be basically carved out and the patient healed (Sewell, 2001)!

The human being on the operating table is reduced to a body as an object of scientific observation, study, and practice – Foucault's medical gaze (*The Birth of the Clinic*) comes to mind.[15] We cannot see who the person is – his (or her) head is hidden from us; the wound, the leg, and the blue fluffy socks are what we are drawn to. We are in the surgical amphitheater of Jefferson Medical College and the four eager assistants have not only their eyes on, but also many hands in or close to the open wound. From today's perspective the painting is certainly somewhat irritating in view of themes such as hygiene and sterility. But considering the historical moment depicted, we cannot but admire Eakins' celebration of the brilliant doctor – surrounded by a halo of light.

The painting puts a lot of emphasis on the onlookers – the men around the body, the people in the proscenium, and the poor terrified woman lower left. And us. The viewer might be represented in the painting by the woman, identified by some scholars as the patient's mother, who, hands lifted like claws, gaze averted, expressed the fear, repulsion, or pure horror some of us might feel, too.

If the medical theater can be seen as a space where scientists and the people meet, where the public discourse about science and its impact and effect on society happens, then it is really just a short skip and jump away from the theatrical performance space and science theater or science plays.

There can be explicit, direct science on the stage, with didactic effects, attempts at 'truthful' (re) presentations of scientific contexts and concepts in order to 'educate' a general public. For example, in plays such as *An Immaculate Misconception*, Carl Djerassi, the chemist who synthesized the birth control pill, provided factual details on ICSI (Intracytoplasmic Sperm Injection) and illustrated the consequences of this medical procedure for new family formations.

15 Alex Mermikides and Gianna Bouchard's *Performance and the Medical Body* highlights this as a general theme.

Some plays highlight more the 'tribal culture' of the scientists and ask questions about what science can, should or should not do for us, where responsibilities have to be faced, and how the scientific 'tribe' 'ticks'. *QED* (Peter Parnell), *Blinded by the Sun* (Stephen Poliakoff), or *Einstein's Gift* (Vern Thiessen) are outstanding examples (Zehelein, 2009).

Many plays and performative projects also originate from the field of history of science and look back to the past, to 'real' scientists and historical events, essentially with a twofold purpose. They work on cultural memory by bringing history and historiography to the stage with meta-dramatic strategies, and they ask their audiences to turn these nuggets of knowledge into a usable past by remembering them in and for the future. History of science has welcomed the stage as an additional space where cultural memory can find expression, where records can be set straight, public images be rectified and forgotten heroes and heroines be resurrected (Zehelein, 2009, p.321) – think of plays such as *Remembering Miss Meitner* by Robert Marc Friedman, or *Photograph 51* by Anna Ziegler about Rosalind Franklin.

Science can – and most often does – feature as a metaphor. Abstract concepts such as eternity, relativity, and uncertainty are employed to illustrate human hubris, or the human condition in general. Michael Frayn's highly acclaimed *Copenhagen* is a fine example. Uncertainty and complementarity are used here for metaphorical reasons and objectives in a meta-historical drama, where history is being made, rather than talked about, and where the illustration of possibilities, premises and limits of historical understanding are at the center. Frayn explores human motivations and characters, searches for reasons for Heisenberg's and Bohr's actions. Heisenberg, Bohr and Bohr's wife step back into the past, which "becomes the present inside your head" (Frayn, 1998, p.6). Together, they re-construct the past, various versions of events, scenes and moments – the plot consists of three drafts, and five versions. The play 'does' history; epistemology of intention is what the play is ultimately all about (Zehelein, 2009).

As I have also argued elsewhere, Tom Stoppard's famous play *Arcadia* is primarily a play of ideas. It does not provide a didactic lecture on chaos theory, fractal geometry or thermodynamics (entropy). Stoppard rather uses these theories and concepts as a means to establish various levels of meaning and to connect different areas of knowledge, such as science and literary studies, garden planning and mathematics, in general: science and the arts (Zehelein, 2009, p.276-78).

Recent scholarship has emphasized the value of devised theater as a form of bringing performance and science together. As Vanden Heuvel has explained, the scientific aspects or contexts are again employed as metaphors, just as the devised performances "reflect the discourse of science in the contemporary world" (Vanden Heuvel, 2020, p.133). He follows Hancock's argument that "devising processes can usefully be understood by metaphorical references to sciences like chaos and complexity theory, and devised creation mimics in surprising ways the cognitive operations of distributed systems" (Vanden Heuvel, 2020, p.134). Devised theater with its emphasis on the procedural and the

joint creation of narrative and experience, maybe also through experimentation, can help elucidate the nature of science as such, and primarily on the level of mimesis, as Vanden Heuvel has also elaborated. Here, the performance of communication is at the center, not the science itself.

And there can be dramatic projects which focus on reactions to science and its impact, on debates about the socio-cultural, legal, political and economic consequences deriving from scientific inventions. The details of a scientific theory or discovery might indeed be less significant for a general theater audience than illustrations of the consequences of the research, its positive effects, as well as its potential harm, the ethical and moral dilemmas that might ensue, the challenges it might bring to established traditions and norms.

The following discusses one recent example, Vivienne Franzmann's play *bodies*, which premiered at the Royal Court Theatre in London, in July 2017.

Bodies, souls, and gestational surrogacy

Medical science has opened new opportunities for human self-determination. One of the fundamental issues in life are bodily integrity, health, and also reproduction – whether we want to reproduce, with whom, when, whether we can, and how. Because of ART – Assisted Reproductive Technologies – we can today have children later in life, we can overcome some forms of infertility, we can have children outside of heteronormative relationships, we can prevent passing on genetically inheritable diseases or genetic defects through genetic screening and pre-implantation diagnostics. And women can also decide not to have children, by using contraceptive methods, or by deciding to have an abortion.[16]

Franzmann's play highlights the bodies and the souls of people. At the center is a gestational surrogacy case and the manifold ethical and moral questions it raises.

In gestational surrogacy, the surrogate is not genetically related to the child(ren) she carries. Intended Parents[17] use their own oocyte(s) and sperm or sperm and/or oocyte(s) from an (anonymous) donor. Through ICSI (Intracytoplasmic Sperm Injection), one oocyte is fertilized with one sperm *ex utero* and one to three blastocysts are transferred to the uterus of the gestational carrier. Genetic and gestational maternity are disconnected. Thus, a second woman can 'be the mother, too': although she does not

16 In view of recent events in the US, the demolition of female self-determination and the rise of fetal personhood law, questions about bodily integrity and control move center stage as never before.

17 The term "Intended Parent(s)" entered the vocabulary through the *Johnson v. Calvert* case (California, 1993). The Calverts, publically presented as a white couple (they self-identified as mixed-race), had commissioned an African American woman, Anna Johnson, as a gestational surrogate. The relationship between the three deteriorated rapidly and after Johnson had given birth, both parties filed for custody. The final court decision rested on the understanding that the commissioning woman, the woman who intended to raise the child, is the legal mother and not the woman who has given birth to the child to whom she is also not genetically related.

share in the pregnancy and birth process, she is genetically related to the child and can therefore claim the infant as 'hers'. To separate gestation and genetics allows for a truly revolutionary act in human history: to abandon the cultural convention that to nurture an embryo *in utero* establishes automatic and exclusive motherhood status and a unique natural bond between the pregnant woman and the embryo. The 'mother' is no longer 'only' the woman who gives birth; nurture is not necessarily nature, and genetics vie with intended parenthood (Zehelein, 2019).

bodies brings this challenge to the stage. The British couple Clementine (Clem) and Josh Kennedy-Clarke, both in their early 40s, finally, after nine traumatic years with many miscarriages, employs a young woman in India as a gestational surrogate – the ovum comes from a Russian egg donor, the sperm from Josh. Thus, the intended mother Clem is not genetically related to the child, which Lakshmi gestates for her – complicating the question of who the 'mother' is, also for the child.

Throughout the play, which is structured not in acts, but simply in seventeen consecutive scenes, this child remains mostly without a name. She appears as a character of sixteen years of age, called "the daughter," right in the first scene, in a dialogue with Clem. This opening scene is rife with allusions to the themes and symbols the theatrical action will elaborate. The play opens with the daughter repeating her mother's sentences, establishing parallelisms, alluding maybe to a form of bond or identification between the two. In the course of the conversation, though, it becomes clear that there are tensions, that Clem, despite her claim "I know you" (Franzmann, 2017, p.4), doesn't really know her daughter, when she asks her which school she attends and whether she plans on going to university (Franzmann, 2017, p.9; 10). The daughter also insinuates this distance earlier on when she answers to Clem's suggestion that the daughter could decide to eat only half of the chips: "I could if I was a totally different person. If I was you" (Franzmann, 2017, p.5). This clashes with the first impression of an intimate harmonious relation between a mother and her teenage daughter. At the end of the scene, the audience begins to wonder whether we have just witnessed a dream or fantasy of Clem's when she asks: "Are you here? – Are you –" and the daughter finally answers: "Yes." "Clem: Because for a moment I thought maybe… Daughter: I'm here. […] Everything will be ok now. – I'll warm your heart. – I'll hold it in my hands like a baby finch. – I'll make the pain go that squeezes your windpipe and fills your lungs. – I'll make you feel clean and light again. Propel you into the air like a sycamore seed. – I'll make up for all the others" (Franzmann, 2017, p.10-11).

As the audience understands from scene to scene, the staged action covers roughly nine months, from the creation of embryos in India via implantation and gestation through the pregnancy and to the birth of the child. The appearances of the 16 year old '"daughter" are, then, projections, inner monologues of the mother Clem with her imagined/imaginary child, the one who is supposed to "make up for all the others" who Clem, sadly, could never carry to term.
Scene 2 takes the audience to the fertility clinic in India where Clem and Josh wait for Josh's

appointment to provide his sperm sample for the in vitro fertilization. Their dialogue boils down to two essential statements: Clem says: "My eggs are rotten. Your sperm is fine. Let's keep it that way" (Franzmann, 2017, p.17) and Josh says: "We've brought a gift. It's called twenty-two thousand pounds" (Franzmann, 2017, p.18). Here, the audience understands that the daughter from scene 1 is this child, about to be conceived via in vitro fertilization, and gestated by a – paid – surrogate in India.

(Commercial) gestational surrogacy is for many individuals and couples the final stop on a long and painful journey towards parenthood. It has (had), however, wide-reaching socio-cultural, legal, and ethical implications, and is illegal in many countries around the world. In the UK, altruistic surrogacy is legal, yet commercial surrogacy is prohibited,[18] and the law considers every woman who gives birth as the legal mother of the child(ren); parenthood, however, can be transferred by parental order and adoption (Government of the UK, 2014). When the commissioning father is also the genetic father of the child, he can, via a DNA test, prove his status as legal parent and pass on his nationality. Due to the strong emphasis on birth as the decisive factor for establishing paternity, surrogacy arrangements require the crossing of a number of legal hurdles in the UK, but also in many other countries, especially for commissioning mothers (Zehelein, 2019). Due to the liberal legislation in some states such as California, the USA are one of the few attractive destinations in the Global North for cross-border reproductive care (CBRC) – the "practice of couples or individuals crossing national or state borders to access assisted reproductive treatment that is illegal, unaffordable or unavailable in their home jurisdiction" (Crockin, 2011 as cited by Hammarberg et al., 2015, p.690).[19] Costs, though, are high. Costs are much lower in countries such as India (until 2016), Thailand (until 2015), Nepal (until 2015), the Ukraine (until 2022), China and Guatemala, where transnational gestational surrogacy was/is/soon might be a flourishing multi-billion dollar business; Amrita Pande has spoken of "wombs sans frontières" (in Davies, 2017, p.329).

In Franzmann's *bodies*, Clem's father David criticizes his daughter for her active and willing participation in a global neoliberal economy where nurses from the Global South and Eastern Europe are paid to take care of him in the UK – leaving their own families behind – and egg donors and gestational surrogates from the Global South and East are paid for delivering children to people who can afford the financial costs.

Three fundamental lines of argument against commercial gestational surrogacy concern welfare and exploitation of the surrogate and commodification of both surrogate and gestated child(ren) (e.g. Humbyrd, 2009: p. 112). We are confronted with a huge and multilayered subtext about various

18 For instance, in France, Italy, Germany, Austria, Switzerland, Poland, Finland and Spain, all forms of surrogacy are banned; the Netherlands, Portugal and Denmark allow altruistic surrogacy. Greece and Russia are among the few countries worldwide where surrogacy is fully legal.

19 Inhorn (2015) has conducted a large anthropological study of CBRC by interviewing 125 infertile couples from 50 countries who sought ART services in Dubai. She found that not only prohibitive laws, but also extremely high costs for fertility treatments in the home countries caused the couple's "reprotravels."

potentially exploitative practices made possible by systemic inequities – (post)colonialism, biocapital, neoliberalism and global trafficking in human bodies and body parts. Gestational surrogacy, understood as a very special form of bodily labor, is articulated via a veneer of altruistic rhetoric, with deep financial and emotional needs lurking underneath. To depict the practice as a "win-win" (people desire a child and can pay, other people live in financially dire straits and offer to "help") can easily gloss over many knotty issues such as potential exploitation, commodification, colonization and disenfranchisement (Zehelein, 2019).

Franzmann's characters bring to the stage the academic discourse that has framed the surrogates as either exploited and colonized victims of a capitalist colonizing Western/globalized hegemony, or as at least in part active agents with reproductive autonomy and freedom, that is, with the right to self-determination and the right to enter a contractual agreement to 'sell' or 'rent' their bodies in order to improve their lives. Krolokke even (in)famously declares surrogates as "repropreneurs" (Krolokke, 2012).

When a woman is paid to deliver a baby for someone else, the child might be perceived as a good, a commodity, exchanged for money on the basis of a capitalist contractual agreement. Thus, concerns for the welfare of the child but also of the gestational host pre-birth and – often neglected or outright forgotten – post-birth arise. After all, surrogacy involves for the surrogate invasive medical procedures, pain, physical risks, and possible death. In *bodies*, another surrogate is mentioned who, presumably because of complications, bled to death in her bed, in the maternity dorm. "Daughter: The baby survived if that's what you're wondering" (Franzmann, 2017, p.59).

In how far poor women with limited to no literacy and education living in a system of colossal structural inequalities can perform any practice of agency, can willingly and knowingly enter contractual agreements, and in how far the money earned is actually money they can use for their own improvement has divided scholars as well. Indian surrogates are dominated and controlled by family, clinic and state. They live in a culture where women are considered inferior human beings, frequently victims of gender-based abortions, child labor, prostitution, forced marriage, gang rapes and wife burning (Zehelein, 2019). Ethnographic studies by Amrita Pande and Sharmila Rudrappa, based on hundreds of interviews in Indian surrogacy clinics and hostels, have suggested to frame gestational surrogacy as a specific form of bodily labor which, despite all criticisms, provides otherwise disenfranchised and disempowered Indian women with at least some form of agency. The work of carrying a child for someone else can even carry moral value, as compared to the work of producing a T-shirt for, let's say, GAP, and a surrogacy hostel can be a "curiously liberating place" (Rudrappa, 2015, p.94), offering time free from familial duties and full of life affirmation. This complicates the narrative of exploitation and turns an "unalienable life experience [in]to an alienable form of employment for which they received wages" (Rudrappa, 2015, p.99).

Bodies, too, presents both sides of the coin. David accuses Clem of buying a child and of disregarding human rights (Franzmann, 2017, p.73-74; 117-18), and for him, the child is not Clem's (Franzmann, 2017, p.76). Clem and Josh wish to believe in a positivist narrative, set against Western feminist neoliberal thought inclined to condemn surrogacy outright. The daughter says: "They [the surrogates]'re getting regular food and they like hanging out with each other. […] And they all enjoy the lack of responsibility. – What I mean is they don't have to get up at 4 a.m. and work sixteen hours in some fucking sweatshop somewhere and then shop and cook dinner and clean and look after the kids and husbands and in-laws and deal with all that shit. – They're taken care of" (Franzmann, 2017, p.57). However, our growing suspicions are soon confirmed: we learn that Lakshmi is a single mother of two small children whom she left alone while she signed up for the surrogacy, hoping they would somehow – miraculously – manage to be safe on their own. For her, the clinic and the center are not a retreat, but a prison, separating her from her children. The play closes on a heart-wrenching moment of silence when we see David ("unable to move"), Lakshmi ("outside the clinic. Milk seeps from her breasts. She holds a paper bag of money"), Clem (bottle-feeding the baby in a hotel room), and Lakshmi's little daughter, who has gone missing, dancing on a table. "She is wearing make-up. Far too old for her. The End" (Franzmann, 2017, p.124). Another objectified body.

David's carer Oni had accused Josh: "Who do you think you are? […] You people just do what you want. Trample over everything and everyone. Say what you want, take what you want. You and your wife go about your business as if it has no effect on anyone else. You don't understand anything about that country, the people, the culture. Nothing. […] Wake up, you stupid stupid people" (Franzmann, 2017, p.118).And Josh retorted by asking whether she had any idea what happens to an unwanted baby girl in India (Franzmann, 2017, p.118). He also explained that his wife had been so depressed after nine years of trying to conceive a child that "she would rather be dead than live without" (Franzmann, 2017, p.116).

(Auto)biographies of pain

Clem's story is indeed one of long suffering and trauma. Clem, who works as a TV producer – e.g. of series such as *The World's Fattest Man*, a show about FGM (female genital mutilation) and "a series about the adolescent mental-health unit up in Scotland" (Franzmann, 2017, p.27) – desires to be a mother. She tells her father: "I wake up every morning with this ache, with this gnawing feeling of loss and displacement and horror that this is it for me. This is all my life will ever be" (Franzmann, 2017, p.76).

The audience may wonder whether, if the female body cannot carry a pregnancy successfully to term, all possible medical interventions are permissible, and whether every woman has a right to a child. We may also question why the motherhood mandate is still so deeply etched into the female bodies.

Clem: "Everyone I know. Everyone I meet has children. […] They are so certain of why they are here. I'm a mother. What are you?" (Franzmann, 2017, p.75). Why, in view of the proliferation of stories by people so desperate to become parents that they undergo myriad cycles of treatments, revert to egg and/or sperm donation and often also seek the assistance of a surrogate, is there no conversation, really, about why there is so much social pressure on people to be parents and mothers?

From the dialogue with her daughter in scene 5 we learn that Clem has suffered at least five miscarriages, that she physically attacked her own mother when her mother said to her that "not everyone can be a mother" (Franzmann, 2017, p.34), and that she insists that she, and not the surrogate, is the daughter's mother: Daughter: "Do you think the surrogate has a heart bursting with love for me? Full of possibilities. – Guarding me with her life. – Roaring like a lion. Clem: No. – You're not her baby. Daughter: No, I'm not. Clem: You're mine. Daughter: Yes. Sorry. I'm yours –" (Franzmann, 2017, p.36-37).

"You're mine / I'm yours" does not only refer to questions of genetic and social belonging, and what it means to be a mother, but also to questions of ownership. In the next scene, Josh and Clem skype with the fertility clinic in India and gaze at their surrogate, scrutinize her body and belly, objectify her with their stares, erase her individuality and invade her tortured psyche by asking for the specific date for the C-section, and how she feels carrying a baby for them (Franzmann, 2017, p.40-44).

The law and the people

In scene 12 the legal aspect enters the picture. Clem and Josh learn that India is about to pass legislation banning international gestational surrogacy, making their entire endeavor, already months on the way, illegal. Indeed, in 2013, India passed a first restrictive law excluding foreign gay couples and singles from entering into commercial gestational surrogacy contracts with Indian women; since 2016, all foreigners have been banned.[20] The scene might evoke a rollercoaster of emotional reactions in the audience: pity for the couple who desperately long for a child and have paid in money and tears and effort to finally achieve this goal, irritation with the couple's stubborn refusal to accept India's new laws, their desperate pleas with the clinic to stay the course and proceed with the agreement and make sure they will not be affected by this new legislation. And we also sympathize with the surrogate who, as we learn, has run away from the clinic and tried to abort the child – a child which she had to fear would have to remain with her post birth, if the ban went into effect. As a widow and mother of two small children, living in utter poverty the idea of having a third child to care for drives her to such devastating measures as to risk her own health and life to try and abort the pregnancy.
In all the debates about the legal and moral implications of ART and surrogacy, we should never

20 Nepal was one of the few open doors for singles and gay couples seeking low-cost surrogacy services (ca. US$ 40,000 (Zeveloff, 2015) to create a family. Thus, many women from India, contracted for gestational surrogacy, crossed the border to Nepal to spend the time of their pregnancy and birth there. Nepal closed its doors to reproductive tourism in September 2015 (Abrams, 2016).

forget the contexts and fates of the gestating women which are characterized by the best and the worst of contemporary global neoliberal capitalism, as well as by deeply personal, also intimate life stories and hardships.

"Who am I?"

We should also never forget another crucial aspect of all our discourses and debates: the children. So far, they surface in public discourse primarily in the context of custody disputes, matters of nationality, and in their parents' reproductive stories. Although scholars such as W. Penn Handwerker had proclaimed already in 1990: "The birth of a child is a political event" (as quoted in Scheper-Hughes and Sargent, 1998, p.1) although Sharon Stephens had pointed out that "there is no way of insulating children from the 'culture politics' of everyday life" (in 1995; (as quoted in Scheper-Hughes and Sargent, 1998, p.2) and Scheper-Hughes and Sargent had four years later demanded a radical paradigm shift towards a child-centered anthropology, scholarship on reproduction and ART to date has hardly begun to move in this direction. In the medical sciences, research on the overall health and thriving of ART children is growing and we should also ask: what does it mean to be gestated by a woman who is neither your genetic nor your social mother (Zehelein, 2019)? And what about all the other children, the surrogates' children who have to live with the danger that their mother will suffer serious health issues during and/or after the pregnancy, or maybe even die?

Franzmann brings all these questions into focus by giving the child a voice. A child which is unmoored and unrooted – with a genetic mother from Russia, a biological mother from India, and an intended mother from England, made illegal by Indian law before she was born, wanted and at the same time not wanted by both, the biological and the intended mother, bought and sold for money, with heavy costs for all involved.

In scene 15, the daughter addresses Clem again, asking her: "Which bits of me are yours? I can tell you exactly what's Daddy's. The maths, the jokes, the spatial awareness and the art stuff […] I'll want to know why I don't look like you. And why I don't act like you. Or think like you or feel like you. Why I feel a million miles away from you when you're supposed to be my mother. I'll look at you and I won't know who I am. Who am I?" (Franzmann, 2017, p.101).

Care is Complicated

Franzmann's play not only highlights the complicated interpersonal network of transnational gestational surrogacy. The plot line with Clem's father David who suffers from a neurodegenerative disease,

gradually depriving him of physical mobility and speech, serves not only to weave in critical positions on surrogacy, but also to provide a comparative topic to gestational surrogacy: care work. Clem tries to organize professional care for her diseased father, and keep the care situation as well as her father's (deteriorating) health "under control" – a repeated phrase (e.g. Franzmann, 2017, p.20, 99).

Just as the surrogate has to surrender her body to physical exams and invasion, so does David. His home and his body are invaded by strangers, his bodily integrity is violated, his self infantilized and disenfranchised. This loss of agency is organized, controlled and paid for by his daughter. Just as she has organized and controlled and paid for the gestational surrogacy. What David criticizes throughout the play is also what he depends upon: money and the plethora of options it can create. He is ashamed of his daughter and her decision to become a mother by exploiting a young woman from India (Franzmann, 2017, p.69), yet in his increasingly desperate health situation he depends on Clem and her financial acumen to ensure his care at home – no matter how invasive this feels for him (Franzmann, 2017, p.68).

The play employs as one overarching symbol birds – finches and crows. In the past, David who loves birds, bred finches, yet ever since the disease has basically immobilized him, he does not visit his aviary in the garden anymore, and he refuses to see it with Clem whenever she visits. Youtube videos of zebra finches make him cry (Franzmann, 2017, p.53), and one day, one of the carers leaves the door of the aviary open and the birds fly out (Franzmann, 2017, p.120). The finches, symbol of good luck, are gone. David loses everything – not too long ago his wife, now his health, his beloved birds, and he is estranged from his daughter because of her overpowering desire to become a mother by means he thoroughly disapproves of.

The second bird in *bodies* is the crow – symbol of death. In scene 1, the daughter says she likes crows. "Crows are cool. […] They're sleek and their eyes shine and their feathers are beautiful like oil." But Clem replies: "A crow got into my dad's aviary once. Destroyed everything. It was awful" (Franzmann, 2017, p.7). Now, a crow brings destruction, too. The surrogate's baby is depicted as a crow. Clem tells the story of what happened to Lakshmi when she was informed about the potential ban of surrogacy in India: "Lakshmi tried to get rid of it. […] She found a woman who gave her a mixture of herbs and poison and stuck a stick up her. Speared it. One of its wings unfurled from her cunt. Black and sleek and shining like oil. […] she's full of bad luck […] She punches her womb every night. They have to restrain her" (Franzmann, 2017, p.112). It is suggested that the doctors decide to move the C-section forward, because the mother "endangers" the child. Just as with those birds, mentioned in scene 1, who reject some of their offspring, the surrogate 'rejects' her child here, and just as with the birds, Clem steps in to take care of them. At first, she perceives the child as bad luck, but, as the play's ending suggests – maybe – she will be a good mother.

No matter our individual takes on all of these issues – all stories about ARTs are also about the first chapters of babies' biographies and maybe, despite all our academic abstractions, the children deserve that we consider carefully what our actions can imply, and how we can love them best. Science plays are highly diverse. At their best, they challenge the audience to play an important part in the democratic process – engage in public discourses about the benefits and risks of modern science, the role science can and should play, where laws and regulations must establish rules and boundaries. Theatrical works should entertain, sometimes inform, and always encourage or even urge the viewers to gather information, to form their own opinions, and then to stand up for their convictions and beliefs. "Science is incredible" (Franzmann, 2017, p.31) – yes, but then…

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THE DRAMA OF PHYSICS

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1. Introduction

Why drama? Which one are we referring to? The tragedy, or to be less melodramatic, the problem associated with physics (and especially, but not exclusively, modern physics) arises in various contexts, but specifically in those of teaching and outreach. We are alluding to the gap, if not the abyss, that prevails between the attitude and methodology that is supposed to guide a scientific investigation and what is taught in the classroom or communicated in the media. Science, we are told, signifies doubt; it means not taking anything for granted and breaking down prejudices. Unfortunately, the teaching and outreach of physics are mainly based on allegedly complete and well-established theories and empirical facts. Resulting in a proliferation of assertive and categorical statements. Something that is closer to dogmatism than skepticism. That is a drama.

In the following reflections, we would like to briefly consider to what extent science-based plays alleviate (or may alleviate) the drama. We will focus our analysis on two case studies in which physics has a wide presence and an important role: Arcadia (Stoppard, 1993) and Copenhagen (Frayn, 1998). But first of all, we will offer some general considerations.

It is not difficult to locate the crux of the problem. The main objective of modern physics (quantum mechanics and the theory of relativity, but also thermodynamics, electromagnetism and statistical mechanics) is to find mathematical relationships between physical quantities. Therefore, the meaning of the conclusions, causal connections, fundamental equations and even the physical quantities involved are not always easy to elucidate in plain language. Because of this, accuracy in explanations is often relaxed, in order to be able to accommodate - to use a term previously used in this context (Fahnestock, 1993) - the content to a discourse that can dispense with those mathematical relationships and which allows us to construct images and illustrative examples. Accordingly, it is not surprising that paradoxes and mysteries proliferate precisely because of this incomplete translation, together with the popular desire for shock value. To mention but a few: an electron can be in two places at the same time, or in the initial instant, the universe was concentrated into a single point. These are not wonders of physics but absurdities or, at most, half-truths. If we also take into account the existing pressure to offer interesting issues to students and the general public, then the situation only gets worse. Certainly, in a world shaped by Big Science (Galison & Hevly, 1992) there is a great demand for vocations as well as capital to continue with research that in most cases requires large investment and personnel. But… at what price? Of course, all this leads us to ask ourselves about the usefulness of scientific popularization. Does it make sense to convey such a distorted idea of scientific procedure?

None of this is related to the two cultures (Snow, 1959) but with the mathematical formalization of Physics. In fact, the main consumers and producers of science popularization are scientists and people with some training in science. Generally speaking, the complication does not come from a lack of

understanding but rather a deliberate choice in the style and aims of the presentations of scientific achievements. Science is set down as the panacea to discover the truth, as the agent in charge of propagating and spread it. Doubt rarely supports or guides outreach. The emphasis is not placed on what has been questioned, or discovered that it is not as obvious as we thought, such as the well-defined location of an elementary particle in an absolute space and time or the possibility of fully understanding the origin of the universe. On the contrary, emphasis is placed on new theories, new paradigms, the unveiled reality that is invisible to the uninitiated. On the discovery of truth. Nothing could be further from skepticism. Nor do the real processes, generally tortuous and non-methodical, by which scientists arrive at these results play an important role in these accounts. We only find constant references to the otherwise indefinable and questioned scientific method (Chalmers, 2013; Feyerabend, 1993).

2. Two-way metaphors

In other words, science supplies the metaphors that nowadays explain the world and provide it with meaning. Let us consider, for example, viruses, the Big Bang, the extinction of dinosaurs or the very concept of information. Needless to say, this does not imply that science is only that – symbolic representations, but rather that it is through them that scientists interpret mathematical relationships. Hence the universe expanding like a balloon, an improper visualization of a consequence of the equations of general relativity, or Schrödinger's cat being alive and dead at the same time, a thought experiment devised by one of the creators of quantum mechanics to reveal the fallacies to which its orthodox interpretation leads.

However, on many occasions the images used were not born out of a scientific context. On the contrary, they had been borrowed and were already circulating previously. In those cases, science outreach restores to common heritage that which has come from common heritage. An illustrative example of this process is that of the term energy and also the concept of entropy. Energy is a word with Greek, Aristotelian roots, that was common in the early 19th century in most European languages (Pérez & Carrasco, 2015). In previous centuries it had been used in a theological sense, but afterwards its semantic field of application changed to one of rhetoric. Energy was punch, vigor, force of a speech or an argument. Scientists, especially the Scots who developed thermodynamics (Smith,1998), consciously searched for a word for the physical magnitude that made it possible to quantify transformations of mechanical effects into electrical, or thermal into chemical, etc. That is, the seed of what we know today as the principle of conservation of energy. They left the terms force and power for other, established technical uses, and adopted energy for the brand new quantity. A few years later, William Thomson (later lord Kelvin) and Rudolf Clausius, among others, constructed thermodynamics and its second principle, which finally gave rise to the concept of entropy. Energy and entropy were the two pillars of the successful thermodynamical world view. Even so, in the first half of

the 19th century, in a post-Enlightenment context, the idea of a degenerating universe and wasting natural forces, had also arisen prior to its mathematical formalization and the birth of entropy, as has been quoted on many occasions (Clarke, 2001). Nowadays, entropy and energy are everyday terms with a scientific pedigree that exist in common language, but are used in a sense that is significantly different from their technical meaning. Significantly different but not completely detached.

Many case studies in the historiography of science have shown how the common cultural context between sciences and humanities can be appreciated in the final form of scientific theories. From Paul Forman's classic study on the birth of quantum physics (Forman, 1971), to the case of Hobbes and Boyle examined by Steven Shapin and Simon Schaffer (Shapin & Schäffer, 1985), as well as studies on the so-called energy scientists (Smith, 1998). Thus the flow of concepts between science and humanities is much greater than the advocates of scientific objectivity like to admit. The myth of a science that develops according to its own parameters and criteria, oblivious to cultural developments, does not withstand a minimum of historical contextualization. This does not detract from its being well-founded or adjusted to empirical facts.

As expected, the formalization and mathematization of cultural concepts previously in circulation, distorts and nuances them until they are no longer recognizable. Hence, this process is not so simple as a family of concepts circulating between spheres: they undergo serious modifications. In light of this, what does this dance of borrowed metaphors add to the drama of physics? In our opinion, it only increases it. Metaphors are so evocative and tempting that it is difficult not to resort to thermal death to describe entropy, or to use an oscillating string to illustrate electromagnetic waves. Still, instead of promoting skepticism, they are always situated in the sphere of explanation, of the world-view, not in the spheres of question or doubt. And with an extra requirement for the audience: a little faith is needed to understand these astonishing, upsetting developments.

3. Theater: two successful plays

The heyday of science outreach and its growing presence in every area of our daily lives has also reached the world of theater. What does the theatrical medium contribute to the transmitted idea of science and scientific knowledge? Does theater make sense in terms of science communication? Does it allow us to communicate concepts, ideas and methods that are expressed with greater difficulty in essays, videos or films? Does it open up new possibilities?

At first sight, it would seem that theater lends itself more to the presentation of personal or social conflict than to the detailed and well-articulated exposition of a theoretical concept. Without entering here into the debate over whether or not science plays constitute their own genre (Zehelein, 2009, p.

86), we can state assuredly that, in fact, some of the most popular plays that tackle physical themes deal with problems of an ethical nature. Surely the most famous, and in a certain sense pioneering, is Leben des Galilei by Bertolt Brecht (1966), though there is also Die Physiker, by Friedrich Dürrenmatt (1964). Both address the responsibility of scientists, although from very remote points of view. They do not give much weight (and in Dürrenmatt's case, none at all) to the presentation of scientific concepts. The atomic mushroom cast – and continues to cast – a long shadow.

We will focus our reflections on two plays in which, besides including social and political aspects of science, concepts of modern physics are developed in considerable detail. What they have in common is the relationship they establish between the uncertainty of events or decisions, with findings related to physics. The difficulty or impossibility of knowing what really happened at some past moment in history or in someone's mind lie at the center of their respective plots, and that is connected with the irreversibility of thermal processes and the uncertainty principle of quantum mechanics. We will see how, in both cases, the flow of metaphors shows two tendencies: that which flows from common heritage to science, and the flow moving in the opposite direction. We will argue that very often, what we are contemplating is not the popularization of scientific ideas but rather a scientification of previously-circulating ideas.

3.1 Irreversibility and Free will

Arcadia is a play based on a fictional plot, although it does use the growing interest by scientists in thermal phenomena and the origin of thermodynamics as its temporal and contextual scenario. This occurs in one of the two storylines, because Arcadia alternates between two stories taking place in the same space: the Coverly mansion, in the early 19th century and in the present. The other scientific topic considered is the dynamics of chaotic systems and their relation to fractal geometries (Vees-Gulani, 1999). In our opinion, this thread is less successful, so we will focus on the analogies with heat phenomena.

It is not difficult to imagine the action of Arcadia without the content of physics and mathematics. They have an important but not crucial function in the development of the events. One of the central ideas that runs throughout the play is the impossibility of ever fully retrieving information from the past, and this idea is expressed by means of burning letters, passionate outbursts (the famous "carnal embrace"), or devastating fires. As in this play we are privileged (albeit impossible) witnesses who can see what really takes place in the Coverly mansion during Lord Byron's visit, we can know why things could never be completely reconstructed in the future. In the action set in the present, two researchers attempt to reconstruct this visit and certain subsequent events, but without success. Many of the circumstances that take place in the years 1809-1812, and which will confuse the

historians of the future, are related to heat. At the beginning of the play we find a good example of an explanation of what an irreversible phenomenon is:

> Thomasina: When you stir your rice pudding, Septimus, the spoonful of jam spreads itself round making red trails like the picture of a meteor in my astronomical atlas. But if you stir backwards, the jam will not come together again. Indeed, the pudding does not notice and continues to turn pink as before. Do you think is odd?
> Septimus: No.
> Thomasina: Well, I do. You cannot stir things apart.
> Septimus: No more you can, time must needs run backward, and since it will not, we must stir our way onward mixing as we go, disorder out of disorder into disorder until pink is complete, unchanging and unchangeable, and we are done with it for ever. This is known as free will or self-determination. (Stoppard, 1993, p. 8)

An interesting way of showing the difficulty of obtaining reversible processes in everyday life. However, note the contrast between the clarity of Thomasina's explanation with Septimus's reply, in which a link - one which recurs throughout the entire play - is established between irreversibility and free will. The dichotomy arises between Newtonian physics and thermodynamics, between reversible and irreversible phenomena, determinism and indeterminism, and even between Romantic and neoclassical gardens (Drugeon, 2013).

In this sense, the metaphorical, explanatory use of the incompatibility between mechanics and thermodynamics is brilliant and appropriate. We cannot go backwards because some of the processes that have taken place are not reversible in time. Furthermore, the way in which the more technical details are explained, whether by Thomasina (as in the example we have just seen) in the 19th century, or Valentine in the 20th, are well embedded in the plot. It is argued that thermal phenomena prevent a reconstruction of the past, and this deleterious effect is associated with thermodynamics, a theory that contradicted (or is presented in the work as doing so) Newtonian mechanics. According to Newton, processes are reversible: given certain initial conditions, it is possible to know what will happen next and what happened before[21]. Thomasina explains it as follows after finding out about the work by Joseph Fourier (1808), who is not explicitly cited in the text:

> Newton's machine which would knock our atoms from cradle to grave by the laws of motion is incomplete! Determinism leaves the road at every corner, as I knew all along, and the cause is very likely hidden in this gentleman's observation. (Stoppard, 1993, p. 114)

21 Strictly speaking, only if we assume that Newtonian mechanics rule the world, it is reversible. But we can also restrict Newtonian mechanics to a class of phenomena. In that case, Newtonian mechanics could still be valid and the world not necessarily reversible (Brush, 1976, p. 608).

Again, an opposition is established between strict determinism and thermodynamic irreversibility. Thomasina is able to discover, before Sadi Carnot (1824), the implications of the heat diffusion equation by Fourier: different initial conditions lead to the same state of equilibrium. It also limits the efficiency of thermal machines. Noakes, the landscaper, has installed a decorative steam engine in the gardens at Coverly mansion that reminds us throughout the play that the industrial revolution had already started:

> Thomasina: Mr Noakes - bad news from Paris!
> Noakes: Is it the Emperor Napoleon?
> Thomasina: No (…) It concerns your heat engine. Improve it as you will, you can never get out of it what you put in. It repays eleven pence in the shilling at most. The penny is for this author's thoughts. (…) Newton's equations go forwards and backwards, they do not care which way. But the heat equation cares very much, it goes only one way. That is the reason Mr Noake's engine cannot give the power to drive Mr Noake's engine. (Stoppard, 1993, p. 118-119)

Valentine, the mathematician in the present-day storyline, emphasizes again the irreversibility of thermal phenomena by talking to Hanna, who in turn is trying to understand what Thomasina was doing almost two hundred years earlier in the same room where they now are:

> Heat goes to cold. It's a one-way street. Your tea will end up at room temperature. What's happening to your tea is happening to everything everywhere. The sun and the stars. It'll take a while but we're all going to end up at room temperature. (Stoppard, 1993, p. 106)

As we can see, the thermodynamical tendency to equilibrium, very significant in the history of physics, is well illustrated throughout the play. An isolated system in thermal equilibrium will never cease to be so spontaneously: it is a "one-way street".

However, in our opinion, its relationship with determinism or free will is brought up in a rather confusing way. After all, thermal equations are also deterministic, and free will may have little or nothing to do with physics and its predictions. It will always be an idea that remains outside of physics, even if we consider quantum non-causality (López-Corredoira, 2018). The idea that both free will and thermodynamics are opposed to Newtonian mechanics does not imply, as the play erroneously suggests, that they are the same. They are different oppositions, and in fact thermodynamics is also opposed to free will, a concept that, as we have said, will always be omitted from physics.

On a more technical level, it should also be noted that Arcadia does not say anything about the theory of physics that attempts to reconcile these two visions of reality (thermodynamics and mechanics); namely, statistical physics. In this theory, heat is understood as random motion, and

reduces thermodynamical impossibility to improbability. Randomness should not be confused with chaotic motion. In any case, both are deterministic.

This mess has a lot to do with the transfer of metaphors from one context to another. None of these concepts derive from physics (determinism, irreversibility, chaos, etc.), though they certainly had been present in many discussions between physicists. Thus, in Arcadia we not only find scientific results explained in common language or an application of scientific topics to daily subjects or emotional issues, but rather the use of specific scientific results to talk about these topics once more, but using a more modern and technical language. Do our actions leave an indelible mark? Can we completely reconstruct past events? This is a theatre piece where science is used to play with (Zehelein, 2009, p. 284). In short, Arcadia is a good example of how to normalize the use of certain topics and terms that come from the field of physics but by using subjects and images that are prior to the considered theories. The references to fractal theory or thermodynamics do not add anything substantial to the plot, and transmit a misleading idea of how physics has dealt with these phenomena. Modifications and nuances introduced in those concepts by physics are lost in translation. In this case, the compatibility between mechanics and thermodynamics obtained through probability is omitted, as well as the impossibility of understanding free will within physics.

On the other hand, the more scientifically-minded characters (Thomasina and Valentine) fare a little better than the ambitious literary scholar (Bernard). Honesty and moral innocence characterize the scientists in both time scenarios. Valentine even makes a speech on the achievements of modern physics that reminds us of certain strategies of science communicators:

> It makes me so happy. To be at the beginning again, knowing almost nothing. People were talking about the end of physics. Relativity and quantum looked as if they were going to clean out the whole problem between them. A theory of everything. But they only explained the very big and the very small. The universe, the elementary particles. The ordinary-sized stuff which is our lives, the things people write poetry about –clouds - daffodils – waterfalls - and what happens in a cup of coffee when the cream goes in – these things are full of mystery, as mysterious to us as the heavens were to the Greeks. We're better at predicting events at the edge of the galaxy or inside the nucleus of an atom than whether it'll rain on auntie's garden party three Sundays from now. Because the problem turns out to be different. We can't even predict the next drip from a dripping tap when it gets irregular. Each drip sets up the conditions for the next, the smallest variation blows prediction apart, and the weather is unpredictable the same way, will always be unpredictable. (Stoppard, 1993, p. 64-65)

Valentine represents an unassuming young scientist who recognizes that physics lies at the beginning of our understanding everyday events. However, he does not problematize the knowledge in the atomic and galactic world; he presents that as knowledge that is sound and, to some extent, useless.

The vision of the world provided by relativity and quantum mechanics is not in doubt, quite the contrary: they are the safe starting point for future advances. We believe that this is a good illustration of the false modesty sometimes adopted by scientists and science-communicators: a lack of certainty is admitted with regard to the unknown, but blind spots in well-established theories are concealed. There is a kind of scientific canon that is barely under discussion. Thus, to promote what is yet to be discovered (that is, fields of research in which investment will become generous in the near future) there is a tendency to present current theories as being unproblematic.

3.2 The uncertainty principle at the heart of things

Frayn's Copenhagen does not avoid the most recurring theme when it comes to discussing the role of physics in society after the Hiroshima and Nagasaki massacres. Not only does it not avoid it, but to a certain extent (and despite the many other subjects the play deals with), it is one of its central themes. Interspersed with stories about the gestation of quantum mechanics and the Copenhagen interpretation, the play tackles the subject of Niels Bohr and Werner Heisenberg's responsibility for the nuclear catastrophe and their complicity with each side (Shepherd-Barr, 2006, p. 135). Margrethe Bohr plays a mediating role between the two characters, but also with the public; she is far more intransigent with the exculpation of Heisenberg than Bohr himself. In general terms, the play begins with a Heisenberg in the firing line and ends up by playing down Bohr's moral superiority. After all, if facts are to be judged, Heisenberg is not necessarily any worse off. Things change if we value intentions, but can we ever really know them? Heisenberg mentions, in a metaphorical sense, when referring to the observable quantities of quantum mechanics, the possibility of devising a quantum ethics that is founded only on facts. And this allows the play to minimize Heisenberg's responsibility. This is one of the many examples of something that abounds in this award-winning play: an apparent application of discoveries made in the atomic world to the domain of the everyday and to common ideas about reality and knowledge.

Karen Barad (2007) made a criticism of Copenhagen that we share to a large degree, since Frayn's work is based on analogies that are unfair to the scientific content to which they refer[22]. Barad argues that Bohr indeed extended the results of quantum mechanics to other fields, and she herself also took that task further. She proposes that, as a matter of fact, metaphorical and analogical thinking should be avoided.

Copenhagen does not have science as its central theme either, but rather as a setting, a context. Unlike Arcadia, it does refer to a historical episode: specifically, the controversial meeting (and which has become even more controversial since the premiere of Frayn's play) between Heisenberg and Bohr in occupied

22 We arrived at Barad's text after having outlined the reflections that we present here for the first time at the conference that has given rise to this volume. We are grateful to Cory Tamler for bringing Barad's thesis to our attention.

Denmark in 1941. Science historians have criticized ad nauseam the spurious use of this episode to whitewash Heisenberg's role (Dörries, 2005). The physics topics that are mentioned throughout the play include such points as the critical mass of plutonium required to build a weapon, and the difference between a reactor and a bomb. On a more philosophical level, Bohr's complementarity principle and Heisenberg's uncertainty principle are undoubtedly the central motifs. Both are surely the best-known results of quantum mechanics in the eyes of the general public, and both are reminiscent of common ideas and hence are easily explained. Let us focus on the uncertainty principle.

It is explained in some detail, but in a way that distorts its original meaning, as Frayn himself acknowledged (Frayn, 1998, p. 98). For example, speaking of the speed with which Heisenberg skied down the slopes of Bayrischzell, Bohr says:

> At the speed you were going you were up against the uncertainty relationship. If you knew where you were when you were down you didn't know how fast you'd got there. If you knew how fast you'd been going you didn't know you were down. (Frayn, 1998, p. 24)

An analogy that cannot but be confusing, since it starts from a perfectly-determined trajectory in which the loss of reciprocal definition of position and speed is only in the mind of the skier, not in the moving object. In the same conversation, Heisenberg adds:

> Decisions make themselves when you're coming downhill at seventy kilometres an hour. Suddenly there's the edge of nothingness in front of you. Swerve left? Swerve right? Or think about and die? In your head you swerve both ways… (Frayn, 1998, p. 25)

An allusion to the principle of superposition, according to which two physically possible states can be superposed to create a new one. Again, not in the mind of the observer, but in the physical system considered.

Do these passages enable us to understand what the uncertainty principle on quantum mechanics consists of? Only in a partial, misshapen way. Before quantum mechanics, the instantaneous decisions of a skier could be described in the same way. Thus, the audience could get the wrong idea that quantum theory has done nothing more than technically endorse things we already knew.

Nothing is further from reality (if we may say). The Copenhagen interpretation is an acknowledgment of the failure of the 19th century physics project to understand and visualize what happens in the atomic underworld. It forced physicists to reformulate the concept understanding to explain what happens to atomic electrons or to light in any elementary process. Detailed images, precise mechanisms, and well-articulated causal connections are not valid. We find none of this in the play

which, once again, prioritizes a new and simplified paradigm over the questioning of the old; the metaphor over the perplexity. Quantum mechanics provides new descriptive and predictive tools, which are explained in the play through psychological concepts. Everything seems to lead to the same place: the relativism of knowledge and its quantum foundations.

Frayn also tries to explain the discrepancies between Heisenberg's original formulation of the uncertainty principle and the correction that Bohr forced him to introduce in 1927 (Heisenberg, 1927):

> Heisenberg: Now, Bohr's an electron. He's wandering about the city somewhere in the darkness, no one knows where. He's here, he's there, he's everywhere and nowhere. Up in Faelled Park, down at Carlsberg. Passing City Hall, out by the harbour. I'm a photon. A quantum of light. I'm despatched into the darkness to find Bohr. And I succeed, because I manage to collide with him… But what's happened? Look - he's been slowed down, he's been deflected! He's no longer doing exactly what he was so maddeningly doing when I walked into him!
> Bohr: But Heisenberg, Heisenberg! You also have been deflected! If people can see what's happened to you, to their piece of light, then they can work out what must have happened to me! The trouble is knowing what's happened to you! Because to understand how people see you we have to treat you not just as a particle, but as a wave. I have to use not only your particle mechanics, I have to use the Schrödinger wave equation. (Frayn, 1998, p. 68-69)

It is hard to understand the scope and meaning of the principle of uncertainty with this type of images when it is precisely the images that we are prevented from constructing in atomic processes (Beller, 1999, p. 103). In no case do we appreciate that bewilderedness that forces the researcher to give up visualizing and causally understanding what happens in the world of atoms. Certainly, this discovery opens a new era. In the play Bohr presents it as an unprecedented success. Heisenberg represents extreme positivism; "it works", it is not necessary to understand. Bohr, on the other hand, is extremely optimistic:

> It works, yes. But it's more important than that. Because you see what we did in those three years, Heisenberg? Not to exaggerate, but we turned the world inside out! Yes, listen, now it comes, now it comes… We put man back at the centre of the universe. Throughout history we keep finding ourselves displaced. We keep exiling ourselves to the periphery of things. First we turn ourselves into a mere adjunct of God's unknowable purposes, tiny figures kneeling in the great cathedral of creation. And no sooner have we recovered ourselves in the Renaissance, no sooner has man become, as Protagoras proclaimed him, the measure of all things, than we're pushed aside again by the products of our reasoning! We're dwarfed again as physicists build the great new cathedrals for us to wonder at - the laws of classical mechanics that pre-date us from the beginning of eternity, that will survive us to eternity's end, that exist whether we exist or not. Until we come to the beginning of the twentieth century, and we're suddenly forced to rise from our knees again. (Frayn, 1998, p. 71)

In these words by Bohr, the impossibility of eliminating the influence of the observer from the act of measuring comes to represent the exaltation of the human being, returning him to the center of creation. It is further implied that objective, "eternal" descriptions such as that of classical mechanics are no longer possible. But this type of reflection presents several problems. On the one hand, quantum mechanics does not force us to dispense with objectivity in explanations; this does not mean that this concept is not problematic, but that it already was before the birth of modern physics. On the other hand, we see how relativism ends up emphasizing an absolute ideal: the subjective observer. Moreover, this is a clear example of the appropriation of an idea prior to physics: the influence of the observer on what he observes. At the level explained in Copenhagen, the distorting role of the observer in scientific investigations can be traced back, for example, to 19th-century discussions on anthropology or zoology, previous to quantum mechanics and modern physics. The dialogue continues:

> Heisenberg: It starts with Einstein
> Bohr: It starts with Einstein. He shows that measurement - measurement, on which the whole possibility of science depends - measurement is not an impersonal event that occurs with impartial universality. It's a human act, carried out from a specific point of view in time and space, from the one particular viewpoint of a possible observer. Then, here in Copenhagen in those three years in the mid-twenties we discover that there is no precisely determinable objective universe. That the universe exists only as a series of approximations. Only within the limits determined by our relationship with it. Only through the understanding lodged inside the human head. (Frayn, 1998, p. 71-72)

A kind of conversion of a technical result (objective, if we may), in defense of relativism. At the end of the play we find, out of the mouth of Heisenberg, still a spurious link between quantum uncertainty and, let us say, epistemological uncertainty.

> (…) by that one short moment in Copenhagen. By some event that will never quite be located or defined. By that final core of uncertainty at the heart of things. (Frayn, 1998, p. 94)

Once again, a reference to ideas existing in common language to explain (allegedly) quantum mechanics. Its role is then reduced to formally supporting old ideas, previously established ways of seeing the world and to understanding human psychology. Instead of accounting for the findings of quantum theory, they are adapted, accommodated, to a certain ideology or philosophical position.

4. Final remarks

The changes that have recently been taking place in society regarding gender roles have led to review the history of science using a new perspective. Although undoubtedly many of the contributions made

by women had been ignored in the established accounts, historiographical studies do not show that science, throughout history, has been an exceptional field in this regard. In other words, it suffers from the same vices and biases of the society in which it develops. Science has not been characterized by being at the forefront of the fight against established ideas, rather it has generally adapted to the status quo and has even provided it with epistemological foundations.[23] As for outreach, this is what we are referring to when we say that it does not always consist of disseminating scientific content but rather of scientifying previously-existing ideas.

It would be strange if this had nothing to do with the image of scientific knowledge that is transmitted in the classroom and in the media. We will not enter here into a debate on the extent to which the dogmatism we have been referring to throughout these reflections is rooted (or not) in scientific practice itself. What interests us here is to point out that if the aim is to encourage critical thinking and a skeptical view, then outreach and teaching cannot be based on an uncritical transmission of established truths.

In the relatively recent participation of the theatrical medium in the popularizing current of scientific knowledge and in the inclusion of modern physics content in plays, we have not found characteristics that have encouraged us to be optimistic. We have seen that in two of the most successful and emblematic plays of this new wave, the strategies that govern science outreach are repeated: the answer prevails over the question, the world-view over the questioning of old prejudices. We believe that it would be worthwhile to make use of the resources offered by the theatrical medium to reverse this trend and to place the question in the center of the stage.

As we said above, uncertainty lies, in one way or another, at the center of the plots of each the plays discussed. However, in these plays, uncertainty is not attributed to the scientific knowledge itself. Without wishing to fall into inane relativism, we believe that limiting the scope of scientific knowledge, with all that this implies of considering probabilities, uncertainties and the absence of absolute and unquestionable truths, would be more interesting, useful and honest. And it would avoid falling into idolatry. The theatrical medium has the ability to show and even accentuate these contradictions, and to avoid dogmatic, pamphleteering discourses.

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23 See, for instance, the famous book by Stephen J. Gould on biological determinism (Gould, 1981).

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THE LECTURE-PERFORMANCE, WHERE SCIENCE AND ART INTERTWINE

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Introduction

How do we orient ourselves politically within the new climate regime? Why are we disoriented in this new regime? And how can we imagine and visualize it? These questions are the pillars of INSIDE, a lecture-performance created by Frédérique Aït-Touati, theatre director and historian of literature and modern science, and performed by Bruno Latour, the renowned sociologist of science and philosopher. Together they developed a lecture-performance resolving around Latour's academic scope of the last decade: climate change. In line with his recent work, Latour reflects in INSIDE on the relationship between us, human beings, and our environment. Latour observes a discretion between the ontology of the planet and how we represent and imagine the planet. When we say "planet", we imagine the globe from outer space: the stereotypical "blue planet". What such an aloof image of the planet neglects are the human and non-human actors, the processes and transitions that compose and constitute the ecology of our planet. As Latour addressed in the performance, our assumption of the globe as a stable object that we can observe and dissect from a distance has long been (and still often is) the assumption of science as well. In our attempts to study the globe from a distance, we have lost out of sight the place that we inhabit and where we live. INSIDE serves as a counteract to depict and imagine the planet differently. Not as a stable object but the depiction of a world wherein the processes and cycles of transformations all the actors of the planet are exposed to. When Latour enters the stage of the theatre space, he is solely assisted by a pulpit and dimmed lights. But when the lecture gradually enfolds, Latour immerses and sometimes vanishes in the imposing scenography.

The lecture-performance Move 37 (2019), stages the encounter between Thomas Hertog, cosmologist and former collaborator of Stephan Hawking, and Thomas Ryckewaert, biologist and theatre maker. Ryckewaert opens Move 37 with a disquisition on Go, a traditional Chinese board game and the oldest of its kind. Despite its simple appearance, the number of possible board positions in a Go game exceeds the number of atoms in the universe. To become a high-class Go-player, exclusively human skills such as intuition and creativity are presumed far more important than pure computing power. Go was long considered impossible to be broken by a computer. In 2016, Google's A.I.-department DeepMind developed AlphaGo, a artificial intelligence-controlled program trained in Go. On March 16th 2016, AlphaGo competed against Lee Sedol, the world champion of Go. What was ought implausible happened: AlphaGo's 37th move in Go is one no human being could have ever imagined. Sedol leaves his chair and returns pale as a ghost. The live commentators fall silent, and the image seems to freeze. In this moment of defeat and wonder, the radical weirdness of A.I. stares us in the face: highly intelligent, creative but also completely alien. Uttering these words, Ryckewaert leaves the stage and Thomas Hertog enters the stage. Assisted by a blackboard, crayons, and a small water vortex project on the back of the stage, Hertog enthusiastically starts to speak about black holes, Einstein's theory of relativity, quantum physics, and the infinity of the universe. On the boundary between human and alien, intimate and strange, reality and fiction both INSIDE and Move

37 explore phenomena that transcend the human imagination. And the lecture-performance seems to be an apt format to articulate these frictions.

Since the 1960s, the widespread practice of the lecture-performance knows a long tradition in the field of contemporary arts. Together with INSIDE and Move 37, we observe a growing interest in the lecture-performance by academics working in other disciplines than the arts. Parallel to the genealogy of the lecture-performance within the arts, such a resort from scientists emerges 'out of the necessity for an experimental concept' to communicates one's research (Rainer 2017:79). Next to many other practices, media and methodologies, the lecture-performance is one of these experimental concepts, with the theatre space as a place where this experimental way of sharing research stands out well. INSIDE or Move 37 are exemplary for a growing need and desire by academics to communicate research differently, but most of all, to try out new approaches of doing research, beyond the calibrated, gauged, and safe methodologies.

From arts to science: the genealogy of the lecture-performance

The lecture-performance already emanates for decades in the arts. The practice originates from the American and European avant-garde of the 1960s and coincided with an academicization and institutionalization of the arts. Artists were invited to teach at art schools or to talk about their work and artistic practice in an academic context. In this period, the lecture performance emerged as a vital aesthetic form, 'both as a result of and reaction against compulsory academicization' (Firunts 2016:19). From the 1980s and 1990's onwards, the institutional critique by artists of the political, ethical, and economic conditions of the art scene became significant topics addressed by lecture-performances. But to dismiss the lecture performance as a mere bashing of academic and art institutions would dishonor the practice of lecture-performance. As curator Jenny Dirksen noted, artists' recourse to 'the academic discourse to gain some control or right to speak about the exploitation of their artistic practice' contributed at the same time to the widening of that artistic practice. (Dirksen 2009:13). This brought the lecture-performance throughout the years to a format and practice that helped 'to imagine how knowledge may be produced and disseminated outside the academy: within alternative institutional frameworks, beyond authorized communicative forms and through embodied modes of performativity' (Firunts 2016:19). Where it once was a format to present and reflect on one's artistic practice, it addresses nowadays a wide variety of topics: from artistic, scientific, or subjective research topics to social, cultural, and political subjects.

The interest of artists in the lecture-performance and its relevance lies in the hybrid character of the practice: it combines a functional presentation with artistic performance, it draws on historical methods but reflects at the same time on the role of art in our world. In doing so, it challenges the

conventional notions of knowledge production, communication, and criticism. Due to its evolution, the lecture-performance as a medium for the presentation, dissemination and discursive treatment of topical questions and standpoints', is no longer a practice restricted to artists, but it is also practiced by art critics, art historians, and art theorists in an academic context (Dirksen 2009:13). And apart from the presence of a phlegmatic artist performing or the attentive audience listening during this social gathering, curator Rike Frank assigns the popularity of the lecture-performance to its affective dimension. As Frank explains, the lecture performance allows the introduction of 'other forms of personal affect that complicate and obscure the understanding of the subject as a 'resource' to be capitalised upon' (9). Blending a scientific with a personal vocabulary, one can turn more easily to 'an affective attachment to objects and ideas that implies more personal less institutionalised relations and directed against forms of fixation, standardisation and closure' (11). This affective dimension is, as performance theorist Maaike Bleeker observed, invariably combined with 'a self-reflexive attitude with respect to one's own doing and the conditions of production and reception' as prominent characteristic of many lecture-performances indicates a close (236). By blurring the boundaries between production and reception, the lecture-performance, Rike Frank summarizes, 'opens up the possibilities to experience knowledge as a reflexive formation that is as much aesthetic as social – in other words, as an open feedback system' (6).

As performance studies theorist Lucia Rainer notes, the concept of the lecture-performance brings into focus that knowledge is not a factum but in constant flux. Because knowledge oscillates between acts of determining and re-determining, Rainer argues, that the individual, spatiotemporal frame influences the ken activity of knowledge as an encounter that is interfused by the presence (10). Consequently, 'Knowledge does not testify to consistency but adheres to its individual processes of the singular' (16). One's research and the presentation of its outcomes are in the lecture-performance, not separate processes but permeate each other. As for performance theorist Sybille Peters elaborates on this interplay, knowledge presentation and knowledge production coincides, and their procedures are made transparent. In doing so, it exposes and realigns knowledge practices that derive from supposed certainty and assurance (170). And whereas artists try to create these interplays and frictions in classrooms and auditoria, Latour and Aït-Touati, as a scientist and historians, tried to do this in the black box of a theatre by transforming the theatre 'into an instrument for visualization and a heuristic tool' (Aït-Touati 2017:153).

Latour's resort to theatre and the format of the lecture-performance might be seen as a mere detail or a frivolous excursion but the opposite is true. From the very beginning of Latour's academic career, the notion of theatre asserted its appeal to the French philosopher of science. Not theatre in particular, but the power dramatization incited Latour. In one of his first books, The Pasteurization of France, Latour outlines how Louis Pasteur became indisputable as a pioneer in the level of microbiology and his study of anthrax. 'Pasteur's genius', Latour writes, 'was in what might be called the theater of proof.

Having captured the attention of others in the only place where he knew that he was the strongest, Pasteur invented such dramatized experiments that the spectators could see the phenomena he was describing in black and white' (85). Not the clarity of Pasteur's expositions and argumentations explained the persuasiveness of his ideas and research. And the contrary, it was 'the visual quality' and the dramatization of his experiments in this 'new theatre of truth' that lured the people (84). With INSIDE, Latour follows this methodological thread tightened by Pasteur. The content of INSIDE is an elaboration of Latour's most recent work: Facing Gaia: Eight Lectures on the New Climatic Regime and Down to Earth: Politics in the New Climatic Regime. Similar to Pasteur, Latour is accompanied on stage by drawings and visualizations of Alexandra Arènes, Axelle Grégoire, and Sonia Lévy, in an attempt to visualize and dramatize his research claims. Although his lecture-performance takes in the black box of theatre spaces, he does not consider it as a work of art or see himself as an artist. As Latour explains: 'constructing a play pushes me to sharpen philosophical concepts. It may be a weak definition of art, but the practical artistic work helps me to grasp ideas that are still half-obscure, hidden in the shadows' (Aït-Touati & Latour 2018:16).

From science to art: the lecture-performance in INSIDE and Move 37

Latour's taste for the dramatization of philosophical or scientific ideas re-establishes the alliance between art and science. In the 16th and 17th, this alliance was very strong, and the powers of fiction helped science to revolutionize the conception of the earth. As pioneers such as Johannes Kepler, Bernard Fontenelle, Christiaan Huygens, Robert Hooke or Margaret Cavendish proved centuries ago, the use of 'fiction is not opposed to knowledge but takes part in the constructions of different kinds of knowledge: it confirms, anticipates, or develops' (Aït-Touati 2011:36). With the work of scientists like Latour or Thomas Hertog and artists like Hannah Hurtzig, Thomas Saraceno, Kris Verdonck, Thomas Ryckewaert, and many others, we see modest attempts to close the gap between art and science the wig of modernity once drove. As is the case with Latour and INSIDE, where the new climate regime invites the arts and science to be explored in different ways. In that sense is INSIDE as lecture-performance an attempt to stage the problem of climate change in a different way than is done in our dominant visual culture, with its obsession with catastrophe, disasters, and dystopia.

INSIDE withdraws from the profoundly perverse delight in the extent of disaster that we observe in visual culture where audiences are confronted with environmental catastrophes. The Romantic notion of the Sublime that was cherished once has been replaced by what Latour termed as 'a dark neo-sublime, a sort of pornography of catastrophes' (Aït-Touati & Latour 2018:19). Instead of reproducing the spectacular pathos of a blockbuster catastrophe movies to the stage and perpetuate the anxiety associated with the dark neo-sublime, with INSIDE, Latour and Aït-Touati try to provoke alternative feelings and possible affective ways to relate to the new climate regime. Even though we

have to say that this provocation is rather unobtrusive. Parallel to Latour's research of the last decade, the key argument of INSIDE resolves to the idea that we cannot longer pretend that we are able to distance ourselves from the world and describe it. We are inherently entangled in this world.

On a theatrical and dramaturgical level, this entanglement is almost literally translated: Latour immerse towards the end of the lecture-performance into the scenography. 'Decor is not decor anymore', Aït-Touati and Latour argue, parallel to how we are confronted today with and by nature in the new climate regime (Aït-Touati & Latour 2018:17). The drawings and projections that we as spectator tend to perceive as mere backdrops and visual illustrations of Latour's argument now start to merge with the foreground of the stage and becomes active. It articulates the authors' search for a new relationship to scenography, by de-centering the human, moving him or her slightly off stage and helps us to 'get closer to the way life forms are in the world through imagining their stories, including the stories of their entanglements with us, human beings' (Aït-Touati & Latour 2018:18).

Whereas INSIDE as lecture-performance is predominated by its "lecture" part, the "performance" part of the lecture-performance predominates in Move 37. In the latter, the presence and impact of the theatrical framework is much more played out and felt, especially towards the end of Move 37. One could say that Move 37 exists out of two lecture-performances: the first by theatre maker Thomas Ryckewaert, discussing the GO-incident. The second is Thomas Hertog's groping exposition on cosmic phenomena. Hartog's eager way of talking about his field of expertise in combination with the theatrical apparatus constantly suggests for the spectator a kind of uncanniness. When Hertog talks about black holes, his commendation is accompanied by a water installation on stage, serving as a visual tool to support his arguments. A video camera captures the black water vortex from above, suggesting a black hole, and projects it on the back of the stage. As a spectator, you are not getting any wiser out of this experience, in contrast to what a 'lecture' and a scientist on stage would suggest. Hertog's partaking in Move 37 is not an attempt to lecture a non-academic audience on the mysteries of the universe. On the contrary, the theatrical and non-academic frame offers Hertog the possibility to show the lacuna of his field of expertise is dealing with: the inability of human imagination to imagine and depict these black holes. Despite the unimaginable amount of scientific work that has been done by experts from various fields dealing with our universe and existence, each the human brain is confronted with its restrictions on the level of imagination. This is what Move 37 outlines regardless of all the mathematical formulas scientists wield in their rigorous scientific methodology; there is still so much of the universe that is beyond human comprehension. Not the transfer of knowledge on the cosmos or GO, but the sharing of an experience of phenomena that go beyond our comprehension is the core of Move 37. Cultural theorist Mark Fisher wrote how 'in many ways, a black hole is more weird than a vampire. The bizarre ways in which it bends space and time are completely outside our common experience and yet a black hole belongs to the natural – material cosmos – a cosmos which must therefore be stranger than our ordinary experience can comprehend' (15).

Therefore, Fisher prefers 'eerie' instead 'weird' to describe this experience. Both the eerie and the weird share 'a fascination for the outside, for that which lies beyond standard perception, cognition and experience' (8). But whereas the weird relates to something that does not belong to our world (like a vampire), the eerie 'is constituted by a failure of absence or by a failure of presence' and provokes a sensation of something present were there should be nothing, or the absence of something that should be there (64). What Ryckerwaert and Hertog by Move 37 want to share isn't the knowledge of the power of artificial intelligence that directed AlphaGo to beat Lee Sedol or the knowledge of the universe, but this eerie sensation they experience every time they think, talk and wonder about them. What Hertog cannot communicate through his highly praised academic work – this eerie sensation for that which lies beyond our perception, cognition and experience – might be communicated through theatre and its parameters. And all though Ryckewaert, as an artists, and Hertog, as a scientist, might be seen on first sight as each other's opposites, they both share the desire to grasp, apprehend and imagine the world. The tools and methods they use to do this might be very different, in the end and each in their own way, they are also confronted again with the fallibility of those tools and methods.

The lecture-performance as a speculative practice

What INSIDE and Move 37 as lecture-performances share with the lecture-performances form the realm of arts is the significant position of experience and the affective dimension, as highlighted by Lucia Rainer. The experience of being affected by climate change's impact on humans and non-humans, as in INSIDE. The experience of wonder, marvel and nullity in relation to the mysteries of quantum physics, as in Move 37. Doing research on these topics is treating preliminary findings not as fixed meanings but as uncertainties that need to be examined before being determined and defined. Such engagement with such uncertainties is accompanied by disagreements, failure, wonder, doubt, and moments of epiphany or frustration. While researching, an array of possibilities is on the table. Considerations and choices are made. Some options are further explored, to test and to weigh some of the propositions. Observing how science and academia over the years became more competitive and focused on quantitative rather than qualitative output, it does not come as a surprise when observing how scientists and academics search for alternative and less competitive ways of doing and sharing research. So, one can apprehend scientist's interest in charting the experience of doing scientific research and sharing it with others in a way it includes this experiential and affective dimension of doing research, as in INSIDE and Move 37, as a reaction against some dominant tendencies challenging the academic and scientific realm.

On the one hand, affected and cankered by populist and neoliberal politics, the humanities – and science in general – are facing declining credibility and persuasiveness in times of fake news and post-

truth. Another consequence of this tendency is the constant demand to social and cultural researchers 'to foster, promote and articulate the relevance' of what they practice and produce (Savransky 2016:25). On the other hand, in the face of the ecological crisis, growing inequality, shifts and the democratic deficit, these disciplines do not seem fully equipped to have a significant impact these days. Where science once was able to formulate and offer solutions to solve our problems, today this seems not the case anymore. The contingency of our time demands for new methods, concept and paradigms in counteracting our dominant modes of response.

This impasse partially explains the (re)newed interest by philosophers of science for the pivotal role experience plays in science. The anti-realist stance of continental philosophy and its repetitive focus on texts, discourses and social practices of the last decades jostled reality and the experience of reality to the background. The more recent revival of the empiricist philosophies of thinkers such as William James, John Dewey and Alfred North Whitehead foregrounds their unconditional 'commitment to the priority of experiences of all natures and manners, as means of feeling, knowing, and thinking the world and the relationship that our practices sustain and with it, also the many relations and modes of togetherness by which things come to matter' (Savranksy 2016:181). In their radical empiricism, as sociologist Martin Savranksy notes, they subscribe to a form of empiricism that regarded experience itself as neither fixed nor fully contained in thought; as a dynamic plane on and through which, thinking is cultivated, articulated and transformed. When we observe reality, we cannot retreat from the flux of reality. One cannot see everything from nowhere and thinking from that outsider-position what reality is or should be. For James and Whitehead, as founding fathers of this radical empiricism, 'thinking is always thinking with and in the midst of experience' (2017:28). Because no thoughts or concepts are fully able to adequately capture the dynamic complexity of relationships when experiencing the world, errors or fallibility of thoughts pose no problem. On the contrary, the fallibility of our thinking is an insurmountable part of every process of thought and knowledge.

Drawing on this radical empiricist tradition, Savransky argues that if the humanities want to overcome of its current impasse, it must mobilise a way of thinking that always 'begins from the facts of experience and seeks to return to these facts transformed by the imaginative leap involved in the invention of concepts that seek to inhabit the possible' (2016:185). This type of intellectual exercise is what Savransky terms as 'speculative experimentation'. In the modern European linguistic variations, "speculation" is derived from a series of Latin verbs and nouns: speculatio ('observation', 'contemplation'), specere ('to look'), speculari ('to observe', 'to examine', 'to explore') and speculum ('a looking glass', 'a mirror'). The Sanskrit root of these nouns and verbs, spàs ('to spy', 'to see', 'to observe'), etymologically connects to sight and touch, to clarity and obfuscation and turns us towards not only to 'speculation as thought' but also to 'speculation as a pressing toward an apprehension of the unknown' (Uncertain Commons 2013:8). Born on the perplexing and poetic capacities of mirrors ('specula') and provocative modes of knowing and thinking ('speculum' was also the name for medieval encyclopaedia), speculation

brought together the visible and the invisible and served as a testing ground in order to push to known to the unknown (Savransky et al 2017:5). 'The speculator', as philosopher of science Isabelle Stengers summarizes, is he 'who observes, watches, cultivates the signs of a change in the situation, opening themselves to what, in this situation, might be of importance' (Debaise & Stengers 2017:18). Such a speculative mode of theorising, Savransky continues, involves a practice of thinking that is rooted in both perceptual and conceptual experience. From thereon, 'speculations must begin from the real possibilities emerging from actual facts and inventively construct abstract and practical tools capable of effecting a different mode of transitioning between present and future by providing an alternative path towards a novel empirical situation' (2016:201). The aim, Savransky concludes, is that of producing concepts, words, or tools that may contribute to the rearrangement of the relationships, the modes of togetherness of the facts that compose a situation so that the latter might be experienced differently, opening a path to the composition of a different future (2016:203). Speculation within social science, philosophy or the arts then becomes a strategy or method to go beyond that what is conventionalized. What these speculative approaches try to acquire is openness and susceptibility for what characterizes contingency: uncertainty, ambiguity and ambivalence. As illustrated by INSIDE and Move 37, the lecture-performance can be considered as a practice where this changing and ambiguous experience of doing science and research can be addressed and highlight how the gap between what is known and unknown, between what is available and unavailable cannot always be bridged.

The lecture-performance as an essayistic practice

Stengers' account of the scientist as speculator reverberates with the way curator Jenny Dirksen compared the lecture-performance to the process of essay writing. Dirksen draws her comparison from the way German writer Max Bense described the process of essay writing as followed: 'he who writes essayistically; composes something experimentally; turns his subject his way and that, questions, touches, inspects, and reflects upon it thoroughly; approaches it from different angles, and collects what he sees in his mind's eye, and formulates in words what his topic reveals under the conditions established by writing' (52). As Dirksen argues, the lecture-performance is related to the process and practice of essay writing in the way subjectivity and inductivity are combined in these (self-)reflexive and critical practices. Both are reflective modes and methods of presentation in which pragmatic and aesthetic criteria are treated with equal validity and complement each other to expand the possibilities inherent in any perspective it explores. The essay form as the lecture-performance function both as a platform for reflecting on the necessities, the stumbling blocks and the possibilities of doing and presenting research (10-11).

Dirksens' reference to the essay form reminds to its epistemological qualities. Because of its connotations with a experiencing, reflecting, and narrating self, one tends to forget the role the essay form played

in the way knowledge was produced. Michel de Montaigne's Essais were a reaction to the dogmatic scholasticism, descended from medieval times but still dominated thinking and writing in the 16th century. In reaction to the scholastic obsession with metaphysics, Montaigne turned his gaze to reality and let his writing flow out of his personal experience of the turbulent times he was living in. His associative, discursive, informal, meandering and slovenly way of writing did not only depart from his experiences but were also a way to shape and to think about his experience. Since Montaigne introduced the literary form, the essay has been and still is a form that not only thematizes contingency, but also tries to make that contingency, or at least the experience of the latter, part of the style of writing.

In the age of Enlightenment, innovative thinkers and scientists were prompted to speak from outside the authorized structures of the traditional methods of science. Rejecting the dogmatic views on nature and science, knowledge through individual experience was valued. Such empiricist methods demanded new forms of expression to examine the subject–object relationship it had discovered. As Lars O. Erickson (2004) observed, the (scientific) essay was particularly apt to host a more process-oriented way of reflecting on how one arrives at conclusions. Attempting to connect the universal with the concrete–particular, the essayistic science of the eighteenth century hovered between the rejection of scholasticism and the relativizing threat of empiricism. As such, the written essay offered a testing ground to develop new methods, systems and provisional knowledge. The latter is an important element in a time of epistemological movement and allowed space for doubts, uncertainty and contingency. So the essay operated as 'a tool for scientific discovery and as a means of expressing subjectivity as a process, for embodying the mind in its unpredictable motions and emotions' (Milnes 2019: 147).

Although eighteenth-century essays are often associated with solipsistic writing and mere belle-lettrism, it is noteworthy that a particular branch of essayist practitioners deployed the literary form to bridge the gaps between various scientific disciplines that were not fully developed at that time. Science as such did not yet have its own place, and its discourse had no fixed form; it made its appearance across a heterogeneous range of texts and domains. For innovators such as Denis Diderot, Robert Boyle, and Pierre Louis Maupertuis, the essay was one of those literary vehicles where fiction, experimentation, scientific hypotheses and knowledge could come together and where the freedom of imagination was preserved. As an irregular, adventurous and unfinished attempt, the essay made 'statements about what could and should be known, and how' (Siskin 2016: 33). As a form of expression for emerging disciplines and for ideas that went beyond the existing ones, the eighteenth-century essay was the repository for topics that belonged to no discipline (yet). Living in the margins, the essay could speak from an unorthodox position in order to express ideas that have no other enunciative structure. And even when these ideas found a structure in a newly developed discipline by the turn of the nineteenth century, the essay as a literary and scientific tool continues to move like an amphibian between environments and disciplines (Milnes 2019: 196).

By coining their work as 'scenic essay' Frédérique Aït-Touati and Bruno Latour inscribe INSIDE in this history and legacy of the essay form as an epistemic vehicle for the development of new forms of knowledge, acknowledging the important role of subjective experience in doing and presenting research (Zone Critiqie 2022). In his canonical book Postdramatic Theatre, Hans-Thies Lehmann introduced the notion of the scenic essay as one of the elements that shaped and characterized the panorama of postdramatic theatre. According to his definition, scenic essays were theatre plays offering 'a public reflection on particular themes' – by dragging theoretical or philosophical texts on stage (112). The means of theatre were used 'to "think aloud"' about the actor's subject, its representation, and the role of language' (113). In INSIDE, as in the subsequent lecture-performances Moving Earths (2019) and VIRAL (2022) of Aït-Touati's and Latour's Terrestrial Trilogy, means of theatre are used in to reflect on the need for a profound renewal of our representations of the terrestrial world, biotic and abiotic. Whereas INSIDE explores visual alternatives to the haunting and deceptive image of the "Globe"; Moving Earths tries to immerse the audience in the experience of a moving, reactive earth. In VIRAL, the closing part of the Terrestrial Trilogy, is an exploration of contagion as an essential process of our closed world, and the political consequences of this expanded definition of life.

Conclusion: reclaiming science

Stating that INSIDE or Move 37 herald a new trend within the field of performing arts and in science would be overrated. But what both examples do indicate is the necessity and urge to practice and foster scientific research in differently so it can respond to today's challenges. In that vein, the intentions of Aït-Touati & Latour and Ryckewaert & Hertog resonate with Isabelle Stengers analysis outlined in her book Another Science is Possible. Observing, and experiencing herself, the growing importance of benchmark evaluation and blind competition in all academic fields Stengers distinguishes 'fast science' from 'slow science'. 'Fast science', as Stengers notes, 'refers not so much to a question of speed but to the imperative not to slow down, not to waste time, or else…' (115). In today's knowledge economy we live, we are encouraged to produce and communicate new ideas at a high pace indented to, in turn, generate more new ideas. But what such a method of working implies is that it evades what slows down this process: frictions, rubbings, uncertainties, and hesitations.

As philosopher of science, Stengers reminds in her book that these elements of friction, hesitation and uncertainty are an inherent part of knowing and valuing those process, practices and experiences making up our common world. In her plea for what she denotes as 'slow science', scientists 'accept that what is messy is not defective but simply that which we have to learn to live in and think with' (120). The strong alliance between industry and fast science disembedded knowledge and ignored the messy complications of this world. But as the current ecological breakdown illustrates, we are now (re) discovering that we have messed up our world. Stengers plea for slow science is not a plea for a new

kind of science. On the contrary, Stengers call for slow science is one of 'reclaiming – recuperating, healing, becoming capable once again of linking with what we have been separated from' (81) and 'recovering or reinventing what that separation has destroyed' (121). 'If reclaiming scientific research means re-embedding the sciences in a messy world', Stengers concludes, 'it is not only a question of accepting this world as such, but of positively appreciating it, of learning how to foster and strengthen' (122). Inside and Move 37 are examples of a joint venture between scientists and artists to embed their practice again in this messy world.

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THEATRE AS A 'SCIENCE OF EXPERIENCE'. SCIENCE AND THEATRE IN TWO PERFORMANCES BY TEATRO PRAGA

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Intention

I would like, in this article, to work with the statement made by André e. Teodósio, member of the Portuguese theatre collective Teatro Praga[24], that 'theatre is the science of experience', by trying to interpret it within the context of the two cultures' divide that shapes this book. Teatro Praga's proposal, when identifying theatre with science, is, as I will try to demonstrate with the help of examples of two of their performances, to simultaneously work with and go beyond the traditional separation. In order to do that, the performances extract objects pertaining to the field of science and, through a process of exposing, dislocating and accumulating information, words or stories, expand possibilities of interpretation and sense, as they destroy the apparatus of capture that both categories (science and theatre) exert upon such objects. This procedure 're-fuses' (Donna Haraway) the culture divide and the way the relation between theatre and science is customarily described.

'Epistemology of separation'

In 1982, Edward Saïd published an essay, 'Opponents, Audiences, Constituencies and Community', on the relationship between universities and academia, on the one hand, and politics and society, on the other. In it Saïd argues against an academic balkanization, 'the notion that intellectual labor ought to be divided into progressively narrower niches' (Saïd, 1983: 138), that ultimately leads to a competition for authority 'existing solely within an academy that has left the extra-academic outside world' (Ibid.: 149). This separation of fields is not just responsible for reducing an epistemic domain. Saïd mentions a second consequence: 'the prevailing mode of intellectual discourse is militantly antimethodological', which means that this resistance to permeability in the academic field acts as a 'blocking device for a methodological and disciplinary self-questioning.' (Ibid.: 149) The isolation that takes hold of the different disciplines while making them resistant to change, results, according to Saïd, in an 'epistemology of separation', where 'each discourse "represents" the field, which in turn is supported by its own constituency and the specialized audience to which it appeals' (Ibid.: 155), a privileged method to acquire a position of authority, where the words '"expert" and "objective" have an important resonance' (Ibid.: 149). Separation is thus viewed as the opposite of a postmodernist or post-categorical epistemology, a contribution to a petrification of academic fields.

However, separation has also worked paradoxically as a strategy towards intersectionality. Saïd himself recognizes in this essay that there does not exist one single method for breaking out departmental divisions (Ibid.: 143). Most of the movements that intend to open their field to other ontologies or discourses require a separatist impulse, a refusal of the status quo. In *Glitch Feminism. A Manifesto*, Legacy Russell prints artist E. Jane's NOPE (a manifesto) as a starting point for her own manifesto that

24 Teatro Praga is a theatre collective that has been working since 1995 with considerable recognition in Portugal and abroad.

challenges the gender binary, in order to 'expand in every direction' (Russell, 2019: 151). E. Jane declares: 'I am outside of it in the land of NOPE'. (Ibid.: 16) To separate oneself from the world is understood by such declaration as a way of establishing new relations with the world that are beyond a binary logic. It is indeed a separation from the epistemology of separation. Separation can thus comprise two effects that apparently exclude one another: a balkanization that strengthens the status quo and the binary divide; or a construction of new places outside the status quo and the binary separationist system.

Donna Haraway, along with other feminist philosophers and scientists[25], has famously approached science in an attempt to build coalitions and promote exchanges between disciplines. Being a biologist, a philosopher and a feminist has allowed her to produce a discourse that has challenged the notions of objectivity and knowledge, science and technology. In her introduction to the *Haraway Reeader* (2004), she writes:

> In the face of many established disorders, we need to practice saying 'none of the above'. There can be an elsewhere, not as a utopian fantasy or relativist escape, but an elsewhere born out of the hard (and sometimes joyful) work of getting on together in a kin group (Haraway, 2004: 3)

Inhabiting 'an elsewhere' (the land of NOPE) can be interpreted as a way to break out divisions (Saïd), a separatist method with the aim of regarding ways of being 'truly present', as Haraway puts it, 'in myriad unfinished configurations of places, times, matters, meanings'. (Haraway, 2016: 1) But it is simultaneously an acknowledgement of the specificity and materiality of disciplines and knowledge. If Haraway feels 'very strongly that technoscience is inherently narrative' (Olson, 1996: 10), she is also opposing Paul Feyerabend's relativist approach towards science. If she is separating herself from the 'traditional narratives of science and technology [that] divide the technical from the political', she is also committed to 'a non-trivial way that is also not relativist'. (Ibid.: 10)

I am convinced that Haraway's location is very much in line with contemporary art and the discussions of the 'post-medium condition' (Rosalind Krauss), as well as the description of a 'post-historical' (Arthur C. Danto) or 'post-conceptual art' (Peter Osborne). And I am mostly thinking of the narrative that takes on the passage from modernist to contemporary art and how the divide between disciplines has been tackled. Haraway's concept of 're-fusal'[26], the simultaneity of refusing and fusing, coincides

25 Haraway herself mentions a number of them, namely Sandra Harding, Bruno Latour, Karen Barad and books such as Karina Knorr-Cetina and Michael Mulkay (eds.), *Science Observed: Perspectives on the Social Study of Science* (1983) and Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch (eds.), *The Social Construction of Technological Systems* (1987). In a conversation with Gary A. Olson, 'Writing, Literacy and Technology: Toward a Cyborg Writing' (2015), she acknowledges Sandra Gilbert, Susan Gubar, June Jordan, Gloria Anzaldúa, Theresa Hak Kyung Cha, among others.

26 'When you re-fuse the technical and the political, you insist on the story-ladenness of knowledge, the story-ladenness of facts. You're not thereby saying, "anything goes", or "it's just what you think," or "it's simply that you have the power to enforce your point of view." It's not a cynical or a relativist position, but it is about the materiality of anything that's going to be able to count as knowledge … which I think is the opposite of relativist.' (Olson, 1996: 10)

with the work of artists who claim a separation from the burden of art's history, but at the same time appropriate or extract this history 'to make art in whatever way they wished'. (Danto, 1997: 15)

'Science' and 'Theatre'

We know that science, like theatre, is not reducible to a single definition. This means we can easily stumble into misunderstandings in a discussion that compares the two. To help minimize such misunderstandings we turn to ideas or concepts of science and theatre that offer the stability of a common understanding. For instance, the idea that the so-called 'exact sciences' or the quality of what is 'scientific' exudes a truth certificate that validates them vis-à-vis other forms of knowledge. And, by opposition, the idea of theatre as the art of illusion and lies. Common to these concepts of theatre and science is the fact that they mostly serve an opposition between 'two cultures' (Charles Percy Snow), which has fuelled more than two centuries of our modern history. The famous Kantian division places art on the side of those who know how to do, of those who possess the technique (*können*), and science on the side of those who have the knowledge, of those who master the theory (*wissen*)[27]. Objectivity, in this context, is used as a scientific token, reinforcing an antinomy that contributes to science's authority. It is precisely this separation and difference, describing on the one hand a culture that privileges facts and objectivity and on the other hand one that works as a space for fiction and subjectivity, that nourishes the traditional relation between theatre and science.

This separation has partially resisted the intersections that complicate distinctions and blend 'cultures'. The text that introduced the call for papers of the colloquium 'Theatre about Science' (2021), where the first ideas of this paper were developed, shows an interest in contributions that intend 'to explore the places where [science and theatre] meet (and where they don't)', presupposing that we are talking about not only two distinct things, but also about 'two sides of the equation', as it is also written[28]: theatre on one side, science on the other. This separation, which is also a representation of an opposition, means that, when the two sides intersect, they both know their place and their differences. There is a presumption of what science and theatre represent and this presumption precedes the encounter, which is usually meant to enhance the effect, either of science or of theatre, in its audience.

Such a relationship is for example contained in some of the questions that are asked in the call for papers for the said colloquium: 'Can theatre help solve scientific problems?' 'Does scientific knowledge transform theatre?' 'What kind of knowledge can theatre add about science?' 'Can theatre inspire new scientific research?' Theatre helps solving, theatre adds, theatre inspires, and scientific knowledge transforms (and we could add: thickens, boosts credibility, etc.).

27 Kant, *Critique of Judgement,* § 43, 2).

28 https://theatreaboutscience.com/theatre-about-science/

A recent project called 'Theatre meets science' organized in a partnership between the famous German theatre Berliner Ensemble and the German Helmholz Association signals its intent in its name. The idea of 'meeting' presupposes an encounter between poles and the acknowledgment of something mutually favourable. The relation between both disciplines is thus viewed as an exchange of opposite qualities and characteristics, which, when working together in the right way, may reveal its usefulness. Roland Koch, Press Spokesperson at the Helmholtz Head Office in Berlin, described the results of the project at the Forum Wissenschafstkommunikation in 2019 as follows:

> While the theatre hoped to get an inside look at the very latest scientific findings, Helmholtz was interested first and foremost in learning how the art world reacts to its work and addresses current topics. It started as an experiment … And, if you ask everyone involved, a very successful experiment! Both partners benefited from the format. ... But what can a theatre and a scientific organisation gain from initiating a project together? How can theatre and the sciences even find common ground? And how can they be compatible partners once they've actually come together? (Koch: 2020)

The encounter is perceived as an 'experiment' and a 'successful' one. Success means results and 'benefits' for both sides of the equation. There is an expectation that works for both sides: science gets a chance to understand how its knowledge production is affecting the art world, whereas theatre has the opportunity to get in touch with inspirational scientific knowledge. Such is the logic of the so-called 'science plays'[29], like Michael Frayn's *Copenhagen* or Brecht's *Life of Galileo*, to mention some of the most famous, a genre that, in some cases, may be the example of the perfect alliance between the two cultures: it communicates science (*wissen*) and it creates art (*können*).

This reunion of differences always seems to aim for one goal, i.e., the idea that 'science and theatre have more in common than it appears' (Frazzetto: 2002) which feeds the investigation of a 'shared cognitive intent' as Eli Rozik puts it, when comparing scientific texts to theatrical ones:

> I claim that like scientific texts, theatrical texts evince a cognitive intent and that, despite obvious differences, both types show similarities on three cognitive levels: (a) the use of equivalent systems of representation and communication; (b) the operation of a mode of thinking; and (c) the embodiment of a rhetorical structure. (Rozik, 2012: 659)

Rozik's claim is an example of a common tendency to be found in most narratives that explore the relation between these two concepts. The search for similarities or common characteristics is a typical description in dualistic comparison, and it usually intends to contrapose the antinomic descriptions, by using the same rhetorical and conceptual map. This way of describing both cultures and their relationship

29 Shepherd-Barr's full-length study of the 'science-play' genre, *Science on Stage* (2006), is a wonderful source for the history and the acknowledgment of the prolificity of the genre, with an appendix where she shares a comprehensive list of four centuries of science plays. In the case of British drama see, for instance, Higgins (2007) for a list of several contemporary playwrights and plays.

depends on considering theatre and science as the only two cultures which are being called for in that specific relation. Their intersection is always dependent on a description of binary characteristics, which means a limitation in its scope. The limits are set on the one side by the acknowledgment of antinomic differences, and, on the other, by the search of what theatre and science have in common. We can thus identify two ways of looking at the cultural divide which correspond to one single way of thinking about both disciplines. Alexander Becker, in an article published in the online-journal *w/k – Between Science and Art* formulates this idea by considering art and science as 'implementations of one fundamental practice that articulates into opposite poles; these poles cannot collapse because they need each other as counterparts' (Becker, 2006: 4).

But we know (and our own biographies as well as biology and its history give us numerous examples) that this is not the only mode of collaboration between two different things. Not only do we know that two things are not necessarily opposites or equals, but collaboration sometimes takes place in unpredictable ways, outside of a logic of winning or losing, working better or solving problems. Indeed, collaboration may result differently according to other factors that influence each encounter and that do not necessarily pertain to the worlds of theatre or science. The encounter does not take place in an ascetic, abstract context.

To this fact we can also add that distinguishing where technology ends and nature begins is as inglorious a task as, in many cases, distinguishing where theatre ends and science begins (and, sciences permitting, vice versa). Physicist Ernest Rutherford's definition that 'science is what scientists do' could accommodate this difficulty in drawing abstract boundaries between these two cultures. If science is what scientists do and art what artists do, then we do not need to bother defining what science or art is, we only have to find out who is doing it. And instead of 'who is doing it' we could also look at where it is made, in which department, in which institution – in a theatre or in a laboratory? In the university's literature or biology department? How to explain, however, when performance describes itself as an experiment or when an artist claims to be a scientist? What does this artist do then? Who is she representing: Theatre or Science?

'Theatre is science'

In 2013, André e. Teodósio, a member of the Portuguese theatre collective Teatro Praga, in a text entitled 'Catachresis (initiation rite)', written in Portuguese, describes art as a 'cognitive tool, the only process of knowing the truth, or, pompously and in a categorical language, art as being the science of experience.'[30] This idea of art and theatre as a science of experience or experiment[31] has been repeated

30 https://www.porta33.com/porta33_madeira/eventos/content_eventos/reflexoes_arte_esteticas_contemporaneas/reflexoes--texto-andre-teodosio.html

31 The distinction between experience and experiment exists in Brazilian Portuguese but not in the Portuguese language.

at different times (interviews, podcasts, texts and performances) by Teodósio and Teatro Praga. The assertion could be interpreted as Paul Feyerabend's *Science as Art* polemic book title or as a return to the classical Greek partition that included art (*tekhné*) as one more among other sciences, but this would be an inadequate understanding, as I will try to demonstrate with the help of two of Teatro Praga's most recent theatre performances: *Jângal* [Jungle] (2018) and *Infomaníaco* [Infomaniac] (2021).

In order to interpret the relation that both performances establish with science and this particular assertion, it is necessary however to introduce some of the thinking on science that contributes more or less conspicuously to these performances. Both shows have in common the fact that they work with a lot of material taken from the field of sciences (of science made by scientists), despite contributing to an erosion of the presupposed separation between theatre and science. This erosion is fundamental for an aesthetic invention that goes beyond the territories of 'transforming', 'adding' or 'inspiring'. I am convinced that both *Jângal* and *Infomaníaco* are examples of a categorical movement, a way of looking at categories not as an end in themselves, but as a temporary appropriated place and nominalism, which is never guaranteed and whose significance is but lateral to the interpretations of the performance.

In her notable essay, 'Situated Knowledges: The Science Question on Feminism and the Privilege of Partial Perspective' (1988), Donna Haraway makes note of the feminist (and others) criticism of the 'doctrines of scientific objectivity', that are regarded as 'appropriations of a fixed and determined world reduced to resource for instrumentalist projects of destructive Western societies, … masks for interests, usually dominating interests'. (Haraway, 1988: 591) The conviction that scientific knowledge is based on a technique of appropriation that reduces the world has been crucial to the understanding of science as a discipline made by people within a context. Not only that, but appropriation is seen as a method through which power can be exerted. The categories 'Nature', 'Sex', 'Knowledge' or 'Objectivity' are described by Haraway as 'slave[s] to the master' (Ibid.: 592), because of their seizure by a white capitalist patriarchal discourse, that uses this analytical tool to excavate 'asymmetrical splittings' between, for instance, 'hard' and 'soft sciences'[32] (Ibid.: 599) or mature and immature sciences. Haraway associates appropriation to arguments of authority and a hierarchization of knowledge based on the essence of each category. What Haraway is describing is very much in tune with Saïd's concept of an 'epistemology of separation' as a 'privileged method to acquire a position of authority'. Hard sciences separate themselves from other categories and concepts, taking hold of 'objectivity' based on the authority of the name – 'Science'.

But if appropriation is regarded as a tool for such separation and conceptual delimitation, the

spoken in Portugal.

32 'Each binary opposition orders the silent term by a logic of appropriation, as resource to product, nature to culture, potential to actual. Both poles of the opposition are constructed and structure each other dialectically. … This is a point about remembering how a particular analytical tool works' (Haraway, 1988: 599).

acknowledgment of such mechanism also opens the door for what Haraway describes as a 'feminist objectivity'. It is precisely the appropriationist logic that allows her to recognize 'the object of knowledge as an active, meaning-generating part of apparatus of bodily production, without ever implying the immediate presence of such objects' (Ibid.: 595). Science depends upon language and metaphor, it is a simulacrum (Baudrillard), a discourse (Foucault). It is thus never immediate and always mediated. Haraway sees the possibility of a feminist objectivity in science by taking hold of mediation, by practicing story-telling.

Looking at science as a method of appropriation (of language, of stories, of facts and fictions[33]) shows light in a process where the scientist deals with 'a node of intersection', with an object that can be seized but is never 'in "final" control' (Ibid.: 596). In a certain sense, Haraway is 're-fusing' the logic of appropriation. Appropriation is no longer a method for gaining control, exercising power, and strengthening asymmetries. It is indeed no longer a method, since it loses its logic of binary oppositions and it becomes the thing-in-itself, because there is no object ('Nature', 'Sex', 'Science', etc.) without appropriation or extraction.

This is not a way for Haraway to propose an objectivity that might be closer to reality or truth, nor is she issuing a post-truth nihilist certificate to science[34]. Haraway prefers to deviate herself from that discussion by concentrating on the refusal of the relativist/realist opposition. As she puts it in a conversation with Gary A. Olson:

> [This] does not mean you do not believe in DNA. It means that now you actually have a pretty good way of describing how DNA exists, how come, what its conditions of existence are; … and this knowledge in no way derealizes it. … The worldliness I'm commited to is what makes me refuse the relativist or the realist positions. (Olson, 1996: 26)

Appropriation, in this sense, means a permeability to other logics that are not dependent on antagonism and opposition. It is by deconstructing and keeping herself away from a simplistic dualist opposition between a relativist and a realist epistemology, that Haraway is able to respond to the authority of scientific knowledge and its blocking devices. As she puts it in her 2016 *Staying With the Trouble*, 'it matters what stories tell stories' (Haraway, 2016: 35).

33 For Haraway facts and fiction are not to be seen separately: "the history of science appears as a narrative about the history of technical and social means to produce the facts. The facts themselves are types of stories, of testimony to experience. But the provocation of experience requires an elaborate technology … Not just anything can emerge as a fact; not just anything can be seen or done, and so told. Scientific practice may be considered a kind of story-telling practice. (Haraway, 1989: 224).

34 In *Primate Visions. Gender, Race and Nature in the World of Modern Science* (1989), Haraway identifies a number of 'temptations' which she considers to be 'enabling and also dangerous', one of them coming 'from the most active tendencies in the social studies of science and technology: the rejection of all forms of epistemological realism and an analysis of scientific practice as 'thoroughly social and constructionist'. (Haraway, 1989: 28) She is thinking of Bruno Latour and Stephen Woolgar's *Laboratory Life* (1979), among others.

Haraway's thinking has been closely connected to the revitalization of Lynn Margulis and James Lovelock's symbiotic evolutionary biology, which in turn has inspired a new wave of descriptions and narratives by scientists, artists, philosophers or anthropologists[35], signalling the proximity between contemporary art and this way of thinking about science.

In an introductory chapter to the now famous *After the End of Art. Contemporary Art and the Pale of History*, Arthur C. Danto describes the contemporary in the context of art as a period of 'quite perfect freedom', because 'everything is permitted' (Danto, 1997: 12). It is in this sense, that, according to this art critic and philosopher, 'the major artistic contribution of the decade [1990's] was the emergence of the appropriated image – the taking over of images with established meaning and identity and giving them fresh meaning and identity'. (Ibid.: 15) Danto is thinking about a number of artists who were influenced by Duchamp's ready-mades, Andy Warhol's Brillo Boxes and 1960's conceptual art, and who imagine artworks which look exactly like 'real things'. Not only do they sometimes look exactly like real things, they are also the real things they replicate with 'no claim to the status of art at all' (Ibid.: 15).

The increasing irrelevance of medium-based categories relates to the freedom to make art from potentially everything. This reasoning is appliable to conceptual artists for whom the idea of exposing rather than imposing concepts and categories has been of central importance. As Robert Smithson, author of the famous *Spiral Jetty* (1970), puts it, in a text written in 1967 ('Towards the Development of an Air Terminal Site'):

> The investigation of a specific site is a matter of extracting concepts out of existing sense-data to site selection or definition. One does not impose, but rather exposes the site – be it interior or exterior. Interiors may be treated as exteriors or vice versa. (Smithson, 1996: 60)

Robert Smithson's interest in working with the idea of extracting 'associations that have remained invisible within the old framework of rational language' is to 'reconstruct a new type of "building" into a whole that engenders new meanings.' (Ibid.: 58). In this sense, appropriation and extraction are ways of separating an object from its semantics and category, allowing it to experience new meanings, by freeing it, for instance, from 'function' or 'tradition'. With this dislocation, an artist is also confusing the epistemological separation between mediums and categories as well as between art and non-art, and the artwork moves, as Baudrillard would put it, into a 'third order' of simulacrum, the ultimate collapse between reality and representation.

As I will try to demonstrate, the relation between the categories of science and art in *Jângal* and *Infomaníaco* is to be better perceived as strongly indebted to this 'transcategorical' or

35 To name a few of the most prominent and mediatic: Anna L. Tsing, Tim Ingold, Vinciane Despret, Viveiros de Castro.

'postconceptual'[36] art of the last decades, that is itself in tune with a certain discourse produced within the realm of science, as previously described. When we read Donna Haraway and Robert Smithson, we understand how the 'postmodern condition' (Lyotard) has produced effects in science as well as in art. Robert Smithson writes that '[l]anguage problems are often at the bottom of most rationalistic "objectivity"', and Donna Haraway asserts that 'any scientific statement about the world depends intimately upon language' (Haraway, 1988: 24). I am convinced that Teodósio's assertion is to be understood within this lineage and that the relation between science and theater in *Jângal* and *Infomaníaco* is far from a description of an opposing binarism that is aiming for benefits and results. As I will next try to demonstrate, both performances appropriate information commonly described as scientific, in order to produce experiments and experiences of dislocation and allow its audience to read such extractions as an opportunity for 'fresh meanings and identity' (Danto).

Jângal **(2018)**

In *Art and Objects, Object Oriented Ontology* philosopher Graham Harman describes our relation with 'objects' (a word that in this context has a 'far broader meaning than solid material things', since it includes 'events and performances' (Harman, 2020:2)) as responding to two basic criteria: 'undermining' and 'overmining':

> When someone asks us what something is, we can answer either by telling them what the thing is made of (undermining), what it does (overmining), or both at once (duomining). Given that these are the only kinds of knowledge that exist, they are precious tools of human survival, and we must be careful not to denounce these three forms of 'mining' or pretend we can do without them. Yet my hope is that the reader will come to recognize the parallel existence of forms of cognition without knowledge that somehow bring objects into focus, despite not reducing them in either of the two mining directions. (Ibid.: 2)

Harman is describing the possibility for art to create spaces where we can recognize parallel forms of cognition that do not reduce objects to their materiality or functionality, i.e. that are not interested in capturing these objects according to a preconceived knowledge that confines their ontology.

Jângal is a performance that puts objects into focus by allowing them to exist outside their common narratives. In the performance, Teatro Praga works with texts and information produced by anthropologists, biologists, philosophers and geologists, whose work has circled around a complexification of the ecological question, refusing the simplistic division that opposes Civilization to Nature. The ecological turn activated by scientists in areas such as microbiology, geology, physics,

36 See Osborne (2013).

oceanography, chemistry, zoology, etc. and that has inspired artists in the last decades, decentralizing gazes and promoting speculative fictions, is conspicuously present in this production, however tenuous and lateral its textual presence may be.

On the stage, which illustrates a computer folder, we watch different entities or ontologies (an ape, a bee drone, a GHB bottle, slime, a snowman, humans, rocks, etc.) that we usually put into categories commonly taken as pertaining to separate worlds: animal and non-animal, real and fictional, artificial and natural, objects and concepts, reality and fiction, etc. (see Fig.1) The mode of relationship between all these figures is unpredictable because it is not contained in any story, in any science, and in that sense, as science-fiction writer Ursula K. le Guin would put it, it has been hidden from us[37].

Throughout the performance, these entities dialogue, monologue, move and create different landscapes with no linear narrative or time. Their existence depends on a process of accumulation and is guaranteed by the materiality of the performance space, a jungle or planet or folder (or literally

37 'It is the story that makes the difference. It is the story that hid my humanity from me, the story the mammoth hunters told about bashing, thrusting, raping, killing, about the Hero. … The killer story.' (Le Guin, 1989: 168)

a stage) where these beings can exist or, to use Haraway's words, quoted in the performance, 'where species meet'.

Jângal starts with the announcement of its purposes in a whispered introduction by the Portuguese Fado singer Gisela João:

> *Jângal* is an effort to change the order of the reality that's been given to us. … It's experiment and tentativeness. It's fiction and invention. And we don't know exactly how to do it. And we're not ashamed to say we don't know. Meaning: we're in trouble...

As we can see in this initial monologue, the performance describes itself as a series of experiments with objects that allow us to see them in contexts that are not associated with their concepts. To 'change the order' requires a procedure, in which the words 'experiment' and 'experience' will play an important role, that depends on the performance and theatre's relation with science and scientific knowledge for a relocation or re-fusing of the objects that are the subjects of *Jângal*.

Contrary to Teodósio's essay, which was written in Portuguese, this performance is mostly spoken in English. This means that, in order to establish a connection with the assertion that 'theatre is the science of experience (or experiment)', we must recognize the use of both words in *Jângal*. If, in the first scene of the performance, Gisela João uses the (English) word 'experiment' to describe what we are about to see, apparently suggesting a scientific practice and methodology (experimenting as in a laboratory), as the performance moves forward the word 'experience' is more frequently used, although its meaning, as we are about to see, isn't that far from 'that kind of experience called, in English, experiment.' (Haraway, 1988: 23)

Art as Experience is the title of Jon Dewey's famous essay, written in 1934, that signals a dematerialized approach towards art objects that accompanied 20th century art criticism. However, 'experiences' in this performance do not refer to a relation between the artwork and its beholder, just like 'experiments' do not follow any cause-and-effect principle nor impose quantitative methods. What the use of both words in this performance shows us is that they do not always have to occupy separate fields or represent different cultures.

The scene shortly after Gisela João's announcement of what we are about to see consists of a dialogue with the Fado singer and a standing fan, whose 'head' is strangely bent downwards (see Fig. 2). The 'experiment or tentativeness' (a conversation with a melting sad fan) does not lead to a conclusion or failure of such conclusion, but to the admission that the question asked in the end by the fan ('what does that mean?') is the 'wrong question'[38].

38 The conversation between the Singer and the Fan: 'FAN: But aren't you meant to be a singer that sings about sadness?

The different 'experiments' *Jângal* invests on frequently end up in unconclusive style. 'File' is the name with which most of these experiments or scenes are introduced: 'the next file is an image of us'; 'the next file is an image of a jungle'; 'the next file is a .Flac file by Violet'; 'this next file is called "the moving darkness"'; 'the next file is a sad song', etc. By naming these experiments 'files', *Jângal* is adding another layer of meaning to what in theatre would be considered or named 'scene'. And the folder, which is a stage (theatre), is their context. In that sense we could add that these files and experiments are theatre because they live inside a folder (the stage) that gives them context. This deposit of locations or situations (experiment, file, folder, stage, theatre) that provides context to the objects prevents them to be captured by one single gaze, one unique category and a total perspective.

One of these 'files' or experiments, introduced and accompanied by the actress and performer Joana Barrios, is announced as follows: 'This next file is called The Antagonist, and it's really experimental!' The adding of the adjective deriving from this vocabular family renders the accumulation of meanings even more striking. We are about to watch an experimental series of 'five different experiences of unidentifying with being human', as the performer puts it.

Your song sounded quite sad. You should be sad. Why aren't you sad? SINGER: Aaaa… good point… but… It's complicated! FAN: You're not sad. I'm not sad. And yet we're all supposed to be sad because there's a lot of trouble and we're heading for disaster. SINGER: Well… inside this folder we stay with the trouble… FAN: Oh. And what does that mean? SINGER: Wrong question!'

In the preamble to these experimental experiences, Joana Barrios introduces herself in a brief monologue as the Antagonist. The preference for this designation, she explains, is due to the fact that she considers herself 'too human' to be the protagonist of a story whose goal (and the protagonist is the character who pursues the story goal) is 'flattening any supposed interspecies hierarchy'. In the first experience of 'unidentification', a ceramic snake informs the human that it seeks an 'intimacy without proximity' (see Fig.3), a suggestion that echoes a number of relationships that are established, throughout the performance, between drones and fiberglass dolphins or humans and computer desktops, and which serve to create images of separation that neither seek proximity nor work with the idea of distance. It is this principle that will also operate during the next experimental experiences in which the performer tries to interact with an egg, with the floor, with a drone bee, with a 'white man' or with a snowman. Their experimental factor consists on the coexistence of multiple surfaces of meaning. For instance, a conversation with the 'Bee' about cyborgian interventions in human bodies, makes us interpret and deal with an object that can be a bee that stinges, a cyborgian bee, a pollinizer, a plague or a linguistic pun ('Human: we need to bee who we wanna bee who we wanna bee who we wanna bee') etc... This happens along the other experiences, where singularities become an accumulation of contradictions and meanings, bodies of possibilities and relations to be found. The 'species' escape, in the experience of the encounter, the taxonomy with which they enter the scene, occupying, in their movement of relation, other places that always seem provisional.

By extracting science ('experiments', facts, objects) into the field of theatre, *Jângal* is simultaneously transforming the stage and reformulating science and theatre's ontology. The performance is not trying to solve ecological problems but wants to find ways of talking about such problems by opening its stage to microorganisms, rocks or apes as well as to unicorns and cables and computer desktops. It is as if the performance is telling us that we have lost theatre and science, but that we have found something else, something we ignore and that we may call 'theatre' for the sake of communication. This extinction of knowledge, allows us to move the relationship between theatre and science away from an epistemology of separation as well as from an antagonistic logic, and let it be permeated by other categories and concepts and open themselves, following Graham Harman's formulation, to 'forms of cognition without knowledge'.

***Infomaníaco* (2021)**

In *Infomaníaco* (2021) (see Fig.4), André e. Teodósio mixes zoological and biological stories with episodes from Teatro Praga's performances and from his own life, interspersed with neuroscientific curiosities or terminology from physics. Science appears in this performance differently from *Jângal*. Its textual presence allows one to identify scientific information quite distinctly. The spectator is succinctly informed about the anatomy of an amphioxus, how gold came to exist on planet earth, the percentage of energy spent by the brain in different activities, what is natto, the life cycle of an eel, allostasis as a model for physiological regulation, organic molecules detected in comet Lovejoy, etc. Such list could indicate that Infomaníaco is a 'science-performance' (inspired by 'science-plays'), created with the aim of informing its audience on scientific curiosities. However, the diversity of areas and subjects as well as the way this information is conveyed obviates such interpretation. As the performance builds up, it creates a sense of submersion in a container or pool of cross information where data can only be interpreted in its complex and multifaceted grid of possible relations with science, theatre, history, life, and many other concepts and categories. By doing that, it escapes scientific knowledge and it starts working in a different realm of cognition that frees its spectators not only from relating with astrophysics, biology or neurosciences but, most importantly, an understanding of these episodes as 'information'. To interpret these episodes as information is a misinterpretation of the title of the performance (*Infomaniac*) and the performance's ironical, maniacal, ungovernable and frantic proposition of an accumulation of inconclusive facts that lead to nowhere.

The performance opens with the following narration, a possible genealogy for a history of theatre:

> Today, in the year 364 BC, Rome was struck by a violent plague that claimed many lives. To appease the gods, the distressed Romans thought of organizing scenic games. But as they knew little of the art, they decided to send for some artists from the neighboring region of Etruria, known for their quality in this practice. The first 'histriones' to perform in Rome performed wordless scenes accompanied by a flute player. Later, on the same day, young Roman artists began to imitate these dancers by reciting verses while dancing accompanied by a flute player.

The mechanism of naming different dates as 'today' is frequently repeated, like a refrain. Today is the day the show is being performed, but also 364 BC, 550 million years ago, December 2020, or the day the performer inherited the golden necklace he carries on his chest. The episodes build up, they accumulate and interconnect, contributing to a journey in a 'curved time' that turns all times into one single day. As Teodósio talks about the flute player in Ancient Rome, he is holding a flute in his hand, and at the end of the performance he will play a farewell melody with it.

The transverse flute returns soon after the start of the performance, in the form of an amphioxus, an important object of study in zoology, since it provides evolutionary insights into the origins of vertebrates:

> Today, 550 million years ago, the Earth was inhabited by brainless creatures. One of them was the amphioxus. The amphioxus lived in the oceans and buried itself in the seabed and consumed all the tiny creatures that passed its mouth. Taste and smell didn't interest it because an amphioxus didn't have senses like us. It had no eyes, just a few cells to detect changes in light, and it couldn't hear. An amphioxus was a stomach on a stick.

The prospect of finding the amphioxus in the flute that André is holding is the prospect of a possible association. This way of establishing relations by associations takes very different paths, here that of a physical resemblance, and later resorting to the memory of a lost fictional childhood narrative: 'Whenever I remember the flute I remember the Pied Piper of Hamelin and the story that was forgotten of the lame child who continued in Hamelin because she was not able to follow the pace of the apt bodies.'

The construction of relationships follows a chain that is being built in a way that escapes any logic of cause and effect. Not only that, but as the episodes accumulate a sense of confusion starts to contaminate the performance, transforming the different stories, episodes and information in an amalgam of references and categories. Is the amphioxus a biological species, a flute, a metaphor, or an image?

The performance refuses any view of an effect, there is no science that is being communicated or a solution that results from the meeting or experience. The scientific information we are told becomes secondary in its facticity and turns into a node that permits rhyming and connections. The experience is the performance, it is the 'day which is today':

> Today is the day I am here speaking to you, and it is also the day I was born, the day you left me, the day I broke my mobile phone, the day the tree fell, the day the volcano erupted, the day I got angry, the day I had an operation, the day we became unconditional, the day we crossed over, the day the moon was formed, the summer of 1911 and the year 2005, … the day colourful species communicate in strange ways, the day we died, the day I started making theatre without making theatre.

This 'today', this folder, is the performance, because the performance is made of theatre, biology, biography and modern physics, just as it is made out of two human bodies (one of them being the set designer with his body as part of the set design), a text, the objects that inhabit it, and a leaflet offered to the spectators. The autonomy with which the materials of the performance operate does not come from the discipline from which they were extracted (science, literature, art or history of theatre, for example), but from the possibility created by the performance for them to reverberate in the same

space. The performance is not trying to amplify its effects, it is not procuring an incrementation of its abilities, but rather creating a place for equality. Not an equality understood as the antonym for difference, but equality as a synonym for heterogeneity as illustrated by Teodósio's dance as he talks.

The relation between Teodósio's body movement and the delivery of the text has some reminiscence of Trisha Brown's iconic piece *Accumulation With Talking* (1973), the difference being the inaccuracy of Teodósio's movements in *Infomaníaco*. He does not try to rigorously draw a certain movement and prefers to stumble and fail, by deliberately interrupting the movement and sabotaging its continuity, thus signalling his preference for an idea of accumulation that does not predict its future nor its interpretations[39].

At a certain point of the performance, Teodósio tells us that the gold necklace he is wearing around his neck, and that he always wears when he is on stage, was given to him by his grandmother, "twenty years ago (today)". To this information, he adds: 'Gold happens when asteroids collide with Earth. This collision took place today, 4 billion years ago. I'm touching it. I'm talking to the gold. I'm connecting to asteroid showers and my grandmother.'

The necklace contains not only different stories but different perspectives that turn it into a subject subjected to movement and indetermination, to a multiplicity of layers of meaning. By a process of 'accretion' ('Collaborating is more important than competing. Accumulating dynamite with symbiosis. Using the word "Accretion". My body isn't my body', he says), Teodósio is able to compose relations that defy linearity and contribute to the loss of the object's stability. The necklace is the grandmother and the asteroid, as well as the different shows where Teodósio performed.

With this experience, which is also an experiment, the meaning of the episodes or words that are extracted from the field of science and exposed as scientific facts in this performance ('4 billion years ago') is not destroyed, although we lose track of their categories and classifications. *Infomaníaco* is letting us experience the freedom of everything being permitted and theatre as the site for such experiment.

Conclusion. 'Theatre is the science of experience'

To conclude I would like to return to the assertion previously quoted: 'Theatre is the science of experience'. I have tried to interpret its words, its language, within the discourse of two specific performances that treat science, theatre and experience as possible material for extraction. *Jângal* and *Infomaníaco* expose these terms and their own contexts and allow spectators to appropriate their contents detached from

39 He is, in this sense, following Haraway's thinking when she states that the 'tripping and stuttering in political and scientific work is a kind of precious moment that blocks idolatry.' (Olson, 1996: 14)

theatrical or scientific conventions. These performances show that everything is permitted in the relation between science and theatre, and while doing so they are signalling, following conceptual art's tradition, that everything can be theatre. If that is so, science is but one among other categories, words, concepts or disciplines that can be extracted. Through appropriation and extraction, these performances and the words or objects that inhabit its space (the stage) never dismiss mediating interpretative categories such as science, theatre or experience, but they escape domestication and a carceral frame, infusing theatre, science and the performance's ontology with movement. This movement disturbs binary opposites and separates the performances from ideas of authority, knowledge, ignorance and idolatry, opening the critical space for interpretation without recurring to a logic of absolute individuation. By doing so their main commitment is to re-fuse science and theatre.

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IS IT REALLY JUST A FISHTANK?
A TOPOLOGY OF ANATOMIC THEATER

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Abstract

On the surface the study of topology and theater could not appear more different, but there is one concern which is fundamental to both – the nature of spaces. Topology, or *analysis situs*, which emerged as an outgrowth of geometry in the late 19th century, led to a recognition that many properties of interest concerning geometrical spaces, such as angles or distances, are independent of metrical quantities, and that spaces that were stretched, crumpled, or folded would find all of their topological properties unchanged. This release from precise measure and quantification admits of a point-of-view regarding spaces which, while still precise, can be more visual than otherwise. Thus theater practitioners can adopt, without rigorous calculations, topological points of view to explore new ways of thinking about physical spaces.

Not only do such perspectives invite theater audiences to explore the beauty of topology, they lend to drama a very rich set of metaphors. A dramatic text, for instance, can become an abstract set comprised of a collection of lines. Physical spaces yield to mathematical structures, either the daily space that surrounds us, or the space describing the physical self, or even the interconnected spaces that individuals create between themselves. Topology seeks, if nothing else, extraordinarily general results.

We will focus here on three fundamental inquiries of *analysis situs* – twistedness, connectedness, and the detection of holes [1]. We will import these concerns, along with some findings that such so-called soft geometry has made of them, into a dramatic context, where they will become metaphors that relate to human experiences. At the same time we will elaborate two concepts central to dramatic study – texts and scenes – as abstract units subject to our lines of topological inquiry. In doing so we will generate a braid of possible environments and scenarios for theater that may be hitherto unexplored. We will also introduce a third abstract unit in our study, the player, but a further analysis of this case will be left to future work.

Introduction

Our inquiries are conducted in the pataphysical spirit of Jarry [2]. We will start with the abstract notions of *set* and *dimension* as borrowed from topology. From dimension we shall elaborate the notion of a *manifold*, that is, the generalization of a surface, and from this we will form a three-tiered hierarchy of curves, surfaces, and solid bodies. Using this hierarchy we will analyse in terms of sets the texts and scenes that constitute our proposed fundamental units of drama. Throughout we shall remain mindful of twistedness, connectedness, and the detection of holes – a topologist's ever-present concerns – and see how an anatomization in these terms can lead to not only new expressions for theater, but to new ways of examining the role of science in our lives.

After we have developed these tools we will present a scheme for a topological play titled *The Knotted Aorta*. In this play we will confront the task of apprehending a widely studied manifold in topology, the Klein bottle, which is impossible to implement in everyday three-dimensional space. As such, it cannot be physically constructed onstage. However through a series of visualization exercises and some inferential reasoning regarding what observable side effects a Klein bottle might manifest, we can provide insight into such topological spaces and offer an avenue for further investigations of their properties.

1. TEXTS AS CURVES AND LINES

1.A. CURVES, CIRCLES, AND CONNECTEDNESS

Consider a dramatic text T that can be performed by actors, hereinafter referred to as *players*, to generate a dramatic experience or play P. We may think of T in the abstract as the text comprising a play, or as the physically printed manuscript of that text, or both. Suppose we treat T as comprising a set, or collection, of members S, where each member is identified with a portion of the text corresponding to some dramatic unit. What types of units are useful for our purposes? We might choose our generating text as a collection of acts, or of scenes, or we could be more granular – our collection could just as well be comprised of stanzas, sentences, or words. Once we have defined our collection we can then impose a structure on this collection – we may want to repeat certain stanzas twice, for instance, or we may want to run the play backwards scene-by-scene. In a mathematical environment this is called the topology over the set. The underlying text is unchanged, it is the structure imposed on the set that differs.

Let us consider two plays P_α and P_β comprised of the same underlying dramatic text T, but with different structures imposed upon this text. Let P_α treat the text as a collection of lines organized in the intended reading order and P_β as this same collection of lines but in reverse order. Then let us conjecture that both plays are topologically similar to a curve. What could this mean? For each case our play, like a curve, can be said to have a distinct beginning, middle, and end. In topological language we would call such plays *open* because they possess edges. For P_α we are proceeding sequentially left to right along the curve, one dramatic line at a time. For P_β, we proceed right to left. Whether this procession is temporal, causal, or something else is up to the playwright; what is important in our description here is that this march from one unit to the next is consistent throughout the play. Also, like a curve, if we excise some portion from the middle of the play, we are left with two parts. The importance of this method is that it separates the dramatic text from the way in which we choose to traverse it. For going back and forth on a simple curve this may seem trivial, but when we start thinking of texts as closed curves, graphs, links, or knots, this separation of text from the structure that is imposed upon it becomes more powerful. Figure 1 presents some configurations that we shall include in our study of one dimensional spaces.

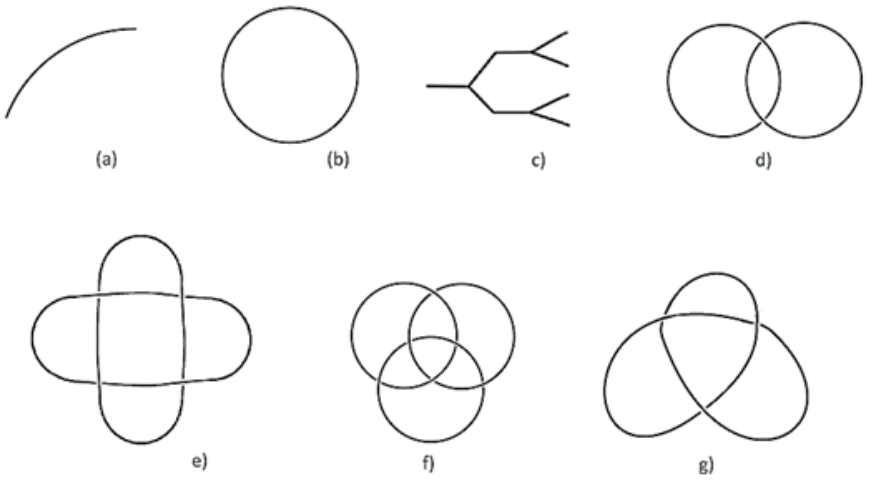

Figure 1: One-dimensional spaces. a) open curve, b) circle, c) graph, d) Hopf link, e) Solomon's knot, f) Borromean link, g) trefoil knot

For the simple cases of P_α and P_β above, we can say that each of the play's lines are *connected* to its neighbours. The first line has only one neighbour, the second line, and the last has only the next-to-last, but otherwise the connections all look the same. But consider now a text we wish to perform over and over again repeatedly. This is useful for the case of a scripted exhibit, where a transient audience continuously shuffles in or out during the performance. In such an environment we would like to return immediately to the beginning once the final scene terminates. The printed text which generated this performance has not changed, but the text we are performing can now be thought of as *loop connected*. Since it no longer has a beginning or an end, we call this structure *closed* instead of *open*. Topologically it now resembles a *circle*; in theory the production goes on forever. We might even wish this loop to continue subject to certain conditions, for instance until some decision has been cast by the audience, or a certain line in a certain scene has been pronounced in a certain way.

The members of a set comprising a dramatic text can also be *branch connected*. Take for example a play containing scenes which have some decision factor at the end of them –a vote from the players themselves. Or some element of randomness, for instance a decision made by some onstage artificial intelligence that is listening to the play [3]. For a text comprising six scenes S_1, S_2, …, S_6, we may use

a decision tree to generate four plays containing three scenes each – $P_1=\{S_1+S_2+S_4\}$, $P_2=\{S_1+S_2+S_5\}$, $P_3=\{S_1+S_3+S_5\}$ and $P_4=\{S_1+S_3+S_6\}$.

Topologically we can think of these four subplays as *graphs*. Each subplay can be *loop connected* as well, if for instance we still want some type of continuous exhibit. And of course we can model individual scenes as collections of lines that are themselves loop connected. This can achieve the effect of looping say the first scene of the play above until a prerequisite is met, such as the audience reaching a certain size, or a passphrase uttered to open a pair of doors.

1.B. LINKED AND KNOTTED TEXTS

Each of the textual structures we have examined so far has the property of *connectedness*, but what does it mean if a configuration does not have this property? Let us imagine two separate texts that are linked in some way, as shown in the Hopf link of Figure 1d. Note the alternating crossings – the first text goes below the second in the upper intersection, above it in the lower. Or consider two texts with four crossings as a Solomon's knot in Figure 1e (a misnomer, for Solomon's knot is a link), or even three texts in a Borromean configuration (Figure 1f). What correspondence does this have with texts that generate theater?

Let a physical space be divided into two floors, with a separate, continuous narrative assigned to each floor. Let T_1 be the text assigned to the top-floor narrative, and T_2 be assigned to the bottom. Most of the time, these narratives are independent. They may proceed simultaneously but with little interference, or they may overlap continuously, so as to generate an effect like watching two channels at once. As we approach a crossing point, let the T_1 and T_2 narratives exchange floors and then resume. At our next crossing point, they exchange once more and are back to where they started. If the actions of these two half-dramas result in modifications to their respective floors, this linked strategy will cause them to interact in very indirect ways, though no less interesting for their indirectness. This approach can be extended to multiple crossings and texts. In keeping with the character of Borromean links, for instance, if a third drama becomes for some reason sundered from the other two, then the first two dramas would not be linked anymore [4].

What could it mean to have a structure imposed on a text exhibit *twistedness*? Consider the trefoil knot in Figure 1g. As opposed to a link, where we considered interactions among multiple texts, we are dealing once more with a single text. But now, instead of crossing another text, this text crosses itself. What can this mean? One property ascribed to the trefoil is that it can be coloured in three distinct colours, a property known to topologists as tricolourability [5]. Suppose we model a text as a collection of scenes instead of lines . Let us stage a drama from this text as a sequence of red scenes

followed by a sequence of blue and then finally green scenes. The sets, lighting, or mood adapt to the next color in the sequence at those dramatic moments where we reach a crossing point. A similar experiment can be held among three characters in a relationship, whose roles at crossing points are correspondingly interchanged.

These concepts of linked texts and knotted texts are independent of one another, and can be combined in interesting ways. For now we will single out the trefoil knot, and take it with us. We will make use of it in *The Knotted Aorta* presently.

1.C. DETECTING HOLES IN A TEXT

We will treat the detection of holes more thoroughly when we move into two dimensions, but for now we can think of holes as simply gaps in a text. How can this notion inform theater? Consider a drama whose events are of historical record and well-known to the audience. Startling effects can occur if the most famous key events are omitted and the audience must supply them on their own. Or take for example a detective sequence containing several gaps that is also loop connected. Let clues be supplied such that, for each iteration of the case, more missing gaps are filled in. In a play about a patient's failing health, the patient's narrative, retold to successive doctors, loses more and more of the scenes it once contained – these holes portray the progression of her illness. Or if we choose a textual model that is more fine – a sequence of words instead of lines, we can let certain words in our dialogue become the holes – forbidden words, no longer to be spoken, remembered, or heard. As a limiting case we can treat holes as missing letters, subject to certain conditions, for instance certain vowels may be conspicuously omitted. This last might strike us as untenable, were it not for George Perec's novel-length lipogram,– *A Void* [6], that accomplishes it.

2. PRINTED TEXTS AS SURFACES

Thus far we have treated a text T in the abstract as a collection of letters, words, lines, or scenes as capable of generating a play P. Since texts encourage linear processing they are a natural subject for one-dimensional spaces. It is natural to move forward, or even backward, in a text, much less so to move from side to side. Even with conditionally loop connected texts we are still moving in the confines of one dimension, and although we make choices in branch connected texts we are taking only one, not both, of the resultant paths. But when we begin to think of text as printed on the page, surfaces in two-dimensions become a much more natural solution space. In this work we will refer to such a printed text as a *script*.

Which properties of a surface can we assign to a script? Certainly a script can be organized into a number of rows along the page. By ascribing meaning to these rows, we begin to think of the text as having a second dimension. Take for instance a tiered reader, whose first several rows employ very simple language. Below these, another set of rows, repeating the first tier's text but in slightly more archaic language. And then at the bottom a third set of rows, repeating the text, but in the most archaic language of all. Such a printing technique is useful for players seeking to learn a drama's overall flow and rhythm before they wrestle with the difficulties of archaisms (or, conversely, neologisms).

Equivalent effects can be achieved by printing in multiple columns. Or, since text naturally flows down columns, let us imagine a double column text as a surface with two sides – the left as front and the right as back – thereby illustrating two sides of the same story. Which side we read could be subject to our faction, political party, or role in a criminal case.

Topologists are interested in the twistedness of two-dimensional surfaces. An interesting but very simple case of a twisted surface is the Möbius band, which is generated by cutting a loop across its width, applying a half twist, and then grafting the edges back together. If we imagine an ant advancing along such a loop we will notice that after one complete circuit it will seem to be mirror-reversed. However if the ant keeps advancing, making for a total of two complete traversals, it will reversed back to the way it was. This illustrates the *non-orientability* of the surface, which is to say, the orientation of its inhabitants cannot be assigned consistently.

How can Möbius bands be extended to printed texts, short of the laborious task of twisting our pages into loops and stitching them back to themselves? Said differently, how can we construct a text which, after we pass through it once, we seem to be mirror-reversed, but after two passthroughs we are back the way we started? Let a text be printed in two tiers of rows, but let the height of each tier vary as we increment the pages. As the drama begins the top tier predominates, and we read from it exclusively. But as we sweep through the pages, the bottom tier begins to grow at the expense of the top tier. By the last page the bottom tier has won out, so with nothing left to read we thumb back to the first page, taking on this pass however the bottom tier as the text to be performed. In doing so, although our eyes have traversed the entire text twice, we have performed it precisely once. Through the judicious use of bold lettering or underlining, we can produce an effect of observing details on the "other side" that will not be actually performed until much later. This can cause flashbacks, paramnesia, or dislocation in the reader.

Holes can be presented in a printed text as simply that – empty spaces, or conversely, inkblots, where text is missing or obscured. The size of the hole is suggested by the lacuna's printed size, and the hole can be filled in real time with improvised text, or audience suggestions, or can be left unfilled to signify emptiness, an unsolved mystery. A dramatic work whose themes are about holes can achieve concrete effects when there are holes in the printed text that defines the drama.

So far we have considered the topology over a set that models a script, but what if we consider dramatic happenings driven by not one but a collection of scripts? Intricate configurations become possible – during a performance our players may utilize texts printed on placards, for instance, presented by players or machinery to a live audience. We may think of such texts as additional scripts that have been *nested* inside the parent script. This can yield synaesthetic effects, for instance, if a scene calls for a text-printed placard to be shown to the audience, but in the next scene that text is now heard instead of seen.

Scenes can also be nested in other ways. A scene's physical set may call for envelopes on a teacher's desk, or in the suit pocket of a game show host. These envelopes, which can be selected according to various conditions, can themselves contain scripts to be taken up and performed. And within such nesting schemes, all of the notions above concerning multiple rows, columns, twistedness, and holes still apply. To illustrate twistedness, our placards, when we proceed in our second pass through the Möbius band, could be printed with text that is the mirror image of what it was before.

3. SCENES AS SURFACES

Although we have already explored surfaces as abstract representations of printed texts, the notion of a surface really comes into its own when we move from texts to the second of our abstract units of drama in this work, i.e. *scenes*. For now we will relegate the physical depth of a scene to future discussion and focus on its two-dimensional manifestation, which we will call a *flat scene*. In Chapter 5 we will relax this constraint and model scenes as complete volumes resembling *fishtanks***.**

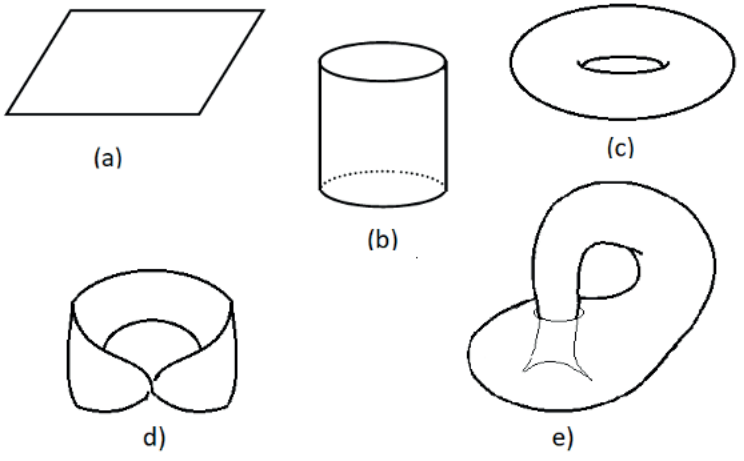

Figure 2: Orientable surfaces: a) plane, b) cylinder, c) torus Non-orientable surfaces: d) Möbius band, e) Klein bottle

3.A. SOME ORIENTABLE SURFACES FOR FLAT SCENES

Let us determine what it means for a flat scene in a drama to be a *cylinder*. The 1980 maze game Pac-Man is a familiar example – when we enter a tunnel from the left of the playing field, we come out on the other side. This is analogous to stitching the left and right hand sides of a sheet of cloth together so that our ant traveling past what was, before the stitching, the left edge will end up on the right edge and keep going until it arrives back where it started.

What does this have to do with drama in physical spaces? A player performing in a cylinder who walks off to the left of the stage would immediately reappear to the right, and vice versa. Such an effect can be produced with a costumed double. As for a ball hurled to the left or to the right, offstage, it would immediately reappear from the other side of the stage, keep flying, and eventually hit the back of the head of the player who originally threw it. Backstage assistance can be supplied to generate this effect.

Another surface very familiar to topologists is the *torus*, as shown in Figure 2c. A scene resembling a torus can be formed by taking the cylinder we had previously, but now instead of merely joining the left and right sides together we also join the top and bottom. The resultant topological space has many interesting properties. It has no boundary, which is to say, an ant wandering over a torus will never encounter an edge. Furthermore, we inhabitants of Euclidean three-space $\mathbb{R}^3$ who behold a torus embedded in three-dimensions can clearly see it has a hole in it. What is not immediately obvious is how an inhabitant of that two-dimensional surface, oblivious to the ambient embedding space, would ever detect such a hole. We will return to this question in Chapter 6.

How would a torus work as a physical scene? The left and right sides of the scene are still stitched together, so the behavior we observed in a cylinder would remain. Now, however, since we can imagine the top and bottom joined as well, a ball thrown up would now disappear and come up through the floor of the scene. Alternatively, a player climbing down a ladder would immediately reappear in the rafters where he continues his descent. Once again our player's costumed double can provide the required effect. Suppose these strange effects were to suddenly disappear during a performance – what implications would this have? A secretly sliced torus would start behaving like a cylinder again, a second cut would sunder the illusion entirely.

Let us investigate what it means to have a hole contained inside of a scene. A mere puncture can be modeled by a portal, gate, door, torn sheet, or oval section of black felt as a prop placed inside the scene – a spot admitting inward passage, outward egress, or both, which raises the prospect of a scene having both an inside and an outside. Two such punctures joined by a flexible cylinder can form a tunnel, or we can merely supply communication between the punctures to simulate a

tunnel. A fishhook thrust into the first puncture can suddenly appear dangling out of the second, all ready for fetching objects to pass back through the tunnel. Or regard a system of four chambers connected by such tunnels – though we may shorten them to valves in some cases – this shall be our ambient performance space for *The Knotted Aorta*. Such tunnels would be rendered inoperable if they became blocked, or if a puncture at either end was repaired. A player in one of the ventricles would be separated from the rest of the performers in the neighboring atrium.

The discussion above focuses on individual scenes, but much as we construed collections of multiple printed texts from a soft geometer' point-of-view, so let us imagine sets of scenes as a means of exploring our theme of *connectedness*. Just as we used placards and envelopes as a way of nesting scripts inside an ongoing performance, so we can present images onstage as a way for nesting a scene inside its parent scene. Pictures hanging in the gallery of a scene that is underway can foreshadow scenes we will actually witness onstage later in the piece. Nested scenes like these can have relationships with their parents that imply interesting topologies – left hands swapped with right, or new sets deployed as exact mirror images of the old. Or, a tricolor relationship between scenes of red, green, and blue lighting, which can suggest the traversal of some scenic trefoil configuration that is currently underway.

3.B. NON-ORIENTABLE SURFACES

For the surfaces we have considered so far as scenes, the orientability of their inhabitants is well-defined. Though a player might travel round and round a cylinder, or a torus, her orientation throughout the journey remains unaltered. Curiously enough, however, some surfaces do not exhibit this sense of orientation that we might otherwise take for granted. Figure 2 includes two such surfaces. The Möbius band is the simplest to understand and we will investigate it first. The Klein bottle we will defer to future discussion. But we will take it with us, much like the trefoil knot of Chapter 1, to use as another prop for our forthcoming exposition.

It is natural to ask how a scene would behave as a Möbius band, that is, if we introduce a half-twist before we suture its left and right edges to make a cylinder? Such a twist need not be visible to the audience, we can assume it has been implemented backstage or behind a curtain. It would, however, have an observable effect on the resulting physics of the scene. A ball thrown to the left would still reappear on the right. For a Möbius band scene, though, since the ball is traveling along a different part of the surface than it did for the cylinder, instead of striking the thrower it would seem to go right through him. The ball with enough velocity however would keep traveling, at least in an illusory sense, and disappear a second time through the left of the scene. This time when it reappears from the right, it will strike the thrower in the head as before.

The incident of the ball thrown across the Möbius band implies that, without any punctures, the scene now possesses an apparent *sidedness* that it did not possess when it was a cylinder. Objects in this scene now possess a left-hand orientation or a right-hand orientation, depending on which apparent side they are on, and opposite-sided objects will seem to glide past one another. If instead we treat the top and bottom edges as sewn together instead of the left and right ones, we will observe that a player climbing up a ladder and out of the scene will, upon their return up through the bottom of the stage, be located on the opposite side of the ladder. It is only by a second climb and a second stage re-entry from the bottom that the climber will return to their original orientation.

We can borrow the topologist's concept of orientation to generate metaphors of inversion applied to theatrical spaces. A looped scene repeats itself over and over, but a Möbius band scene, owing to its non-orientability, has some opposite at work – left versus right, red versus black, backwards versus forwards – that is toggled each time we make a circuit around the loop. Or, we can step back from scenes and regard sequences of scenes as something that can be twisted. The temporal positions of two scenes, for example, might be swapped with one another on a second passthrough.

4. SCENES AS 3-MANIFOLDS

4.A. FISHTANK SPACES

As we move to examine theatrical spaces in three-dimensions we can proceed from flat scenes towards spaces that correspond to a local part of Euclidean 3-space $\mathbb{R}^3$. Informally we can imagine such a space as a fishtank, which allows us to focus on qualities of *depth* which may be otherwise obscure. Let us reconsider, for example, the spatial relations between players – how bodies below or above one another can illustrate patterns of ruler and subject, parent and child, domination and submission. We can also compare the locations of players to their observing audience and how that affects behavior – where the audience sits, for example, relative to the fishtank. In one instance they can sit right before the fishtank like visitors to an aquarium, observing the nearest aspects of the scene even as more distant events are happening in the background. But for an audience sitting slightly above the fishtank, relations will change. Our audience can watch the scene then in the way a child beholds a diorama – with a privileged point-of-view that gives them more information about the scene's contents than any of the players performing inside of it. An elevated fishtank, on the other hand, can communicate a certain archness, or privilege, at the audience's expense. Variations of elevation during the course of a drama can produce variations in effects.

Now let us keep the audience inside the fishtank alongside its players – they go to the theater only to encounter a scene that is happening all around them. This suggests a porous boundary between players and their spectators. Consider what happens when a player suddenly puts a script into the hands of an audience member? Let the player sit down and exchange positions with them, so that we can observe what changes come over the spectator's behavior. We take note of any changes in the drama's rhythms when our former audience member takes up the performance.

Such exercises carry us back to our theme of connectedness, which we can explore in other ways through different kinds of boundaries. A fishtank separated into compartments by transparent walls can preserve visual connections while distorting or blocking spoken ones, or vice versa – allowing speech to flow freely even as certain compartments are temporarily blacked out. It is also natural to explore holes in a three-dimensional context. Doors, or holes in the floor or ceiling, are analogous to the punctures of a flat scene. A solid fireman's pole installed in the center of a room, disruptive of a space's connectedness and a foil to all lassoing attempts, transforms a fishtank-shaped space into a toroid-shaped one. A series of walking tunnels between four chambers establishes a working heart installation that visitors can attend. Such anatomical inclinations suggest a connection to the Leiden anatomical theater, first opened in 1610 [7] as a hosting area for dissections of the human body. Figure 3 presents a floor plan of how a modern theatrical space like this can be organized. Let the hall be delimited, by ropes, rails, or theater stanchions, into two or more concentric ovals. Let the main drama take place inside the centermost partition, where in early modern times the lecturer would stand, anatomizing the cadaver for his audience. So then can a modern audience, seated outside the inner partition of this installation as *The Knotted Aorta* begins, observe a cast of players taking the place of Leiden's old cadaver, thereby turning inside-out, or in topological terms, everting, the anatomical theater of early modern times.

Consider also whether these established boundaries can be made permeable. Just as the lecturer once handed out the scalpel to a volunteer, so too our players can pass scripts outside the central oval and into a second oval, or a third, to generate (possibly unexpected) involvement from audience members, or extra players working *incognito*. The undercover rogue sitting in the third row who is invited to cut – consider the effects when he suddenly hits upon a precalculated gusher. A mistake, or part of the show? Either way it will help the observers to remember their anatomy lesson – which artery the surgeon has hit.

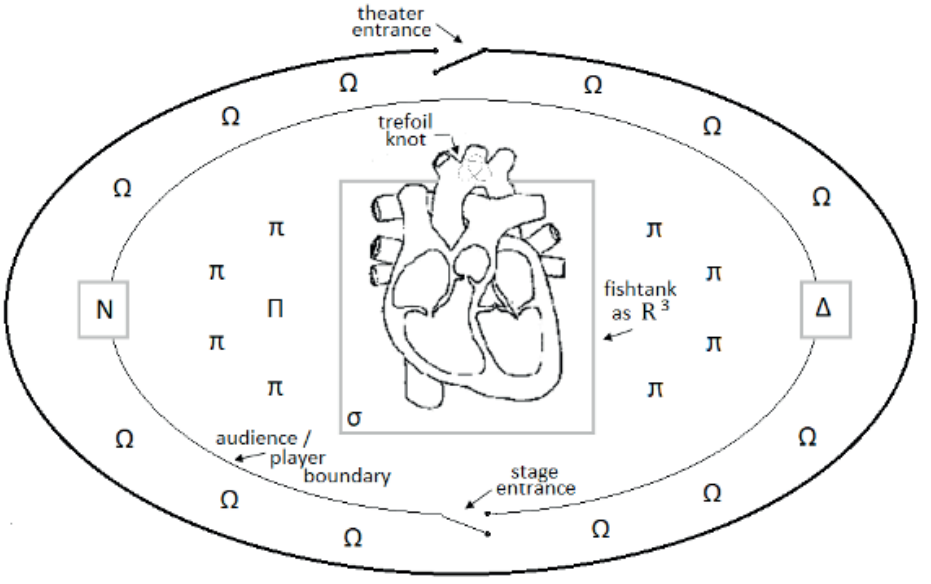

Figure 3: Top-down view of an anatomical theater. N: narrator, Δ: director, π: players, Ω: observers, σ: swimmer (clip art: http://clipart-library.com/unlabelled-diagram-of-the-heart.html)

4.B. BEYOND FISHTANKS

Once scenes are ascribed a third dimension, we have seen how they can become a fertile environment for experiencing the effects of depth, of inside and outside, of radical inclusion versus radical exclusion. But this perspective allows for some topological speculation as well. We can pose the question, after all, of whether the three-dimensional space we live in is really just a fishtank? Exploring alternatives to fishtank space in a dramatic environment can help audiences visualize a fourth dimension in space. The surfaces we have analyzed as scenes so far, for example, can be embedded in $\mathbb{R}^3$, but some, such as the Klein bottle and the projective plane, cannot. In the strictest sense then, the Klein bottle cannot exist in a fishtank, just as a curve cannot be knotted in a two-dimensional plane, because we don't have a third lifting dimension available for the necessary crossings. However, as we can draw an approximation of a knot on a flat page, so too we can recognize that while a Klein bottle cannot be embedded in $\mathbb{R}^3$, it can be immersed in $\mathbb{R}^3$ if we allow it to have self-intersections.

To see this, we can imagine a Klein bottle similarly to the way we imagined a torus construction as an extension of a cylinder, except that a twist is introduced before the cylinder's ends are joined back

together. By introducing this twist, we observe that the ends cannot align properly unless the surface is allowed to pass through itself. Although this may seem like a trick, such self-intersections are precisely what would fall away and resolve themselves if we had a fourth spatial dimension available to us. As such, they are a useful construct for visualizing how a hyper-dimensional fishtank modeled as $\mathbb{R}^4$ might behave. In this type of environment, linked rings can be drawn apart effortlessly, and impossible knots can be untied. Presenting such manifolds onstage via rubber models, papier-mâché, or glycerin bubble mixtures can help us envision what having access to a fourth spatial dimension might be like.

There are also possible spaces besides $\mathbb{R}^3$ that do not require recourse to a fourth dimension. We are not limited to the zero curvature of Euclidean three-space – we have only to elaborate hyperbolic three-spaces ($\mathbb{H}^3$) or elliptic spaces (S^3) (also known as the 3-sphere) to encounter negative and positive spatial curvature, respectively. In a visual presentation of $\mathbb{H}^3$, as the negative curvature inherently present in it is increased, all of our triangle set constructions begin to look skinnier and skinnier, sapped of their angle sums. Sets that are actually very large in $\mathbb{H}^3$ will be designed to look very cramped [8]. Floor tesselations, previously limited in $\mathbb{R}^3$ to triangles, quadrilaterals, and hexagons, can take on a fantastic number of combinations in hyperbolic spaces. Conversely, inhabitants of S^3 will find their triangles have grown puffier and puffier. Though such curvatures exaggerate what is observable in our daily environments, they illustrate what cosmologists consider as actual possible configurations for our universe [8].

5. A KLEIN BOTTLE PLAY

Let us then employ these ideas we have developed to present our scheme for *The Knotted Aorta*, a dramatic performance read by a team of players, who occupy our anatomical theater of Figure 3. Let our scene be as like to a classroom environment, with our players as students sitting in concentric ovals and facing an exhibit in the center of the hall, which is attended by an instructor with his pointer. This exhibit is an enormous fishtank filled with fluid, which can be elaborated through our players' dialogue as a metaphor for Euclidean three-space $\mathbb{R}^3$. Let a swimmer be immersed in the fishtank under study. If this swimmer presents no awareness of the surrounding theater and has no recourse for interacting with it, then to the swimmer's mind the surrounding theater makes a good representation of Euclidean four-space $\mathbb{R}^4$, i.e., the fourth dimension, to which his senses, like ours, are denied any access. The students observing the fishtank however possess a privileged awareness, so to speak, and due to this privilege can perform operations on $\mathbb{R}^3$ that the swimmer cannot.

Suspended inside of our fishtank is a gigantic working heart. Labels upon its surface may be used to provide some basic anatomical notation, with accompanying vector fields of red and black arrows to represent arterial and venous blood flow, respectively. Our instructor, as he points at various locations upon the specimen, can provide the class with some useful observations while it operates. However

since both the students and we, the audience, like the swimmer, have only recourse to observing the heart's surface, our insights into its workings are limited. To gain more familiarity with our specimen, we have no choice but to go inside of it.

Our inclination at this point might be to undergo a set change, with our classroom environment replaced by a representation, via painted sceneries and onstage props, of one of the heart's working chambers. We might even try to depict all four of them onstage at once, in some composite way, drawing connections to our four individual chambers by way of the requisite tunnels and valves. A flow of red players with 'o's printed on their costumes could represent arterial flow, whereas a party of black players, depleted of oxygen and wearing 'x's on their chests, could give us the venous flow we need.

Then, with a rhythmic lub-dup chant, we could proceed through the scenes one by one, experiencing as we go a complete cardiac cycle, and observing, as we traverse, the patterns of the heart's circulation. The right atrium could fill up with black blood as we enter it, only to disgorge this blood as the scene switches to the right ventricle, the second of our four chambers. All would then become awash once more in black blood, until a trip across the pulmonary tunnel is made, sending our players into a third chamber – where all the black has now been turned to red! For we will have reached the left atrium, and thereafter the left ventricle, and so on back to the right atrium where we started, with everything repeating from before, except that this time the blood in our right atrium will have turned to red. Also, our right-handed players will have all suddenly become left-handed, and the names printed on their shirts will be mirror-reversed.

These last changes signify a mystery, and remind us of our topological endeavours. Shouldn't there be black blood in the atrium, not red? What has happened? To investigate, we remark upon the limits of the scenic representation outlined above. Since this expression would be enacted on a physical stage, in predominantly visual terms, it is limited to the three spatial dimensions that we as human beings can observe. An alternative approach is to forego any set changes, to remain instead in the classroom alongside our telltale specimen, and to then express our circulatory environment more abstractly, while we are sitting there, through the medium of the text itself. We can begin to think of our performers of the play less as players and more as participants. We arm them with scripts and assign them red and black roles to read from the text. Their instructor now becomes their director and conductor. Through descriptive ecphrasis and rhythmic verse, drawn as in the vein of the preceding paragraphs, our readers participate in making, out of the poetry printed on their scripts, an imaginative reconstruction of the heart's interior. Like topologists, they hold the images in their minds inside of before their eyes. Although the fishtank is still available to our field-of-vision, indeed almost ominous in its omnipresence, mentally it now inhabits a nested context that the spoken verses have brought us without.

Once this first traversal of the four chambers has revealed our environment's curious malfunction, our instructor can return to an examination of our throbbing model inside of the tank – indeed, this

is done easily enough, since we have never left the physical presence of our classroom scene. At this point the instructor adjusts or reorients the tank to reveal some hitherto hidden markings on the heart, or simply draws attention to some markings that were already there. These markings signify self-intersections in our model, and reveal that the surface before us, as discovered by our instructor, is actually a Klein bottle in disguise. Like the Möbius band it is non-orientable, and traveling once around its apparent extent will result in the same kinds of reversals we saw there – left swapped for right, or black exchanged with red. Since this is a new idea, we are inclined as participants to project ourselves back through the chambers a second time, for pedagogy's sake and per the requirements of the script, with certain stanzas reduced or compressed as the timing of the performance demands. But once we have reached the right atrium yet again we will find that, curiously, black is again black, right is right, and everything has been restored to its original condition.

So what then is the reason for this strange behaviour? Returning once more to the embedding context of the anatomical theater, we go along, inspecting our beating surface– aha! We find that one of the heart's feeding cylinders is extruding from the tank. What's more, our instructor detects a small trefoil in this offending cylinder, the largest one in the entire specimen, in fact – the aorta has a knot in it! This is the source of the twist that gave to our surface its Klein bottle character. Our swimmer cannot repair this knot, he is unable to observe it from the context of the fishtank's interior. But we from our privileged context have access as it were to $\mathbb{R}^4$, where we can unsettle the knot, and restore everything to its working order. A simple cut by the instructor's scalpel, a stitching back together with the twist removed, and the surgery is complete. A subsequent traversal through the heart's chambers will find that the heart is now operating correctly.

Similar such dramas for performing these kinds of demonstrations can also be elaborated. These include *The Twisting Aorta*, which examines the clockwise rotation of the heart's base during systole, or *The Severed Aorta*, in which fissures are located and then mended, thanks to the invention of surgical zippers.

6. A TOPOLOGY OF PLAYERS

We have investigated connectedness as it pertains to collections of texts and the properties of scenes, but relationships between the players themselves can also present new experimental opportunities. Players can be physically connected or disconnected via handcuffs, or their connections can be portrayed in more abstract ways, such as being unable to hear, see, or understand another. Connections between players can also be mediated by onstage objects. Twistedness can be portrayed too, through bodily articulations, or systems of ropes among players, and here again topology offers a means of yielding descriptions that can help us imagine new possibilities for theater.

For since players, like all living creatures, are three-manifolds incarnate, so studying the properties of such topological structures can tell us much about ourselves. Hydras, for example, are capable of turning their bodies inside-out [9], which presents interesting philosophical questions about our own insides. A three-manifold such as a fishtank, however, may be insufficient or incapable of describing the human body. Euclidean three-space for one thing is infinite in extent, and has no boundaries. Nor does the three-sphere S^3 furnish a good model, since it is does not possess any through tunnels that would correspond, for instance, to a human digestive tract.

The three-torus T^3 however does admit of such tunnels, and by appending handles to it we can add as many holes as we need. The Atharthaveda of Vedic scripture catalogues nine openings, or *navadwara* – two eyes, two ears, two nostrils, one mouth, one anus, and one reproductive organ – which suggests that the human body is in fact aptly characterized by some variation on T^3, although, depending on interpretation, it may best be furnished with a mixture of punctures and proper tunnels. But the genus and overall curvature of a punctured three-torus can be readily analysed from a topologist's point-of-view. Furthermore, by allowing for self-intersection and imaginatively embedding ourselves in an accommodating manifold, $\mathbb{R}^4$, for instance, we can study aspects of our physical predicament – the body's own twistedness, for example, or its disconnectedness from itself – that, should a fourth spatial dimension ever become available for our perusal, would be made explicitly manifest to us. This topology of players will be more thoroughly explored in a future paper.

CONCLUSIONS

In this work we have prescribed a course of dramatic study informed by the three principal concerns of topology – connectedness, twistedness, and the detection of holes. We have applied this course to not only the *texts* that generate drama, but to the *scenes* in which drama is performed. We have seen how these principal concerns in the mathematical context of *analysis situs* can be applied figuratively to drama to initiate procedures for generating new environments, circumstances, and contexts for theatrical experiences.

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II. ON PRACTICE

PEOPLE ARE MESSY:
BIOETHICS AND THEATRE

NIGEL TOWNSEND
(Theatre of Debate)

People are Messy (PAM)

> "Today a young woman came into clinic to hear she has a new diagnosis of aplastic anaemia. I found myself wishing Jake and Vic were real and I could put her in touch with them. That's how real they felt in the play - People Are Messy - And it made me see her very differently, this patient. It's not me who gave her the diagnosis today, but if it had been, I really think that consultation would have been influenced by my having seen that play. Powerful stuff."
>
> Dr Noemi Roy - Academic Clinical Lecturer in Hematology, University of Oxford

PAM was developed in collaboration with the National Institute for Health Research (NIHR) , Oxford Biomedical Research Centre (BRC), a partnership of Oxford University Hospitals NHS Trust and the University of Oxford, and was jointly supported by a Wellcome Trust strategic award.

PAM targeted pupils aged 14+ and engaged its audiences in an informed debate about the ethical, political and social issues around public and patient involvement in research [PPI[40]].

PAM toured secondary schools from Monday 25 January 2016 to Thursday 24 March 2016 and was seen by over 4,951 students and teachers.

Created to be experienced by a whole secondary school year group (150-200 students) PAM consisted of a stimulating performance by professional actors (60 minutes) followed by a thought-provoking, facilitated audience debate (40-50 minutes) featuring the actors "in character" who returned to the stage to discuss the topic from their perspective. Questions debated included:

- Why should the public have a say in what research gets funded and how?
- Would you want to have a say in research tackling your own illness?
- What impact does involving "lay" people have on research questions being asked and money being spent?
- Surely doctors and researchers know best?

Electronic voting technology allowed us to capture what our audience knew, thought and felt about PPI before and after the performances.

40 PPI is research being carried out 'with' or 'by' members of the public rather than 'to', 'about' or 'for' them. See https://www.invo.org.uk/

Creative process

TOD'S creative process (method) has two key features, each project involves;

- Working in partnership with academic and research partners
- A creative collaboration between Artists (theatre practitioners), Scientists and members of the target audience

PAM was developed in partnership with an advisory group of experts including Simon Denegri, the National Institute of Health Research's National Director for Public Participation and Engagement in Research, Maryrose Tarpey, Assistant Director of INVOLVE, the NIHR-funded national group that supports PPI in research and John Cleland, Professor of Cardiology at Imperial College London.

Other experts, including patients and carers, were from the worlds of nursing, ethics, health experience research and public engagement. Bringing a diverse range of views, both supportive of and challenging to the principles of PPI, they have led this process, guided by Dr Sophie Petit-Zeman, Director of Patient Involvement for the NIHR Oxford BRC/Unit and Scientific Adviser to Theatre of Debate.

Each TOD programme starts with an interactive workshop. On Monday April 20th 2015, members of the advisory board and of the TOD creative team, young people from one inner city school and the playwright Judith Johnson participated in an interactive workshop exploring what they think, know and feel about PPI, and listening to presentations by members of the advisory group including:

- Patient and Public Involvement (PPI) in research: What it is, What it's not and some of the debates
  Dr Sophie Petit - Zeman, Director of Patient Involvement for the NIHR Oxford BRC/Unit and Scientific Advisor to Theatre of Debate;
- How is PPI done? What methods and mechanics do individual researchers and research teams use?
  Maryrose Tarpey, Assistant Director, INVOLVE;
- What does national policy - i.e. the Dept of Health - want from PPI in research - and why does it want it?
  Philippa Yeeles, Head of Patient and Public Involvement , NIHR Central Commissioning Facility;
- Is PPI a good idea? - a researcher's perspective
  John Cleland, Professor of Cardiology, Imperial College London/cardiology consultant, Royal Brompton Hospital;
- The carer's perspective on PPI - love it or hate it?
  Lester Firkins, former chair, James Lind Alliance/carer;
- What do we know about public and researcher views of PPI from detailed analysis by

Healthtalkonline?
Louise Locock, OxBRC Health Experience Research Fellow/Director of Applied Research, Health Experiences Research Group;

- What does PPI in research mean to young people? How are they involved? Does it make research different or better?
  Jenny Preston, Consumer liaison manager, NIHR Medicines for Children Research Network.

As ever with Theatre of Debate's work, the presentations were selected to ensure that a range of views about PPI were represented, not just those of the converted or the naysayers.

At the PAM workshop we heard from Lester Firkins about being asked to join a group of carers to discuss what research should be carried out into Creutzfeldt-Jakob Disease (CJD) (the "human" form of "mad cow disease") after his son died from the condition. He said "This was back in 2001 and yet we were being consulted. If it was right to do when an illness was in the public gaze, surely it's right to do it always?"

Simon Denegri, Chair of INVOLVE, reflected that "PPI is messy, people are messy, but given my own family experiences and campaigning background, I'm passionate about helping people break open the system and make it listen to them.'

After the presentations, the participants were divided into groups, and asked to consider the following question "If you had to write this play, what would you focus on?"

After 30 minutes each of the groups fed back to the whole group. Suggestions included the importance (and challenges) of PPI in research with children; conveying uncertainty; why much research focuses on drugs, rather than more subtle issues of quality of life; how to do good PPI when one person's view about what matters differs radically from another's?

Three weeks after the workshop, Judith Johnson submitted two synopses. PAM was the synopsis TOD chose to commission.

As with previous TOD projects, the advisory group continued to support and engage at key stages of the creative process including –

- reading each draft of the script
- Assess and comment on the Learning objectives for the production
- attend a public rehearsed reading
- the development of the debate that takes place after the play

- attend rehearsals and supporting the actors where appropriate
- attend dress rehearsals and preview performances
- the expert group also participated in the debates when we do public non school performances

Developing the Script

While creating the characters, Judith consulted with Dr Noemi Roy - Academic Clinical Lecturer in Haematology, University of Oxford who suggested the possibility of a rare blood disorder - aplastic anaemia (AA) as a possible condition for a least one of the characters.

In most cases of aplastic anaemia, it is thought to be an acquired and idiopathic (of unknown cause) condition. This means that it is neither present at birth nor inherited but has developed during the patient's life. Judith was hoping to find a condition that is being researched that has (or has the potential for) PPI and that her character Jake (a young man, age 18) could discover that he has during the course of the play (i.e. when he is 18) and then become involved with some kind of PPI which also involves a research scientist doing research into the condition so that they would meet.

Our immune system plays a very important role in aplastic anaemia. It is understood that in most cases the damage to the stem cells is caused by an auto-immune reaction. Our immune system normally surveys our body and helps it to fight infections, bugs and germs but in rare cases attack the bone marrow itself assuming it to be faulty/foreign. The bone marrow function starts to slow down, and in doing so, results in the under production of all the blood cells. The playwright wrote three drafts of the script, each one reviewed by the advisory group and the creative team. She also met with a young person Adam aged 21, with AA as did the actors during rehearsals.

To meet its various objectives the final script touches on a range of themes including bereavement, grief and living with a rare and sometimes terminal disease. Our immune system plays a very important role in aplastic anaemia. It is understood that in most cases the damage to the stem cells is caused by an auto-immune reaction. Our immune system normally surveys our body and helps it to fight infections, bugs and germs but in rare cases attack the bone marrow itself assuming it to be faulty/foreign. The bone marrow function starts to slow down, and in doing so, results in the under production of all the blood cells.

PAM tells the story of 18-year-old Jake, a spiky, opinionated A level student, and Vik also 18, a laid-back, cheerful apprentice electrician. Both have a rare blood disease, aplastic anaemia (AA) and their consultant is Adam, – bright, self-assured, driven – whose research has been turned down for funding because he didn't sufficiently demonstrate involvement of patients and the public in his

plans – a pre-requisite of Department of Health funding for medical research.

Adam then recruits his long-term patient Vik to be an adviser knowing Vik will be an easy-going ally, but when Vik then recruits combative Jake, Adam finds himself challenged. The two inevitably clash, with an exasperated Vik caught in the middle.

Other characters include:

Jen is 15 years old. She is Adam's daughter. Jen is thoughtful and kind-hearted with a wry sense of humour. She is in Year 11, studying A levels - Advanced level qualifications (known as A levels) are subject-based qualifications that can lead to university, further study, training or work. Jen's mother died during childbirth of AA;

Gran is in her late 50s/early 60s. She is Jen's Gran and Adam's Mum. Gran is quirky with a down to earth sense of humour. She has a love for and curiosity about life; at the same time, she is a nurturing and caring person. Gran appears in the play on film in skype links from her travels.

The script raises various questions for the debate such as:

- Who should make decisions about medical research? Are patients (and members of the public) only needed as 'guinea pigs' for clinical trials or should they have a role determining what research is done?
- Should patients take an active part in decisions about their treatment or is it better if they rely entirely on the expertise of their doctor?
- How can patient and public involvement (PPI) benefit doctors, patients and research?

This fabulous, entertaining, and moving play goes to the heart of why involving patients and the public is so important to science and to society. It will appeal to audiences of all ages and will bring the issues to a whole new audience nationwide. I am very excited about its potential impact.

Simon Denegri, NIHR National Director for Patients and the Public

Working with actors

TOD demands excellence not only from our playwrights but from the actors too, without an authentic performance the audience won't engage emotionally and there will be very limited debate. Whereas the challenge of finding the right actor/s for a more traditional production for a theatre going audience is always a considerable one, actors who appear in a TOD productions are faced

with a multiple set of additional requirements - not only must they perform characters in a staged narrative, sustain audience interest and entertain in the process, but they must also at another level inform, educate and frequently challenge preconceptions their audiences may have and further in the Debate elements of the programme pivotal to TOD, they have to engage directly with the audience in dialogue about the issues raised which in turn requires of them detailed knowledge of the subject matter and it's wider social implications. The PAM production had three weeks of rehearsals, and a 10 week tour, two performances and debates - 5 days a week.

The first performance of the day started before 9 am, which means the actors had to be at the venue as early as 7 am in order to transport the sets, costumes, props into the school and set up, supported by the Company manager. The performing environment was often less than perfect, with poor acoustics, no lighting and the disturbances and interruptions that are common in any school i.e. end of period bells, noise from the kitchens as lunch is cooked. The majority of our professional actors who range from 16-year-olds to very experienced over fifty-year-olds have said that what gives them enormous satisfaction is the proximity of the audience, the immediate feedback that they wouldn't get in a traditional theatre setting and the sense of achievement from using their art form to engage audiences in informed conversations about subjects that wouldn't normally be on the average 14-year-olds agenda.

Being cast in a TOD production confronts many actors' preconceptions and previous lack of interest in science, and it can engender an ongoing interest in the subject matter/issue as the actor immerses themselves in the necessary research to play a character who is let's say a geneticist.

How we cast

For all these reasons we operate an open ended casting process, choosing to work with an experienced Casting Director who understands the work, our creative processes and the challenges involved. We have worked for many years with Derek Barnes who as well as being one the first UK's first black casting director's - cast long running TV series such as Casualty, Holby City, The Ant and Dec show, and the Bill.

Filming our Productions

"The PAM film portrays a true reflection of the many emotions that patients, carers, health care professionals, family and acquaintances go through when a single member of that unit is diagnosed with a critical illness. The actors were brilliant and plausible, showing and expressing raw emotion. They did a splendid job. I hope the whole nation gets a chance to watch it."

Alero Dabor, Cancer survivor and patient involvement in research advocate at Guy's and St Thomas' NHS Foundation Trust

Theatre of Debate started filming our live productions in 2011. Inspired by the National Theatre live programme, for which the National Theatre film their productions live and screen them into cinemas, TOD has filmed performances of PAM, People Like Us, Dayglo, Hungry, Mind the Gap and Stunted Tree and Broken Bridges.

Filming the productions has opened up new audiences including home educators, health professionals, university students and community educators.

We have screened the films

- in cinemas with TOD providing a facilitated debate
- In schools with teacher's facilitating the debate
- in mixed venues i.e. art house cinemas, community halls, hospitals for public audiences with Science Communicatirs facilitating the discussion
- at festivals and conferences with a TOD facilitated debate
- All the films are available on our website through a subscription model and also on Digital Theatre plus.

We have found that using filmed live performances offer us the following advantages

- Increasing the quality of the audience experience. Filming and screening provide every student with the 'best seat' in the house with the added benefit of enhanced sound.
- Increasing our existing audiences and reaching new audiences - the combination of a live performance tour and digital screenings on demand not only ensures higher audience figures over time but it potentially broadens our audience . In pilot screenings, people over 60 and older have proved to be an enthusiastic audience as have home educators who have welcomed an opportunity to bring their children to screenings.

Impact

In March 2016 Leeds University carried out an impact evaluation in target 16 schools in West Yorkshire The 'Target 16' schools are deemed to be some of the most disadvantaged or poorly served schools in West Yorkshire. Part of our survey asked participating pupils to identify their home postcode, which enabled analysis by HEFCE's POLAR3 classification, as well as indices of deprivation (IMD) indicators issued by the Department for Communities and Local Government. Almost all participants (97%) reside within postcode areas classified as belonging to POLAR3 quintile 1 to 3, with 44% residing

in postcode areas identified as the most deprived (quintile 1 or 2). Mapping postcode data to IMD indicators (Chart 2) provides that 60% of participants reside within deciles 1 to 5, with 45% residing in postcode areas identified as the most deprived.

Almost all participants (82.5%) indicated that it was 'good' or 'very good'. Less that 2% thought the performance and debate was 'poor'. The most visible 'gain' for participants post-performance was in the area of learning from actors and live theatre, a stronger belief that patients should help decide what medical research work is done, and that patients can be viewed as experts.

… from my point of view as a science teacher, it's very difficult to put across medical ethics issues, and have that kind of informed debate. You've got to allow the students time to develop their knowledge and understanding before they can apply their ideas – I think the performance and debate gave them a nice safe environment within which to do that.
Teacher, Brigshaw High School

Theatre of Debate's 'People are Messy' provides an innovative and interactive way to engage young people in discussions and debates about the ethical and human issues involved in medical research work. Feedback from teachers provides evidence that the content of the production links clearly to a range of curriculum areas covered by GCSE learners. The content links not only to science-based subjects but also personal development and citizenship provision.

The value or 'gain' experienced by participating students has been measured and is statistically significant. These changes or developments in understanding and perception highlight, amongst other things, the impact of the production. This should be commended and celebrated and many of the teachers interviewed would welcome such interventions in their schools in future.

MATTERS OF LIFE AND DEATH: USES OF HISTORICAL KNOWLEDGE OF MEDICINE IN THE THEATRE PLAY *ALL TOO HUMAN* (*DEMASIADO HUMANO*)

DANIEL GAMITO-MARQUES

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Medicine has provided much inspiration to writers within the Western theatrical tradition, but the representation of physicians, patients, and medical practices has significantly changed in the last decades. Distancing themselves from heroic narratives of progress and inventiveness common in the first half of the twentieth century, contemporary writers for the stage have instead focused on problematic aspects of the relationship between physicians and their patients. The target of these critical perspectives is the "medical gaze", the objectification of patients that results from addressing illness as a mere scientific problem requiring a quick solution, thus downplaying the patient's personal experience of suffering (Shephard-Barr, 2006; Garner, 2020). In this article, I discuss the methodologies that guided the writing of my theatre play *All Too Human* (*Demasiado Humano*), which reflects on the ethical questions associated with the development of new medical treatments. These methodologies were inspired by my work as a historian of science.

Since my undergraduate years as a biology student, I have harboured a deep interest in understanding how new scientific theories and concepts emerge. This interest led me to embark in a Ph.D. in history of science, and later to study how storytelling techniques could be deployed to better explain such processes (Gamito-Marques, 2020). Through simultaneously working as a playwright and dramaturge, I noticed that many stories from science also had an interesting performative potential. There were already some, if few, examples of staged stories of scientific discovery, such as Frédérique Aït-Touati's and Bruno Latour's lecture-performance on the Gaia Hypothesis (Aït-Touati, 2021). But I felt that there were ways of discussing similar stories by using formats other than the lecture-performance.

When I began working on *All Too Human*, anti-vaccination discourse was rife, thus driving me to write a play about medical contexts in response. Although I was and still remain entirely opposed to anti-vax movements, my aim was never to write a dramatised defence of vaccination; rather, I wanted to present the complexity of the issues at stake in new vaccine production. Contemporary plays about medical contexts usually focus on the ethical dilemmas of the application of treatments that have already been developed, or whose consequences are predictable, even if only for the experts who apply them. But before a treatment is reached, ethical questions of no lesser relevance also emerge. As researchers struggle to produce meaningful results, conflicts, doubts, and power asymmetries among physicians, scientists, and patients become poignantly visible. This process is thus filled with the kind of dramatic tension one can find in engaging plays. More importantly, however, the ways in which the participants in those processes respond to the conflicts that medical research generates, may impact society as a whole. For this reason, I thought that wider audiences should be able to appreciate the complexities of the development of medical treatments.

One episode from the history of medicine that had previously caught my attention was the development of the rabies vaccine in the late nineteenth century by Louis Pasteur's team. The case raised complex ethical questions, notably the sacrifice of hundreds of animals, and the rushed

administration of experimental treatments in humans. I could have constructed a fictional narrative based purely on speculation, but since these and other questions had been discussed in the historical literature (Geison, 1995; Robbins, 2001), I tried to ensure the historical accuracy of all scenes. My point, however, was not to create a full historical adaptation of the case, but rather to discuss specific situations from the past that resonated with present-day dilemmas. In this way, I established a chronology of events in the discovery of rabies vaccine, identified the main agents (human and non-human) and their participation in the process, and mapped out the conflicts between them. However, as I worked on the initial drafts, I stumbled on a fundamental problem. The more I focused on the details of this convoluted story, especially on how scientific knowledge was constructed, the more I lost the human element that made the story engaging.

As I was writing the play during the covid-19 health crisis – although the initial idea predated the onset of the pandemic –, ongoing public discussions made me think about the role of empathy in society. I had been struck in recent years by Byung-Chul Han's defence of listening (Han, 2018) and Yayo Herrero's ecofeminist emphasis on vulnerability and co-dependency as fundamental human characteristics (Culturgest, 2019), both highlighting the centrality of practices of care. After much reflection, I realised that the discovery of a vaccine could be told as a story of vulnerability that united physicians and patients. While vulnerability is conspicuous in patients it also affects researchers, who are dependent on the existence of patients, funding, and results, often facing uncertainty in their careers until an acceptable treatment is produced. Of course, this shared vulnerability does not eliminate the power dynamics that almost always puts patients in a disadvantageous position, but I thought it provided an interesting and unusual way of looking at a medical discovery. Having vulnerability at the core of the play also led me to pay more attention to the situation of the patients, posing two additional problems. First, most historical sources provide scarce information on them, which forced me to imagine what they were thinking and feeling. Second, to do it by putting words in their mouths, when their lives were so far removed from my own, risked to severely misrepresenting them. Such a puzzle seemed almost impossible to solve, especially because the text felt rigid and less engaging when I tried to present the events by using declarative sentences.

After much experimenting with narrative formats, I realised that raising questions rather than resorting to plain statements made the text more suggestive, and provided a direct means of addressing spectators and bringing them to the heart of the events. In fact, I could construct a whole dramaturgy of vulnerability that utilised the many uncertainties and difficult choices related to the case to propel the narrative. The story could be told by an external observer that is trying to make sense of the witnessed events. Take as an example the moment in which a young boy who was bitten by a rabid dog awaits with his mother for the experimental treatment to be brought (Gamito-Marques, 2021).

"The virus that lies here has a problem.
They cannot preserve it.
They need animals. Living.
The virus is passed from animal to animal. Always.
And the outcome is almost always the same. Death.
First, they used dogs. They could be dangerous.
Then, rabbits. Dozens, hundreds of them.
It was easier.

How many dogs is his life worth?
Tens? Hundreds? Thousands?
How many rabbits?

But the rabbits were not enough.
It was not working.
So they used monkeys.

How many monkeys is his life worth?
More
or less
in rabbits' lives?
in dogs' lives?

But there was no other chance.
They had to use dogs, rabbits, monkeys,
inject them in their brains,
extract the vaccine.

If he knew this, what would he have done?
Would he accept it?
But even if he knew nothing
could he not feel it?
And what if his mother knew it?
Would she accept it?

But everything was done.
The dogs had died.
The rabbits, the monkeys.

There was no other way.
And the decision was not his.
But if he doesn't get the shot
he will die.

[...]

Some weeks ago
they started a new experiment.
They injected several dogs with the new treatment
and the dogs are still alive.
But the experiment
is not over.
No one knows
if they will survive.

The boy knows nothing.
His mother, the same.
But if they knew
what would they choose?
Accept the treatment?
No one told them, but
if they had been told
would they say yes?"

By imagining an omniscient voice that discussed the events while lacking the power to intervene, I felt that the dramatic tension was heightened. As I continued in this direction, I started to realise that an additional layer of meaning was being created. Since I was asking questions about life-and-death matters, the play could also be understood as a reflection on what it means to be human. In fact, I could bring the reflection further if I included other stories that explored human vulnerability at other levels. I then applied the same methodology to two other revolutionary and well-discussed medical discoveries: psychoanalysis, and the first immortalised human cell line (Appignanesi & Forrester 1992; Skues, 2006; Littlefield & Pollock, 2011; Skloot, 2019).

In the second part of the play, I explored human vulnerability not as a result of a disease that affects primarily the body, like the rabies virus, but rather the mind. I retold the story of Anna O. and the struggle of her physician, Josef Breuer, to treat her mental illness, showing that he had no solid guidelines to follow and that there were countless setbacks, which could have culminated in Anna's collapse. My text emphasises the enormous effort that Breuer had to make in order to bond with the patient, the role of

chance in finding a possible treatment, and the long and painstaking duration of the process.

In the final part of the play, I presented the audience with the ultimate human vulnerability – death – and discussed whether human suffering is always pointless or can be utilised to provide a new opportunity to other people. I focused on the case of Henrietta Lacks, who died of an aggressive cervical cancer, but whose diseased cells constituted a medical breakthrough. Scientists discovered that these cancerous cells had the remarkable ability of multiplying indefinitely in vitro. It was the first time that human cells were shown to survive for long periods outside the human body, and now they could be used in scientific research to speed up treatments and save lives. The ethical problem was that physicians did not ask for the patient's consent, and probably disregarded the severity of Lacks's health condition because she was a black woman from a lower class. My text, however, emphasises her humanity over historical considerations. Lacks's case shows that it was precisely when she found herself in her most vulnerable condition that an element capable of easing the suffering of others was revealed. In this sense, vulnerability can be more than a state resulting from bodily and mental suffering. It can be the condition without which there would be no hope, no possibility to give life a new opportunity.

The patients at the centre of each part of my play have all fallen into a life-threatening health situation they did not want nor anticipated. They find themselves in a moment of extreme vulnerability that goes beyond the differences that separate them because it speaks directly to their own human condition. By delving in these extreme cases, I therefore confront spectators with their personal vulnerabilities. The physicians and other scientists who attempt at treating the patients also inhabit a place of vulnerability as they struggle to make sense of the diseases and find appropriate solutions. Both sides are thus co-dependent on each other, since both need the other half in order to carry on with their lives. In this way, I am not just asking how would spectators behave, or in whom would they trust if they faced similar situations. I am rather showing that, regardless of the side we find ourselves in, we will always inhabit a place of vulnerability and need the presence of others. Co-dependency is thus at the core of our humanness, and to fail to recognise it is to lose what makes us human. This is the reason why I think that such stories from science belong in the theatre. Their significance can only be properly felt in that most powerful and human machine of amplifying affects that the theatre is and has always been.

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I FELT MYSELF INSIDE THE FOREST: A STUDY WITH THE AUDIENCE OF THE CHILDREN'S THEATRE SHOW CURUMIM QUER MÚSICA! AT THE MUSEUM OF LIFE (BRAZIL)

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Introduction

Theatre and science communication established a partnership that has spread to several museums and science centres around the world in the last decades. Indeed, there are now theatre companies devoted exclusively to science communication who produce shows that touch on topics related to science, as well as conferences and other events in the fields of theatre and science communication which are mirroring the growth of such initiatives and helping to share and explore further their experiences and ideas. Similarly, a number of studies have sought to understand the relationship between these two areas, investigating the dynamics of how visitor interact with museums' offerings and evaluating theatre-based activities from the perspective of the educational goals that intersect this interaction. But what makes theatre so appealing for science communication? How can the performing arts help foster a greater engagement with science? Essentially, what is the potential of combining science and theatre in the context of science communication?

Authors who investigate these issues argue that it is theatre's capacity to arouse feelings and emotions which makes it so good at holding the attention of audiences, for whom learning and being entertained occur simultaneously (Bicknell & Fischer, 1994; Bridal, 2004; Hughes, Jackson, & Kidd, 2007). The idea is that theatre has the power to address complex or controversial scientific topics in an engaging manner (Black & Goldowsky, 1999), that it can offer a more humanistic approach to science, showing scientists as individuals with their own passions and conflicts (Moreira & Marandino, 2015), making the supposedly cold and calculating nature of science more palatable (Lopes, 2005) and encouraging reflection on science and its impacts on society (Shepherd-Barr, 2006). Conversely, empirical studies on the role of theatre in the museum context prioritise basically two aspects when they address the interface between science and theatre: the eminently educational nature of theatre and its cognitive impacts, particularly its potential to foster the learning of scientific knowledge and concepts (Hamilton, 2021; Weitkamp, 2021).

The above studies address factors that have certainly helped expand the scope of theatre in the field of science communication, but by focusing on the didactic dimension of this form of theatre – learning about science – they fail to take account of one key aspect of the performing arts: the relationship between the stage and the audience, between the show and the spectator. Theatre is a collective endeavour – it is produced by a team – but it only reaches completion when the production is performed to an audience. The audience members occupying the stalks during a performance are not passive subjects, but active participants in the theatre experience (Rancière, 2014; Desgranges, 2015). They must be willing to take part in the game, to engage in the dialogue created between them and the actors during the performance, such that each performance becomes an unrepeatable, ephemeral experience. To think about theatre from this perspective means being aware of the totality of the theatre event and not just the text, the content of the play and what an audience may be

capable of absorbing from it. Furthermore, conferring centrality on the "game" (Guénoun, 2004) itself is a way of valuing the developmental qualities of theatre and its role as a community activity, where diverse elements of human experience come together (Lehmann, 2011). It also means valuing theatre as an autonomous artistic experience which may affect the audience members in unexpected ways (Hamilton et al., 2022).

Viewing theatre as an unfolding creative process that encompasses all those involved in the experience allows us to speak of participation, dialogue and the co-creation of meanings that permeate the audience's relationship with the play. Participation, dialogue and co-creation are also the bywords for the reflections and efforts, both academic and practical, by those involved in science communication who wish to look more closely at the audience, transcending the idea of the vertical transmission of knowledge and prioritising dialogue as part of citizenship and a keystone of democracy and encouraging reflection so that the public can appropriate science critically (Bauer, Allum, & Miller, 2007; Castelfranchi, 2010).

The audience in the spotlight

Public engagement with science forms the theoretical backbone of this study. It is a term that has come to be used to designate the movement towards greater dialogue and inclusion in science communication. This model advocates changing the theoretical and practical focus of science communication, moving away from the transmission and comprehension of scientific facts to envisage a more complex understanding of the processes of science and the politically engaged involvement of citizens with such topics (Brossard & Lewenstein, 2010).

According to Lewenstein (2003), science communication activities whose focus is on engaging the public are driven by a desire to democratise science through some form of participation and empowerment. Various types of engagement can be considered, such as engagement in making or shaping science policies, in taking personal health-related decisions, in the production of scientific knowledge, in specific areas of science, or in the development of critical thinking. This model also presupposes taking a more sophisticated view of the public, considering their knowledge, values, attitudes and beliefs, and making them the starting point for more symmetrical and dialogic exchanges (Brossard & Lewenstein, 2010).

Highlighting the central role of the spectator in the consolidation of the theatrical event, Parry (2020) understands that theatre does not produce engagement, but is itself a particular and peculiar form of engagement whose potential for science communication is essentially twofold. Firstly, it can promote understanding of or engagement with knowledge and help encourage discussion on the

processes and practices of science. Secondly, as it constitutes a form of participation and co-creation of meanings stemming from the relationship between the spectator and the show, it creates a space belonging to the gaze of the other, from which fiction can emerge (Parry, 2020).

But how can the engagement of children, the objective of this reception study, be associated with the model of public engagement, centred as it is on participation in the making or shaping of science policies and the governance of science? How can projects for children devised by museums and science centres be assessed in this respect? Although it is often associated with political processes, the public engagement model has guided the work of several institutions, including museums and science centres, which have appropriated it in different ways. Davies et al. (2009) advocate forms of engagement that emphasise a dialogic approach and presuppose more symmetrical interactions between science and the public without necessarily seeking any direct influence on political decision-making.

Just as the field of science communication has gradually turned its gaze to the public, so have efforts to probe and question the potential for communication between stage and audience gained prominence in recent decades in the field of the performing arts and begun to guide reflections on the role of the spectator, opening the way for important changes in the dynamics of theatre productions and investigations in the field. Desgranges (2017) points out that in this process, the text has gradually lost its hegemony, giving way to the constituent elements of staging, visual and sound signals that challenge and stimulate the imagination, and the productive and critical attitude of the spectator in relation to the play.

For Rancière (2014), the spectator's experience cannot be controlled, since the show itself stands between them and the artist with an autonomy that defies ownership. It is in these terms that he envisages the figure of the emancipated spectator, who, despite being "just an observer", also has agency, translating what he/she sees in his/her own way and producing his/her own interpretations; essentially, co-creating the show from his/her own experiences – a task that calls for numerous complex operations.

This understanding of the spectator's position as an active participant in any performance lies at the heart of the kind of pedagogy of the spectator proposed by Desgranges (2015). As he explains, the spectators' active participation in the performance can be likened to the acts of artistic creation made by the playwright or director, as it involves articulating and interpreting a complex set of dramatic signals. To develop an understanding of the various narrative and scenic elements, they must be conversant with the language and codes of the theatre, which itself implies a kind of training, be it formal or informal, based on the practical experience of frequenting the theatre and taking advantage of what it has to offer. For Desgranges, this training is an essential part of encouraging individuals to take their place in the world – not just the theatre.

Taken together, these theoretical approaches suggest that research questions involving the relationship between science and theatre in the context of science communication and its audiences need to be rethought. The point is not to find out whether the audience of a given show took on board any new scientific concepts or knowledge contained in the play, but to probe the quality of their engagement with it: how they appropriated it, what knowledge and experiences their interaction with it brought to the fore, what new meanings emerged from this engagement. This approach resonates with the proposition of public engagement with science, since it prioritises a point of view that seeks to produce knowledge on the range of experiences audiences have of theatre activities in museums and science centres while also feeding these findings back into theoretical reflections and practices in the field of science communication, in a two-way interaction that shapes the relationship between science and society.

Museu da Vida Theatre and Curumim Quer Música!

Opened in 1999, Museu da Vida is part of the Oswaldo Cruz Foundation (Fiocruz), a research institution in the area of health based in Rio de Janeiro. The museum is devoted to the communication and popularisation of science and health and it is a place where the culture of science and society meet. Since its founding, it has held a prominent position among the country's science museums for bringing together different areas of knowledge and establishing fruitful dialogue with the arts. It is free of charge and receives around 60,000 visitors a year, consisting mainly of school groups and local residents, as well as people of all ages from the city and state of Rio de Janeiro.

Even before the museum was formally opened, theatre was already part of the Museu da Vida programme (Bevilaqua et al., 2017). Ciência em Cena (Science on Stage), created in 1997, is the hub of activities that combine science and theatre at the museum. Counting on a multidisciplinary team which has variously included physicists, biologists, social scientists, educators, artists, musicians, actors, theatre directors and professionals from a great diversity of disciplines and arts, it has developed a repertoire of 20 plays and sketches, which are staged at the Virgínia Schall Science Tent, a 120-seat space equipped for live productions, Epidauro, a small semi-circular theatre with seating for 60, several other spaces at Museu da Vida and in the Fiocruz campus, as well as other theatres, schools and external venues. The repertoire of Ciência em Cena includes plays that cover a wide range of science-related topics in different formats written by Brazilian and foreign playwrights, some of which are stage adaptations of works of fiction and others are original works based on objectives defined by Ciência em Cena itself in line with the mission of Museu da Vida (Lopes, Hamilton, & Guimarães, 2019).

Curumim Quer Música!, the play the children involved in this research saw, narrates the story of Ynhere, a boy from the Kayapo tribe, who wakes up one morning only to realise that the Amazon forest is silent, so he calls on the audience to join in his search for the lost sounds in an attempt

to restore balance to the aural environment. On the way, he meets three characters from Brazilian folklore: Curupira, Boitatá and Saci Pererê, who introduce the children to two musical instruments – cuicas and rattles – made from recycled materials and lead them on an exploration of the concept of sound and its different properties.

The play is set in the village of Kendjam on the upper Xingu river, a region threatened by the construction of the Belo Monte hydroelectric power plant and the protagonist's birthplace. However, the play is not designed to teach environmental concepts or convey information, but to suggest environmental issues through a storyline which revolves around the loss of diversity of the sounds in the forest and the characters' and audience's mission to restore balance to the sound environment. The final question of the show – Why are the sounds of the forest disappearing? – can be understood as an invitation to the audience members to think, research and formulate their own answers, rather than providing any ready-made explanation.

The team involved in the production of the show was multidisciplinary and included the Ciência em Cena interns and professionals from the social sciences, theatre, art, music and physics (Hamilton & Rodrigues, 2015). It was officially debuted in 2014 after being piloted for a year with children.

In a bid to avoid any stereotyping of childhood or a production that might see children as empty vessels to be filled with information, but rather to help transform them into active spectators who shared responsibility for creating the show (Machado, 2014; Juguero, 2014; Lehmann, 2011), the team who developed Curumim Quer Música! decided to ensure there was a constant flow of dialogue with the audience. Although the play has a script, it is not restricted to it, since the performance can only happen if there is interaction with the spectators. By involving the children in the performance, it transforms them into co-performers. Listening and improvising are the core elements of the show, forming the basis for the theatre game and calling for actors who are willing and able to react creatively to the unexpected situations generated by the audience (Ryngaert, 2009). The staging follows the principle of frontality (Lehmann, 2011), where words, gestures, actions and objects are directed to the audience.

In this direct contact with the spectators, there is no fourth wall or barrier between the stage and the audience, both of which are lit. The idea of having no fourth wall is that it enables the direct participation of the spectators, who are encouraged to notice their own and each other's presence, the physical space of the theatre and the stage and the distractions around them. The performance becomes a social experience (Lehmann, 2008). During Curumim Quer Música!, the Epidauro Theatre transmutes into different places depending on the narrative, transporting the spectators to the imaginary village of Kendjan. The audience turn into the Iriri river or the Kendjan mountain and the stage may be the home of either Ynhere or Saci Pererê.

There are four actors on stage the whole time. They narrate the story, introduce and describe the characters and say their lines, sharing the speech of each character among themselves. They wear the same costume throughout and no props are used to distinguish the characters (Figure 1). This means that all the characters (except Ynhere, represented by a foam puppet) and the different scenes must be imagined by both the actors and the spectators.

Figure 1: Actors in the meditation scene of the show Curumim Quer Música! at Epidauro Theatre, Ciência em Cena/MV/Fiocruz, Rio de Janeiro, 2017. Photo: Maria Buzanovsky.

Methodology

The objective of this chapter is to analyse the potential of theatre in the context of science communication based on data from a study with children who watched the show Curumim Quer Música!, part of the permanent programme of events at Museu da Vida, in Rio de Janeiro, and thereby contribute to our understanding of the different facets of the relationship between science and theatre in the context of science communication. More specifically, it investigates whether and how children joined in the theatre game, which elements of the play had the greatest impact on them, and what connections they drew between what they saw in the play and their prior knowledge and

experiences, constructing meanings and making interpretations in an act of co-creation. In addition, given the subject matter of the play, the aim was to understand how the children connected with the environmental issue it suggests and whether it encouraged them to reflect on this topic, drawing on their own repertoire of knowledge.

This qualitative study sought to understand these phenomena from the perspective of the children who took part in the research. Three data collection instruments were used: observation sheets (one per performance), drawings done by the children after watching the play and interviews with these children. The fieldwork was carried out with eight groups[41] (labelled G1 to G8) of 6- to 8-year-olds from municipal schools near Museu da Vida who watched Curumim Quer Música! in May and June 2019, summing a total of 182 individuals. The corpus of this study consists of drawings done by 19 of the children (ten girls and nine boys) and the interviews with them, as well as the eight observation sheets. The interviews lasted between three and eight minutes, totalling 110 minutes of recording.

The use of different data collection procedures – relatively common in qualitative research – has several advantages (Bauer & Gaskell, 2002), as it enables the phenomena under study to be comprehended from different perspectives. The observation sheet was used to record data on the children's collective engagement in the theatre game, as proposed in the performance, and how involved they became in the different interactive moments of the play. As for the drawings, this is a form of language that allows children to externalise what they are feeling or thinking and is a useful research tool as it provides information on how children translate their experience into pictures (Studart, 2000; Studart & Hamilton, 2022). The drawings were described and analysed without any consideration for aesthetic criteria, but to seek out patterns in the work produced by the children. Meanwhile, the interviews had the purpose of accessing the meaning that they attributed to their drawings and building up an understanding of the broader question of their relationship with the performance, including their evaluation of the show and how they chose to describe it, as well as the power of the theatre to encourage reflection on the part of the spectators.

Results

The children recognised and appreciated the fact that the play was open to participation, confirming the success of the opportunities for dialogue and interaction that were interwoven into the plot and recreated in different ways with the audience at each performance. Our observations, and especially the children's drawings and interviews, showed how they interpreted and translated their experience of the play, revealing the co-creativity activated by participating in a play and how the show stimulated reflections on their part.

41 The project was submitted to the research ethics committee of the National Research Ethics Committee (CONEP) and approved in May 2018 (project no. 88126218.3.0000.5241).

Joining in the game

The analysis of the observation sheets revealed that the children from all the groups took part actively in the interactive parts of the performance, answering the actors' questions and commenting on the action, paying close attention to the way the events were staged, expressing emotions, laughing, crying and cheering according to the narrative.

In addition to reacting creatively to the opportunities presented to them to interact along the performance, actively participating in the musical numbers and excitedly playing the instruments, the children showed interest in sharing their discoveries with the audience. They commented on the quality of the sound emanating from the instruments, developed a different way of playing the cuica, which was incorporated into the performance, and on several occasions expressed their preferences, citing their own musical tastes and sharing their own experiences.

Involvement in the theatre game was also borne out in the way the children spontaneously reacted to the play. They were transported to the fictional world it created, communicated directly with Ynhere, made up translations for what he said in Kayapo and identified which animals made the sounds reproduced in the theatre at the end of the play. But at the same time, they were attentive to details of the dynamics of the performance, such as when they expressed a desire to know how actors get around the stage without the spectators noticing.

The interviews with the children offered a deeper understanding of their experience, revealing that some were truly transported into the fictional world created by the show. The children qualified this experience, identifying the characters and their mission as the catalysts that immersed them in the play, as the following passages illustrate:

> Interviewer: Did you take part?
> Interviewee: Yes.
> Interviewer: And what did you feel when you were watching the play?
> Interviewee: Like inside, deep inside, I was also trying to find out, help them.
> (Interview 17, G8, 06/06/2019, afternoon - boy aged 8)

> Interviewee: The four [characters] worked together. It's a story with friendship, because one helps the other.
> Interviewer: Did you feel like you were taking part in the story?
> Interviewee: Yes, I felt myself inside the forest.
> (Interview 5, G2, 22/05/2019, afternoon - girl aged 7)

Another factor identified as helping keep the children's attention fixed on the action was curiosity as to how the events of the story would unfold. In the interview below, the child reports that he was transfixed by the play and that he appreciated taking part on the interactive activities:

> Interviewer: What do you feel when you're watching a story being told by other people?
> Interviewee: Like, I just look and I don't hear anything else, just so I can find out how it's going to end.
> Interviewer: And did you make the sounds? Did you take part a lot?
> Interviewee: Yes.
> Interviewer: Do you like taking part?
> Interviewee: Yes, I do.
> (Interview 2, G1, 22/05/2019, morning – boy aged 8)

Not only do the interviews reveal what the children felt during the play, sharing the characters' goal to restore equilibrium to the sounds of the forest, they also indicate that the play provided a chance for them to tune in with the other audience members, as the following passage shows:

> Interviewer: Do you think you took part?
> Interviewee: Mm-hm [Yes].
> Interviewer: How?
> Interviewee: I was inside the play on my own. I was there having fun with everyone else.
> Interviewer: And what did you feel when you were watching the play?
> Interviewee: I felt my heart was happy.
> (Interview 10, G4, 29/05/2019, afternoon - girl aged 7)

Co-creation

The analysis of the drawings revealed that the children resorted to their imagination and creativity to represent, mainly, the characters from the play, interpreting in their own way the elements from the performance. Most of the children who participated in the research put the characters in scenes and settings where the drama took place in the play. Of the 19 drawings collected, 11 depict specific scenes involving the forest, identified whenever a tree appears, Kendjan mountain or Iriri river. Just like the characters, these features do not appear in the play in the form of scenery, only in the descriptions given by the actors. Therefore, the pictorial representation of these elements came wholly from the imagination of the children, who expressed in the drawings their own conceptions of the characters, scenes and places where the story takes place. The central theme of the play – the silence of the forest – caught the children's attention and was expressed creatively and diversely in eight of the drawings.

In Figure 2 we see the four characters surrounded by apple trees on a sunny day with some clouds in the sky. The picture shows evidence of an attempt to include the characters' main features: Saci Pererê with one leg, Ynhere with body paint, Curupira with his feet turned backwards and Boitatá (the snake) with his big eyes. The picture represents the scene where the characters are trying to figure out how to bring the sounds back to the forest, particularly the scene where Saci Pererê is going to lend his hat to Ynhere.

Figure 2: drawing n.17 (G8) – boy aged 8.

The children embellished the drawings according to their own personal preferences and tastes, choosing the colour scheme and drawing objects not directly related to the play, like the apple trees, sun and clouds in Figure 2, which share the composition with the components from the show.
The children also depicted complex and abstract ideas. Figure 3 portrays the concept of sound addressed in the play, where curved blue lines are crossed out with a large X, representing "no sound", according to the child's explanation. It is from a different point in the play when the forest is silent. The other elements in the composition are a house, Ynhere himself, and an animal which is trying and failing to make a noise.

Figure 3: drawing n. 7 (G3) – girl aged 6.

A reflective gaze

The silence of the forest, which indirectly conveys the environmental issue addressed in the play, was identified in eight of the 19 drawings collected in the research. In Figure 4 we can see the sun, clouds, grass and an apple tree. The box from which Ynhere emerges, which is part of the scenery, becomes the "puppet's hut", inside which there is a yellow bed. This is the point in the play when the character wakes up and realises, as the child writes on her drawing, that "there is no more sound in the forest".

Figure 4: drawing n.19 (G8) – girl aged 8.

In order to understand whether/how the play encouraged the children to reflect on the environmental issue, the interviews included the question asked at the end of the play: Why are the sounds of the forest disappearing? Four of the interviewees said they did not know why the forest was silent, but the other 15 children provided interpretations of their own as in the passage below:

> Interviewer: Why are the sounds of the forest disappearing?
> Interviewee: Because lots of animals are running the risk of extinction. Some are already extinct.
> Interviewer: Why are they becoming extinct?
> Interviewee: They're destroying the forest.
> (Interview 19, G8, 06/06/2019, afternoon - girl aged 8)

Other children mentioned deforestation as the cause of the absence of sounds in the forest, as the passage below:

Interviewer: Why do you think the sounds of the forest are disappearing?
Interviewee: Because of deforestation.
Interviewer: Can you explain how?
Interviewee: The animals live in trees, birds, parrots. So, they're cutting down the trees and that kills the animals.
(Interview 7, G3, 29/05/2019, morning - girl aged 6)

The play also prompted reflections that caused some children to ask questions, as in the next passage:

Interviewer: Why do you think the sounds of the forest are disappearing?
Interviewee: I have a theory. What if man was capturing the animals? Then in the song they sang and other animals came to take care of the forest.
(Interview 2, G1, 22/05/2019, morning – boy aged 8)

Even though they talked about deforestation, the extinction of species and the destruction of the forest, when we asked what could be done to reduce the environmental impacts caused by human intervention in the forests, the children mentioned waste as their main concern. Living in a large city, they referred to the problems that are part of their daily lives, proposing to solve them by recycling, not using plastic bags or not dropping litter, as we can see in the passage below:

Interviewer: Is there anything we can do so that the animals don't die?
Interviewee: Yes.
Interviewer: What?
Interviewee: Help them.
Interviewer: How?
Interviewee: Not using plastic bags or anything made of plastic and not dropping litter.
(Interview 16, G7, 06/06/2019, morning – boy aged 7)

Discussion

The model of public engagement with science is based on the premise that science communication initiatives and reflections stem most effectively from the participation of society in debates and decisions related to science in spaces that allow for more symmetrical exchanges of knowledge (Brossard & Lewenstein, 2010). The theoretical and conceptual nature of the model poses a number of challenges for those who engage in and study science communication. In practical terms, questions arise about how to make public participation real and meaningful and what are the best conditions and procedures to encourage more balanced, two-way exchanges between the public and scientists and science communicators. In terms of research, the challenge is how to produce knowledge that

analyses and reveals the participatory nature of science communication initiatives and indicates ways to make them more effective.

Participation and co-creation are both addressed in studies that analyse concrete experiences of engaging the public actively with science communication, especially projects at museums and science centres (Davies et al, 2009; Martorell, 2017; Becker, 2017). Although theatre has been noted for its potential for fostering public participation and co-creation in science communication (Jackson & Kidd, 2007; Moreira, Coelho, & Souza, 2020), there are few studies aimed at revealing how this participation and co-creation is achieved in such productions (Weitkamp & Almeida, 2022). The present study sought to fill this gap.

When a play begins, so does the game between the stage and the spectators. This interplay underpins the whole theatrical event, moving back and forth between the actors and the audience and creatively stimulating both. This unique feature of the theatre transforms the spectator into a player willing to be involved in the event, an interlocutor who participates actively and creatively, responding to propositions from the play, interpreting the language of theatre and bringing their subjectivity and point of view into play (Guénoun, 2004; Desgranges, 2015). It was this dynamic of the theatre game that we were keen to capture in this research, analysing how the play stimulated the participation of the children in the proposed dialogue and what kind of experience they took away from it. The main findings are that the children did indeed join in the game in their own way, creating their own narratives from the one proposed in the performance, and reflecting on environmental issues from their own context and lived experiences through a multifaceted experience which included both cognitive and affective dimensions. We believe that all these aspects were fundamental for the positive reception of the play and the successful engagement of the target audience in this science communication activity.

As we have seen, involvement in the theatre game was expressed in different ways, going beyond the children's physical and verbal participation during the performance and in the interactive parts of the show, which corroborates Desgranges' (2015) and Rancière's (2014) conceptions of the role of the spectator as an active participant who observes, compares, interprets and creates. The drawings and interviews enabled some subtleties regarding this involvement in the game to come to light. The children approached their participation in different ways. Some said they felt transported into the forest, while others reported having taken part by helping the characters restore the balance of sounds in the environment or concentrating fully on the events in the play.

The interviews also revealed that the play offered a moment of harmony between the spectators. The children said that although they were watching the show "alone", they had fun "with everyone". This finding differs from Peleg & Baram-Tsabari (2017), who found that their child-spectators did not identify with a feeling of collectiveness when watching the play in their study. In line with the findings of

Jackson & Kidd (2007), the children in our study demonstrated strong empathy with the main character, who was portrayed in most of the drawings and mentioned in all the interviews, which certainly helped them engage in the game and enjoy the play in a way that resonated both affectively and cognitively.

As for the children's role as co-creators of the show, we saw that this was also manifested in different ways. But what drew the most attention in this regard was the fact that they did not represent exactly what was depicted on stage in their drawings, but what they imagined, producing their own, sometimes unexpected aesthetic conceptions from the stimuli the play offered. As pointed out by Desgranges (2005), this is in line with the idea that children interpret the complex set of signs from a plot to develop their own understanding of its various elements, creating new narratives. Another result which simultaneously confirms their involvement in the game and the co-creative nature of the act of watching a play is the fact that children referred to the main character, represented by a puppet, as a "boy" or an "Indian" or else drew him as a child, themselves producing the "magic" theatre is capable of conjuring by transforming it into something they imagined. Although it is made clear to the spectators that Ynhere is a puppet handled by two actors, with the mechanics of this procedure in full view, the potential of theatre to imaginatively stimulate the spectators, making them co-creators of the show, was materialised in the moment they treated the main character as a Kayapo child.

According to Guénoun (2003), the theatre puts words – which belong to the world of sound and are therefore invisible – "into view". We understand that in theatre, words are made visible not only when they are expressed in objects, costumes, props, scenery or even the actors' body movements, but mainly because when a word is enunciated in this context, it has the power to create images and make something that is not physically represented on stage visible. The contrast between the photograph of the play (see Figure 1) and the children's drawings confirms this effect that the words had on them, conjuring forests, suns, clouds, mountains, rivers, characters and scenes imagined from the story.

Another important finding was that the aesthetic decision not to physically represent characters from Brazilian folklore opened space for the spectators to fill the gaps in their own minds, recreating their own story. This decision was instrumental in making the children imagine and create their own characters using a variety of shapes and colours in their drawings, in which they appeared in scenes and settings where the drama of the play unfolded. In this sense, our results differ from those of Moreira, Coelho, & Souza (2020). Although in both cases the characters were the elements that were most represented in the children's drawings, these authors indicate that the public's attention, in the show they analysed was attracted to the characters with the brightest costumes and the most striking body movements. In contrast, our research found that the four characters in the play, including the ones who were not physically represented by the actors, attracted the children's attention and were represented in many of the drawings. This finding also contradicts the conclusions of studies which claim that the difficulty of imagining physically absent characters in a play has to do with the fact that children find it easier

to assimilate visually explicit dialogues and images (Peleg & Baram-tsabari, 2017; Moreira, Coelho, & Souza, 2020). The discrepancy between these results may indicate that the authors did not consider the distance between a play's intention – which in the cited studies was to convey scientific information – and the multiple potential interpretations that open up in the unique mind of each spectator.

The expression of complex and abstract concepts in the children's drawing in our study, such as the concept of sound, raises yet another issue vis-a-vis the work of Moreira, Coelho, & Souza (2020), who concluded that in their study participants had trouble assimilating the implicit messages of the show. Our results demonstrate that children can transform concepts that are hard to materialise graphically into images. Indeed, they found original ways to relate to the elements in the show which conveyed the sound properties, such as when they made up an original way of playing the cuica by moving the drum itself rather than the string. Not only were the musical instruments identified as pivotal for one of the participatory moments, but they also prompted several spontaneous comments by the children during the show, which were the result of the exploration of the various potentials of sound.

The quest for a science communication capable of putting the audience centre stage converges with calls for a pedagogy that offers tools for reflection. Stilgoe, Lock, & Wilsdon (2014) indicate that public engagement must be attracted to inconvenient, emerging or marginal issues to have any political impact. It is fair to say that the environment is currently one of the greatest challenges facing humanity and that in many ways it is anything but convenient. In Brazil, the question is even more serious. While denialism is the stance taken by the current government towards environmental issues and their consequences, such as climate change, and environmental protection policies are being deliberately dismantled, regions of the country such as the Amazon and the Pantanal are witnessing rising levels of deforestation. By approaching the environmental issue tangentially in the play, the aim was to engage the children in a way that encouraged them to reflect on the topic; that is, the idea was to associate the aesthetic dialogue that sprang up in the theatre setting with reflections on current topics.

From the research point of view, the task consisted in understanding whether the play Curumim Quer Música! was able to get the spectators to reflect on the environmental issue by drawing on their own accumulated body of knowledge, since the environment is only addressed indirectly in the play. The problem of the silence of the forest is raised, but no information is provided as to what its causes are, allowing the audience members to elaborate their own interpretations and reflections.

The results obtained indicate that the children activated prior knowledge to reflect on the environmental issue, which corroborates the proposition that the way theatre can interact with its audiences can contribute significantly to science communication when its primary goal is to engage and encourage reflection. In this sense, we clearly identified a cognitive response to the play; however, this response was not related to the learning of a specific item of scientific knowledge or concept –

which several studies in the field seek to measure – but to the association of elements from the play to the spectators' own previous knowledge and experiences, enabling them to imaginatively interpret the theatre experience.

The fact that the play was open in terms of aesthetic solutions was pivotal in bringing forth the diversity of representations that emerged in the children's drawings and interviews. Therefore, we suggest that creating plays whose content is open to interpretation and which excite the imagination and pose questions, rather than proffering ready-made messages and attempting to impart specific information, and which open windows of reflection that encourage the audience to create their own interpretations, is another significant contribution the theatre can make to science communication.

Concluding remarks

This research presented the concrete experience of a play for children that incorporated the public in every stage of the process, from its design to its staging, demonstrating that theatre is a powerful tool for fostering public engagement in museums and science centres. It also showed that theatre can promote a more dialogic and symmetrical relationship with audiences and help the production of knowledge, revealing more participatory routes for science communication.

Reflections from the field of drama that analyse the role of the spectator propose alternative ways to explore and interpret the potential of theatre for public engagement with the world of science other than simply the transmission of information or the presentation of scientific topics. Supported by theories from the field of theatre and performance studies, we looked at the procedural dimension of the theatre, the encounter that takes place when a play is performed (Lehmann, 2011), paying attention to the entirety of the event, in which the relative weight of the text, the content of the work (Desgranges, 2015), is redistributed to enable more room for the game itself, dialogue between the actors and spectators, and all the resources that make up the staging. In these terms, theatre becomes a participatory aesthetic experience because it is a game that requires the spectators to interact with all the stimuli provided in the performance in a process that is at the same time interpretive, creative and reflective.

It was from these conceptions that we focused on the set of information that the children offered us during the research, which reveals the richness and diversity of their theatre experiences. We were also able to confirm that the participatory, co-creative and reflective dimensions of drama are central to what theatre has to offer to science communication, without losing its potential, without submitting exclusively to the content. Therefore, by proposing a place of equality for theatre in the context of science communication, we are also advocating, in both research and practice, a conception of science communication that is geared towards reflection and the formulation and

implementation of an inclusive, participatory, more audience-oriented practice. We believe that the performing arts in the context of science communication should be understood for their power to engage, bringing about true participation with science.

This study also joins forces with others conducted by Museu da Vida in that it produces knowledge geared towards understanding the different facets of the relationship between science and theatre in the context of science communication (Almeida et al, 2018; Almeida, 2019). It also indicates potential science communication activities where dialogue and participation can guide the creation of a more balanced, symmetrical relationship with the public in a way that respects their diversity and autonomy**.**

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DEVELOPING DRAMA UNDER THE DOME

SADIE BOWMAN

(Matheatre)

Imagine dynamic images from the far reaches of the solar system washing over you in 360 degrees. Meanwhile, live performers sing engaging, pop-inspired music that lyrically illustrates concepts from astronomy and planetary science. Fully realized characters dramatize the true story of an ambitious human mission, and speculate on the future of its legacy, as you are swept away by planetary flybys and transported into an immersive set that re-creates the room where it happened for a team of NASA scientists in the 1970s and 80s. The story unfolds to a disco-inspired soundtrack that fills your head with catchy music that lingers in your mind long after the show is over, along with far-reaching thoughts and questions about the cosmic perspective. This is the experience sought to be achieved by Matheatre and Fiske Planetarium in the collaborative project, Voyagers.

Matheatre's stated mission is to use live theatre to tell stories that inspire excitement about math and science. It is Matheatre's belief that stories are a powerful way to connect learners with complex or abstract concepts, and that the experience of live theatre fosters creative thinking, listening skills and empathy, making it an ideal medium by which to teach, or encourage intellectual engagement with, science concepts. The majority of Matheatre's audience are students and laypeople, and Matheatre's artists approach science with an intent to capture essential truths and communicate them in engaging and memorable ways, most often through avatars based on figures from science history. Thus the company's work is offering educational content in two camps: not just STEM, but also history, and with it the manifold nuances of human and social systems and psychology that shape the characters and the worlds they inhabit. By embedding science concepts into emotionally compelling human stories, the viewer is able to engage on numerous levels, and science concepts that may seem dry or challenging in a more traditional academic context are rendered inviting and engaging through the use of story, character, and metaphor. Besides carefully researching the historical context and doing the playwright's and actor's work of creating fully rounded characters with psychology and depth, it is Matheatre's standard practice to include at least one expert in the relevant scientific field as a consultant on every project (for instance, a professor of Physical Chemistry to consult and ensure accuracy in the content of a chemistry-themed stage musical). Matheatre is firmly committed to communicating science with the simplicity that is necessary for an engaging story, but does not compromise on scientific accuracy or educational integrity.

This specific project was born when Matheatre's artists met Dr. John Keller, the director of Fiske Planetarium, at the annual meeting of the Association of Science and Technology Centers in 2018. Dr. Keller expressed interest in bringing more live theatrical events into Fiske Planetarium, a 206-seat dome situated on the campus of the University of Colorado, Boulder. The synergy between the two organizations was immediate, and soon Matheatre's artists were meeting with the team at Fiske responsible for creating animations and visual assets for dome projections. Throughout the creation process, it was an immense benefit to have access to the knowledge and expertise of a team of creative individuals for whom astronomy, planetary science and space exploration are a specialty.

Not only did the animators and Dr. Keller volley many of Matheatre's scientific questions, they raised ideas and suggestions about what could be possible in the dome environment that was beyond the prior experience of artists who were accustomed to more traditional performance venues. A typical creative exchange would be Matheatre pitching a loose storyboard idea for the visuals of a given scene. The planetarium team would then come back with ideas that were even more ambitious. The nature of a planetarium dome is very different than the possibilities of a traditional stage set. For example, at the stroke of a button, a planetarium operator can re-create the vista of a night sky with explicit fidelity. Not just a general panorama of a night sky, but the night sky precisely as it looked from a specific vantage point on Earth on a specific date, with all the stars and planets in alignment as the character would have experienced them at that particular time. When creating a flyby of a planet's surface, the planetarium animator can not only recreate an interpretation of what the planet looks like, but can also replicate the specific trajectory of the spacecraft's approach. By incorporating these original animations as well as actual NASA images taken by Voyager itself, the "set" of Voyagers creates an environment of heightened fantasy grounded in very clear and specific historical precedent. This project was in that regard a refreshing collaboration for artists in two very different media to play off of each other.

An additional source of guidance on this project was the living memory of NASA scientists who had worked on the Voyager mission. After reading a book about the history of Voyager and reaching out to its author, planetary scientist and space historian Dr. Jim Bell, the author put Matheatre in touch with numerous individuals who were instrumental players on the Voyager team. These individuals were remarkably generous with their time and stories, and the script and characters were built around many of their specific anecdotes and insights into the culture of the team during that time. From a narrative and storytelling standpoint, it was a challenging script to write in Matheatre's typical style, because Voyager was very much a team effort, with hundreds or even thousands of individuals playing crucial roles in the mission's development and success. Matheatre's other productions are told from the point of view of a specific protagonist (for instance, Marie Curie or Nikola Tesla), so their storytelling style had to stretch and adapt to meet this challenge. The playwrights went through many more drafts than usual to find the right angle by which to tell a story that is about a team rather than an individual. The finished product features six characters, portrayed by two actors: four characters are amalgamations of individuals who represent just a few of the teams on the mission. Rather than having names, these characters are identified by their job title or role on the mission. One pair of characters is a Planetary Scientist and an Instrument Representative, and their personal journeys and relationship over the course of the 12 years of the primary mission unfolds in one arc of the Voyagers script. Another pair of characters is a Fault Engineer and Project Director, who also develop their own character arcs during the 12 year course of the play's events. The playwrights avoided giving these four human characters names because every real-life team member they talked to emphasised pride in their work as part of a team, not in their individual contributions. This composite character device

also allowed the playwrights to compress many real-life stories and anecdotes into meaningful scenes and dialogue that informed characters who were inspired by real people but not representing any specific individual. The final two characters, portrayed by the same actors via some simple yet clever costume changes, are Voyager 1 and Voyager 2–the spacecraft themselves. While it is a running joke through the script (and the favorite joke of nearly every single NASA scientist the playwrights interviewed) that one should "not anthropomorphise the spacecraft," these fantasy characters, inspired by 20th century science fiction, provide an avenue to explore another key element of the Voyager story: The Golden Record. The Golden Record is an artifact created by a team of scientists and artists and attached to both spacecraft on the fantastically improbable chance that a future alien civilization should ever find one of the Voyager craft after it has left our solar system. The Golden Record is encoded with images of life forms and various technologies, sounds and music from Earth, with instructions to play it based on clues like the size of a hydrogen atom and its rate of decay, presuming that the one universal language that exists is science. The Golden Record and the Voyager spacecraft will, eventually, very likely be the last trace of our planet, long after Earth is incinerated by the sun. With its story and the story set in NASA's Jet Propulsion Lab, there are two parallel stories that intersect in the script: one on the scope of human time, and another on the scope of cosmic time. While we see the journeys, personal development, and discoveries made by the team of scientists on Earth between 1977-1989, their story is interspliced with the fate of the craft they have created, as Voyager 1 and Voyager 2 introduce the audience to The Golden Record, decode its contents and the marvelously improbable nature of the human race, and attempt to make sense of its existence to an alien civilization in the far distant future.

As the characters of Voyager 1 and Voyager 2, with the benefit of billions of years of hindsight, work through the heartbreaking confusion of humanity's purpose, they finally achieve a sense of understanding when they come to the part of The Golden Record that preserves one of humanity's most natural but distinctive achievements: music. The music on The Golden Record is what finally lets them understand the sense of hope that motivated humans to reach out into the cosmos. Music also plays an integral role in the production of Voyagers and the experience of its four human characters. From the overture through the mission's liftoff to every planetary flyby and the mission's major discoveries, the human characters experience these big moments through music. There is a song for each planet and some of the moons, which allows the audience to experience some of each celestial body's features in a kinetic and enjoyable way, and music is used to explain astrophysical concepts like orbital resonance. Matheatre's songwriter and sound engineers worked to emulate the historical aesthetic of the 1977-1989 time period with original songs inspired by pop and disco sounds of the '70s and '80s. The backing tracks are pre-produced and the actors sing live in each performance.

Every aspect of the production, from the live performing cast to the props to the videos that comprise the immersive dome images, is built to tour. There is some further technological collaboration

necessary on the part of each planetarium the show visits, as different domes use different projection systems with different sizes and projector configuration, and there is much variation in the seating and interior layout of different planetaria which will necessitate adjustments to the technology and the blocking each time, but the purpose of the collaboration was to create a work that can travel the world. The production's premiere was delayed due to the Covid-19 pandemic, but finally opened at Fiske Planetarium in Boulder, Colorado, USA on October 22, 2021. It ran for three matinees for schoolchildren and six public performances, and the entire Boulder community was invited. With a mix of college students, families, arts patrons and the scientific community, the reception was enthusiastic. Some performances included a post-performance panel discussion with various Boulder community members who had played some part in the Voyager mission, so the audience had an opportunity to hear their first-hand perspective on the events depicted and gain a deeper appreciation for their work. All the creators were surprised by the number of individuals who introduced themselves and identified some connection they had to the mission–which underscores the point that the story has no one protagonist, but a true cast of thousands. One professor emerita of planetary science, who worked on Voyager as a graduate student in the 1980s, was moved to tears during the panel discussion as she relived some of the events that the production depicts as history, but for her are precious memories. Feedback from the audience had a recurring theme. Most people who spoke to the creators expressed surprise at how much they learned–about science, about history, about the US space program, and about the solar system, and how much fun they had absorbing the information. At a run time of one hour and twenty minutes, with fourteen musical numbers and continuous presence of dynamic dome visuals, it's confirmed that Voyagers achieved Matheatre's mission to use live theatre to tell stories that inspire excitement about math and science. The creators look forward to many more opportunities to share this ambitious and inspiring story, particularly as we head toward the 50th anniversary of Voyager's launch coming up in 2027.

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THEATRE AND SCIENCE FICTION AS A LABORATORY OF FUTURE VISIONS FOR SCIENCE: THE CASE STUDY OF "2069 – OLTRE LA LUNA"

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"The Earth is the only world known so far to harbor life.
There is nowhere else, at least in the near future,
to which our species could migrate.
Visit, yes. Settle, not yet. Like it or not, for the moment the Earth
is where we make our stand."

Carl Sagan, Pale Blue Dot, 1994

INTRODUCTION

In modern societies, the role of science communication in framing expectations and future visions for science and technology is increasingly important. Neither science nor its communication happen in a vacuum: on the contrary, science communication is intimately related to the values and organisation of the society we think we live in, or the ones we wish to build (Davies, 2021). Outer space, as the ultimate frontier of humanity, provides a unique framework to investigate the relationship between science, exploration, their public communication and the various languages through which this discourse is articulated and performed (Drigani, 2020). One such language is theatre, which shares a long history with science (Shepherd-Barr, 2006), stimulating imagination and inspiring possible visions of future worlds.

Science fiction, one of the most popular and influential genres of literature – one that is greatly various, in continuous evolution and notoriously difficult to define – is itself an exercise of collective future imagination, whether a far distant future or not long ahead from the time of publication (Stockwell, 2000). Science fiction is ripe with questions on culture, technology, society, their mutual relationships and how they shape each other. As such, it offers a forum to engage with citizens and discuss science in the public arena, especially on topics pertaining to space science and exploration (Brake & Thornton, 2003).

In 2019, on the occasion of the 50th anniversary of the first Moon Landing, the Italian National Institute for Astrophysics (INAF) co-produced "2069 – Oltre la Luna", a theatre piece inspired by science and science fiction. This paper presents an investigation of theatre, science fiction and their power as a laboratory of future visions for science, using this production as a case study.

THE THEATRE PIECE

"2069 – Oltre la Luna[42]" is a co-production between INAF[43] – the major public research institution in Italy dedicated to investigating the Universe, with a strong record of public engagement activities at local and national level that also include a portfolio of theatrical performances[44] – and Teatro Boxer[45], a theatre company based in Padua. The production was part of "Destinazione Lune[46]", a series of public outreach events organised in the city of Padua to celebrate the 50th anniversary of the first Moon Landing. The piece, written by Rossella Spiga (astronomer and science communicator) and Andrea Pennacchi (actor, author and playwright), premiered in Padua in July 2019, followed by a second performance in Verona a few months later (Figure 1). Unfortunately, due to the onset of the COVID-19 pandemic, no further performances have taken place by the time of writing.

Figure 1: Poster of the piece "2069 – Oltre la Luna". Credits: Teatro Boxer.

42 Trailer: https://www.youtube.com/watch?v=kxZ2akmibTc
43 http://www.inaf.it/en
44 https://edu.inaf.it/inaf-teatro/
45 https://www.teatroboxer.com/
46 https://www.destinazionelune.oapd.inaf.it/

The plot revolves around a hypothetical future space mission designed to capture an asteroid, set to launch in 2069, in an imagination exercise that speculates 50 years into the future while celebrating 50 years since the Moon Landing. In this futuristic scenario, concepts that are just making their way into our imagination today, such as a permanent lunar outpost or space tourism, are part of everyday life. This choice was meant to trigger questions around space journeys and human exploration of the Solar System: What does it mean to "conquer" new worlds? What will be the new "frontier" for humankind?

The piece was written as part of an iterative, collective creative process between the two authors over a period of about five months, with a first raw script drafted by R. Spiga and further developed by A. Pennacchi. INAF set no constraints on the content and form, leaving the authors complete artistic freedom to engage with the audience rather than promoting an institutional message**.**

SCIENCE FICTION AND SCIENCE FACT

Among the scientific and technological projects that inspired the writing was the Double Asteroid Redirection Test (DART) mission, launched by NASA in 2021 to demonstrate the feasibility of asteroid deflection in the context of planetary defense, an experiment successfully performed in September 2022 (Cheng et al. 2016, 2018). Such an ambitious mission, intentionally crashing a spacecraft into an asteroid to verify whether it is an effective way to modify its trajectory, would have been the stuff of science fiction only twenty years ago, but has now entered the realm of science fact. A similar approach was recently employed by the European Space Agency in the production of the short science fiction film "Ambition", inspired by the comet-chasing Rosetta mission (McCaughrean, 2016).

Performed by two actors accompanied by acoustic live music, "2069 – Oltre la Luna" includes a series of key readings from the history of space exploration (Figure 2). It begins with the contingency speech for the Moon Landing, prepared in 1969 to be read by US President Nixon in case of failure. A speech that, of course, was never pronounced, but which reiterates the epic character of space exploration: imagined and narrated even before the actual endeavours took place.

It also features a selection of masterpieces from classical science fiction literature, including Isaac Asimov but also Soviet authors such as Stanislav Lem, who pictured space exploration not only as a thrilling, heroic adventure but also as an ensemble of routine activities carried out by ordinary women and men. Closing the piece are the poignant words of Carl Sagan, astronomer and visionary science communicator, who wrote the Pale Blue Dot, a poetic reflection upon a portrait of Earth taken by a spacecraft six billion kilometers away. Juxtaposed to the grandeur of the space tales, a very essential scenography with iconic imagery of Earth and the Moon was projected in the background.

Figure 2: Pierpaolo Spollon (left) and Andrea Pennacchi (right). Credits: INAF/Teatro Boxer.

INTERVIEWS

In 2021, as a first exploratory study of the themes touched upon by the piece, we conducted short interviews with three relevant stakeholders involved in this project. We asked Andrea Pennacchi (AP), who co-wrote and co-starred in the piece, about the co-creation process and the exchange of knowledge in this collaboration. Next, we talked to Caterina Boccato (CB), Head of public outreach and education at INAF, and to Roberto Ragazzoni (RR), astronomer and research manager, Director of INAF in Padua who approved funding for the production at the time, about the role of theatre and science fiction in the imagination of scientific and technological futures, both within the research community and when engaging with the public at large. Relevant extracts from the interviews are reported below.

Q: How did the co-creation process work?
AP: It was based on a mutual sharing of knowledge. There were a few things I was unsure about, whether they could work scientifically. I wanted to tell a story, then Rossella would tell me what could work or not, updating me on scientific endeavours that could be useful for the project.

Q: What are the advantages and limitations of such a project, in your opinion?
AP: The laws of the narrative universe are different from the laws of science. This is the gift of storytelling: to stimulate imagination in different scenarios from those you are used to from science. A theatrical text is perfectly fitting, considering the emotional impact of space exploration. After all, if you think about Elon Musk, he just did a project like ours but with a whole lot more money. Imagination has no limits. Then, taking it to the theatre has other constraints. For example, I wrote a piece about Galileo, trying to make theatre but without anything that could be a historical or scientific fake. On the contrary: I tried to clarify how you get to a discovery from the point of view of a human being.

Q: Why did you choose a narrative, epic approach for this piece?
AP: My material is the narrative approach. Even when I work on more traditional dramaturgy, I always start from the narrative. It's easier to decompose the different voices. We call it a first experiment of science-fiction theatre, but not much happens on the scene. In this case, logistics also played a role, as we did not have a lot of time to write and rehearse.

Q: Why the choice to invest in theatre for science communication?
CB: Because it allows you to reach a type of public that would otherwise not respond to purely scientific events. Science cafés, public conferences... These are all very valid formats but they attract people who are already interested in scientific content, while the theatre attracts people who are interested in the performative arts. The public appeal can also come from the performer (someone like Andrea Pennacchi, who has his followers whatever he brings on stage!) so in this case there is even a greater power of appeal.

RR: Why not...??? Any language functional to the dissemination of science is legitimate. What distinguishes theatre, with its visual and narrative ductility, from other models is the possibility of striking chords or grasping aspects otherwise difficult to reach or even precluded. Science is ultimately made up of people, men and women who work to push the boundaries of the unknown, and stories that can somehow be connected or stimulating, that can bear unexpected fruit. The theatre allows, at a modest price compared to that of other arts (e.g. cinema) to experiment with new approaches and solutions. It is, by way of use, an experimental field of audiovisual production for the dissemination of science.

Q: Why investing specifically on a science fiction theme?
CB: Science fiction allows for scientific storytelling, especially in the field of astrophysics and is therefore a natural terrain for us astronomers. However, science fiction can also always be used as a metaphor for the present and is therefore powerful in giving voice to socio-political aspects that everyone experiences in their daily lives.
Besides, there are few cases of science-fiction theatrical stories because science fiction is often associated with great cinematic special effects but the innovation lies right here, in proposing content

of this type in a traditional format such as the theatre. Today, different techniques and technologies can be combined on the stage (even holograms!) and this can be a very interesting field of future experimentation!

RR: I cannot but mention Marco Savini [graphics design and new technology innovator; eds] noting that science fiction has always inspired dreamers who then realised the technological dreams they longed for. From Jules Verne to Arthur Clarke via Isaac Asimov. The important thing is either to imagine the future or to build it, and to avoid wasting time in between.

Q: How do you think that theatre and/or science fiction can contribute to the imagination of future visions in the dissemination of science?
CB: Theatre is also a representation of everything that can be imagined, so why not using science fiction? Ancient Greek tragedies are represented at the theatre and therefore it is perhaps even easier than at the cinema (where special effects are still expected, whereas they are not in theatre) to represent the humanity of the future, leaving the public the great and beautiful opportunity to imagine the context, the environment... A bit like when you read a book and you get to the end, where much more is left to our ability to construct mental representations of people and places.

Q: How do you think that theatre and/or science fiction can contribute to the imagination of future visions in scientific and technological research?
RR: The mechanics of science fiction either extrapolate from existing technology and imagine pushing it beyond current limits, or they hypothesise the existence of a certain technological capacity and go as far as wondering about the consequences. My very personal opinion is that many of these tales have turned out to be less fanciful than reality has proved to be.
Science fiction theatre can be a driver of development, if not directly, at least indirectly, for scientific and technological research. To show the public that the current description of our scientific knowledge or our technological capabilities does not develop in the directions that we usually imagine in our laboratories. This education to dare, to conceive as possible the introduction of new paradigms, sees, in my opinion, science fiction as its formidable advocate. It will be up to us, on the other side of the stage and with the responsibility of the best observatories and laboratories, to ensure that this is done with the humility of those who already know what exists, but are ready to dare and accept the most unusual.

CONCLUSIONS

The production and co-creation of the science fiction theatre piece "2069 – Oltre la Luna", performed twice in Italy in 2019, is an example that it is possible to build a collaboration, a bridge between the theatre world and a scientific institution, and that science fiction works well as a mediator in this process.

Two years after these performances, we have conducted preliminary interviews with three relevant stakeholders involved at various degrees in the project. Among the themes that emerged from these interviews, we noticed a common understanding that the act of performing can trigger curiosity towards the imagined future that is represented on stage, facilitating speculations about the future of humanity as driven by science and technology and ultimately questioning our role in these futures. As indicated by the interviewees, this approach has the potential to empower all parties – starting from a collaborative dialogue among scientists, actors and science communicators and by opening a conversation that eventually engages also the spectators – in the co-creation of the society we want to live in.

To further investigate the power of theatre and science fiction to imagine scientific futures, we plan to extend the study involving also the spectators, conducting in-depth evaluation and audience surveys during future performances of this piece.

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AN ARTSCIENCE DISCOURSE. AUGMENTED LECTURES TO OUTREACH, INSPIRE, TEACH AND UNDERSTAND SCIENCE

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The difficulties of Theatre About Science

Finding good "theatre about science" is hard. This statement may seem a bit tranchant, so let's delve into it. First of all let's define what we mean by "theatre about science" which, to simplify, we will call from now on *sciencetheatre*. One possible definition is that a sciencetheatre play is a stage event, with some scientific content, that generates emotions while at the same time providing a certain level of science literacy.

This definition sounds reasonable, but what is science literacy?[47] Is it the capacity to understand science, or is it also the ability to make use of scientific findings, interpreting one's life through them. This question is rather important because the way science is traditionally taught in schools is mostly geared towards providing the basic knowledge of it, and not how science impacts in our existence, our lives. In other words, what is often missing in formal education is the personal, human connection to science. As a matter of fact it is my personal opinion that science literacy should be interpreted as the ability to navigate through the most basic ideas of science, making good use of them, while being able to judge what is scientifically sound and believable while at the same time identifying what is not. In other words, to develop the skills of awareness, ownership and critical thinking about science. This set of abilities is often defined as critical science literacy[48]. Finding good "theatre about science" is hard because very little of it satisfies the two requirements: to entertain with powerful emotions while at the same time providing the skills to improve critical science literacy.

Regular lectures, the deficit model and all that

It is granted that a good sciencetheatre production can have the sole honourable aim to entertain the audience. But if we agree that one of the objectives is also to raise the level of critical science literacy, then one could question the efficacy of mainstream sciencetheatre. One could then opt for the time tested way of delivering a regular albeit well crafted expert frontal lesson, maybe with a performative twist. This is the typical method of imparting information from a knowledgeable source to a less knowledgeable general audience. It is a very straightforward method that is easy to produce and reproduce and can achieve good results in terms of content delivery. This lecture format falls into what is often called the Deficit Model, also known as the Diffusionist Vision.[49] The main drawback of this method is that a regular lecture may not be able to consistently provide the level of emotional involvement that is

47 For a substantial discussion on Scientific Literacy and its different interpretations, consult the PISA 2003 Assessment Framework - Mathematics, Reading, Science and Problem Solving Knowledge and Skills (Copyright OECD 2003).

48 Medvecky, F. Public Understanding of Ignorance as Critical Science Literacy. Sustainability 2022, 14, 5920. https://doi.org/10.3390/su14105920

49 The literature on the pros and cons of the Deficit Model (DM) is quite rich. For an interesting review on the issue, including why the DM is often the top choice in science communication, see Molly J. Simis, Haley Madden, Michael A. Cacciatore and Sara K. Yeo. (2016), 'The lure of rationality: Why does the deficit model persist in science communication?' Public Understanding of Science, Vol. 25(4) 400 – 414. DOI: 10.1177/0963662516629749.

needed in order to really create a connection with audience: Too often the lecture appears as a formal, authoritarian, paternalistic and top down event that can put off part of the audience. Most importantly, it often fails to create a real empathetic relationship with the public and those that really connect with this format tend to have a pre-emptive interest in the contents. In other words, the regular lecture format based on the diffusionist vision often fails to excite and generate audience development.

Storytelling in the communication of science
- connecting with the audience

In the previous section we argued that some sciencetheatre does not improve critical science literacy because it is too edulcorated on the science, while a regular "deficit model" lecture, albeit spectacularized, may fail short of generating emotions and therefore a real connection with an audience that is not already convinced.

One way to overcome this double limitation in a consistent way is to develop a sort of storytelling approach where the rigorous scientific content is delivered in a narrative, more engaging, if less direct, way. This is the way of storytelling that theatre audiences know very well, but that has been used somewhat sparingly in the field of formal, informal and non formal education. Yet, storytelling has been shown to be a very efficient way to engage with the audience, to create emotional and empathetic links[50,51,52]. In other words, to create connections that are based on shared experiences and that, from those, move to a level of understanding that is also factual and cognitive.

When I talk about "science storytelling" I mean the construction of narratives that include science as a necessity, a content that cannot be overlooked or else the story itself is not credible or even understandable. Because of this, the science needs to be explained in the story. This is a hybrid connection between regular theatre and a deficit model lesson. The storyteller needs to master the scientific content but also possess an understanding of the human dimension. The audience needs to feel that what they are witnessing is a journey of understanding and not a lesson, even if the declared intent is to provide critical science literacy.

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50 Dahlstrom, M. F. (2014). 'Using narratives and storytelling to communicate science with nonexpert audiences'. Proceedings of the National Academy of Sciences 111(Supplement 4), pp. 13614–13620. https://doi.org/10.1073/pnas.1320645111

[7] The organization I work for and which I direct is Arditodesìo, an Italian theatre company based in Trento, devoted to creating theatre about science through its Jet Propulsion Theatre Project (www.jetpropulsiontheatre.org).

[8] Teatro della Meraviglia is a joint effort of the Arditodesìo Company, the University of Trento and the Opera Universitaria. More information can be found at www.teatrodellameraviglia.it

51 An entire issue of JCOM was devoted to storytelling in science. See as a reference: Marina Joubert, Lloyd Davis and Jenni Metcalfe (2019) Storytelling: the soul of science communication. Journal of Science Communication 18(05). https://doi.org/10.22323/2.18050501

52 Susana Martinez-Conde et al. (2019). 'The Storytelling Brain: How Neuroscience Stories Help Bridge the Gap between Research and Society'. The Journal of Neuroscience, October 16, 39(42):8285–8290. https://doi.org/10.1523/JNEUROSCI.1180-19.2019

Choosing the conveyor

In our research we investigate how these special hybrid lectures should be structured. How are they built? And who should deliver them? In other words, since we are stepping into a hybrid territory where science meets storytelling and the performing arts, who should take charge of conveying it? A scientist or a performing artist? This question is quite relevant since the scientist is usually quite proficient at delivering the content but at the same time the artist possesses the skills to generate emotional responses in the audience. In this case the form is just as important as the content, otherwise the content may fail to provide emotions! This conundrum ceases to become a problem when we realize that there are no limitations on who should be on stage: both the artist and the scientist should be entitled to do it, together. That is what I propose here and their creation is what my colleagues and I call an "Augmented Lecture" (AL).[53]

This research goes back several years, the first ALs were created for the Teatro della Meraviglia (Theatre of Wonder) festival, held in Trento (Italy) starting in 2017[54].

What is an Augmented Lecture?

At its core, an AL is an art-science dialogue between a scientist and an artist. By dialogue we mean an encounter on stage where the two "performers" find ways to connect around a scientific topic by means of their own special abilities and, together, they create an emotional as well as cognitive bridge with the audience. The artist and the scientist need to negotiate a way of elevating the scientific content from a lesson to a story, from scientific talk to an existential dimension. Their roles on stage are fully equal, none should prevail on the other and their common aim is to raise the level of scientific awareness in the audience while, at the same time, creating the environment for an emotional connection. In this quest, the scientist carries the scientific knowledge, but the artist is needed in order to consistently open up communication channels with the audience, to generate the conditions for real bi-directional trust that is needed. Trust exists if there are powerful emotions, empathy and image sharing[55,56] and this is the typical role of art while often scientists do not explore this dimension in their lecturing. In an Augmented Lecture scientist and artist should be complementary on stage, putting each other off balance, pushing each other in the other person's game field.

53 The organization I work for and which I direct is Arditodesìo, an Italian theatre company based in Trento, devoted to creating theatre about science through its Jet Propulsion Theatre Project (www.arditodesio.org).

54 Teatro della Meraviglia is a joint effort of Arditodesìo and the University of Trento. More information can be found at www.teatrodellameraviglia.it

55 Emma Engdahl and Rolf Lidskog (2014). 'Risk, communication and trust: Towards an emotional understanding of trust'. Public Understanding of Science, Vol. 23(6) 703–717. DOI: 10.1177/0963662512460953

56 Jack Barbalet (2011). 'Emotions Beyond Regulation: Backgrounded Emotions in Science and Trust', Emotion Review Vol. 3, No. 1 (January) 36–43. DOI: 10.1177/1754073910380968

An example: 'What is Life?'

This Augmented Lecture was produced for the 2021 edition of the Teatro della Meraviglia festival and has toured extensively throughout Europe since. On stage there are professor Gianluca Lattanzi (Department of Physics, University of Trento, Italy) and Italian actress Maura Pettorruso. I had the pleasure to direct them. The title was originally that of a series of lectures given by the famous physicist Erwin Schrödinger, who took refuge in Ireland during WWII. Surrounded by reports of death, Schrödinger questioned the processes that allow life to proliferate on our planet. The principles of physics and chemistry must account for this. But how? Why is it so? Does it have to be so? And ultimately: what is it, really? While we can hold out reasonable hopes of being able to explain how life works, we are a long way from answering the real existential question: why? This is the dramatic question that both Maura and Gianluca, whose characters are siblings, try to answer by means of a story. The plot makes its moves from the death of their grandfather to whom they haven't been able to talk for many years because of their cultural distance: a humble and unschooled man who could not possibly understand Shakespeare, Checkov, thermodynamics and quantum mechanics. Grandfather's funeral offers the occasion for a final reconciliation and the two siblings finally find the courage to tell him what they have been doing with their lives, delving into the details of what is life after all: from a scientific point of view as well as the artistic side. This catharsis allows them to come to terms with their guilt feelings and, most importantly, to reconcile with life and their kinship.

'What is Life?' is a well crafted production that opens up existential questions but that, at the same time, allows professor Lattanzi to explain some deep concepts such as non stationary physical processes, the law of large numbers, chaos, entropy, order and disorder, making them vital for the understanding of his own personal journey. The actress Maura Pettorruso makes a real effort to try to understand these concepts (she has no formal training in science) while at the same time putting Gianluca off balance with her own view on life and a solid sense of humour. The end result is a rather deep and touching play that never fails to charm the audiences while at the same time providing a real science lecture.

Creating an Augmented Lecture: the steps.

Since 2017 we have produced more than 20 ALs[57] both in Italy and in other countries around Europe (more on this later on). This experience has helped us fine tune the creation process and also come up with ways that the procedure can be streamlined with consistency. I will now describe the process in detail.

The ideal production team is composed of a scientist, a performance artist and a director. The scientist

57 Augmented Lectures have dealt with all kinds of scientific issues ranging from future studies, gravitational waves, Dante's Divine Comedy, the chemistry of foods, pandemics, the double slit experiment in quantum mechanics, brain sciences, interstellar exploration, evolution and more.

can come from any field of study since the overall process does not depend on the content of the lecture, as long as it is scientifically sound.

The artist should be someone with good familiarity with being on stage. Although we have experimented with all kinds of artistic fields (from acting to singing, from painting to cooking), we have discovered that the most powerful ones, for this type of art science format, are actors because they connect with more immediacy with the audiences compared to artists coming from other art forms. But maybe more importantly, the scientist typically has more familiarity and therefore relates more easily with spoken word contexts than with any other art form. Because of this, the connection between the scientist and the actor is greatly facilitated. The director should be able to guide the creation process and s/he should possess playwriting skills too. The director should also have some understanding of the scientific concepts being dealt with, because s/he acts as a link between the two performers both from a point of view of art but also from that of science.

Our starting point in Trento has always been a two days workshop that we run yearly for University researchers and professors. This workshop aims at connecting with those candidates that are actually willing to go through the AL creation process. The contents of the workshop are centered around the standard Hero's Journey,[58] necessarily simplified and applied to scientific topics. At the end of the workshop the scientists are asked to present a 5 minutes short personal story to be delivered to a group of invited artists. This very short story should contain some elements of the science that they would like to deliver in the AL but without any educational purpose. This is where one of the invited artists may decide to pursue a connection with one of the researchers and explore a potential collaboration. At that point a connection is made and the company producing the AL finally associates a director to the scientist and the artist couple, so that the AL triplet is made.

The next step in the preparation is to ask the scientist to deliver a real frontal lecture to the other two creative partners, so that the scientific content of the AL is made clear. Then the artist should describe how s/he would like to connect to it. Possible ways are: via a personal story related to the topic, a reference to a book or a movie, a song, a dramaturgical construction, or any idea that connects somehow with the topic[59]. Finally, with the help of the director, the overall dramaturgical construction is created into a possible storyline, following the basic ingredients of the Hero's Journey: status quo, complication, resolve, return with a deeper understanding.

Once the structure of the AL has been devised the team moves to a rehearsal period. We have discovered that the most that we can really ask the scientists to devote to the project is about 40

58 A lot of information can be found online on the Hero's Journey. For a quick reference go to https://en.wikipedia.org/wiki/Hero%27s_journey

59 Here the possibilities are truly endless. They depend a lot on the artist's inclination, on the topic and on the final outcome that is desired.

hours of rehearsal, divided in 2 or 3 hour sessions. This rehearsal time is significantly shorter than for regular plays but it actually works to the advantage of the production: on the one hand it allows the overall result to remain somewhat improvisational and therefore highly malleable with respect to the the situations and, on the other hand, it prevents a "rehearsal burnout" on the side of the scientist who is typically not used to the gruelling repetitions of the play staging process.

The staging should also include minimal technical and scenery requirements because one of the aims of ALs is to be performed in all kinds of venues and situations, schools included, where regular theatres may not be available. The agility of ALs is a fundamental characteristic that, in time, we have found to be extremely valuable for touring. The final Augmented Lecture should last about one hour.

What are Augmented Lectures good for?

ALs have several advantage points and some drawbacks. I will try to illustrate them here.

First of all, ALs can be quite powerful tools to connect scientific ideas with all kinds of audiences that typically may not be interested in theatre or they may not have an inclination to attend a regular science lecture. ALs can find interested audiences in schools, libraries, science festival and museums, universities and, in the right circumstances, in theatres too. In schools and universities they may be used as tools to open up specific topics, getting the students interested in alternative ways. Having said that, it should be clear that ALs are not full theatre productions, they retain a certain level of pedagogical aim, they are somewhat improvisational in nature and should not be confused with other forms of (science)theatre. It is our experience that they can attract many different types of audiences and, at the Theatre of Wonder festivals, they are usually more popular than the invited shows.[60]

ALs have also other benefits: the scientists involved become more comfortable with being on stage and they learn novel teaching techniques connected with the storytelling methods. Similarly, artists become more involved with science and, ultimately, they also have the opportunity to become science literacy ambassadors. Finally, ALs provide audience development, allowing access to diverse and previously uninterested audiences that typically do not attend theatrical events (young students are a prime example of this).

Augmented Lectures as a research process

The procedures described here are quite solid and have produced some really interesting results. Nevertheless we are continuously striving to develop the AL format. Arditodesìo, together with its

60 Ticketing statistics at the Theatre of Wonder festivals in Italy show that Augmented Lectures consistently have higher audience participation than the the more traditional theatre shows.

European partners, is now building on the experience of the Theatre of Wonder festivals in Italy by expanding it through the European-funded project[61] CURIOUS (Culture as a Unique Resource to Inspire, Outreach & Understand Science). CURIOUS is set to produce eight Theatre of Wonder festivals (two in each country involved: Italy, Bulgaria, Republic of Serbia and Belgium) and at least 22 original Augmented Lectures in five languages (the four 'native' languages, plus English). Some of these ALs will tour among the partner festivals and be seen by a wide array of audiences.[62]

CURIOUS has been providing us with the opportunity to expand the AL creation process to different approaches and needs[63]. The results have opened up a wide array of opportunities that we are currently exploring. These experiments have been providing us with further testing on the value of this novel format, its reproducibility and consistency and how it can be expanded to other theatrical genres. The final aim is to setup a strategy to turn Augmented Lectures into a time tested way to do science outreach but also to create real artistic performances, elevating the critical science literacy of (novel) audiences while at the same time creating emotions around science.

61 CURIOUS is a joint venture between Arditodesio Company (IT), Arte Urbana Collectif (BG), the Interactive Arts Laboratory of the University of Arts in Belgrade (RS), and the Arenberg Theatre (BE) and runs from 2020 until early 2023. Agreement Number 616819-CREA-1-2020-1-IT-CULT-COOP1. More details can be found at: projectcurious.eu

62 CURIOUS aims to step up the quality and the experience of AL creation and transnational touring.

63 For example, adapting the format to access inner city youths, or creating immersive theatre events.

AI: WHEN A ROBOT WRITES A PLAY

RUDOLF ROSA
(Charles University)

DANIEL HRBEK
(The Švanda Theatre)

On the occasion of the centenary of Karel Čapek›s play R.U.R (Čapek, 1920), the Švanda Theatre prepared a presentation of a unique project, THEaiTRE, conceived by a Czech innovator Tomáš Studeník, which examines whether artificial intelligence can write a play. Within a few months, the computer generated images from the life of a robot that has to face the joys and sorrows of everyday life. And it revealed to us how it perceives basic human issues such as birth, dying, the desire for love, the search for jobs, or aging.

THEaiTRE (www.theaitre.com) is an interdisciplinary project directly combining theatre and science. The project team is lead by Rudolf Rosa, an expert on computational linguistics and natural language processing; however, the team is composed of both computational linguists as well as theatre experts, under the lead of Daniel Hrbek, the director of the Švanda Theatre in Prague. The goal of the project is to explore the potential of current artificial intelligence techniques to be incorporated into theatre practice, and to directly confront the general public with the outcome while explaining the process behind the creation of the play and thus educating the audience about the current state and capabilities of the techniques used. We found that this immersive experience can spark a lot of interest both among artificial intelligence enthusiasts as well as among people generally ignorant to the current developments in the field. Our goal here is to demystify AI, to explain the rather simple basic principles behind the machine learning based on textual training data, and hopefully to bring the AI closer to people so that they neither glorify it nor fear it irrationally, but rather understand its basic principles and thus set reasonable expectations and precautions, making it clear that AI should be taken with caution but can be very useful for some tasks in practice. The project bears some similarity to the theatre play Lifestyle of the Richard and Family (Helper, 2018), the musical Beyond the Fence (Colton et al., 2016), the short movie Sunspring (Benjamin et al., 2016), or the performances of the Improbotics theatre group (Mathewson & Mirowski, 2018).

The project team is composed of experts from three institutions, all based in Prague, Czechia:

- Computational linguistics experts from Charles University: Rudolf Rosa, Ondřej Dušek, Tomáš Musil, David Mareček, Patricia Schmidtová, Dominik Jurko, Tom Kocmi, Ondřej Bojar
- Theatre experts from The Academy of Performing Arts: Máša Nováková, Klára Vosecká, Josef Doležal
- Theatre professionals from Švanda Theatre: Daniel Hrbek, David Košťák, Martina Kinská

The THEaiTRobot system (Rosa et al., 2021), which was used to generate the theatre play script, is based on the pre-trained GPT-2 generative language model, created and made available by the OpenAI consortium (Radford et al., 2019). A generative language model is a tool that first needs to be trained on large texts; GPT-2 is an artificial neural network trained on 8 million English documents from the internet, thus learning how words can be combined together to form sentences and textual documents. Then, when a trained model is provided with a beginning of a document (called a prompt), it can hypothesize, based on its knowledge, what a likely continuation of the document might be; similarly to when a

person is given a beginning of a sentence, such as "I woke up in the morning and went to the...", their brain immediately suggests possible ways of continuing the sentence, such as "bathroom" or "kitchen" (statistics performed on the whole text of English Wikipedia reveal that "went to the bathroom" appears about three times more frequently than "went to the kitchen", so a model trained on texts of Wikipedia would be more likely to generate the word "bathroom"; but since randomized sampling is used, it can also randomly choose to generate "kitchen", or other words; also the neural network is somewhat more cunning than computing such simple statistics). And like that, word by word, sentence by sentence, the model generates new text that, if we are lucky, is both grammatically as well as semantically coherent. More details about shortcomings and adjustments of the system can be found in (Rosa et al., 2021).

To generate an actual theatre play script with the THEaiTRobot tool, we employ the human-in-the-loop approach, where a machine and a human interactively collaborate to jointly produce a result. Here, it was the dramaturge of the play, David Košťák, who operated the system and thus became a sort-of co-author of the play. The theatre experts soon noted that the system is not yet mature enough to put together the complex structure of a well-written play, and we decided it was better to generate individual scenes as independent simple dialogues and to compose the script out of those. The starting prompt for each scene (to provide as the start of the document to the language model) was a short description of the scene and of the characters, and the first line of each of the characters. Then the generator took over, with the operator only guiding it as necessary by choosing which of the possible paths it should follow. To ensure that these independently generated scenes can be composed into a coherent script, they were interlinked through using a common character and related scene settings. Approximately 16 scenes were generated in this way, out of which 8 were chosen, ordered into the play script, and slightly post-edited as needed; in the resulting script, 90% of the text comes from the generator, while the remaining 10% are either the input prompts or the post-edits. The dramaturge expressed a pleasant surprised with how far the AI has already gotten and described the experience as demanding yet interesting. He also noted that the generated script is mostly connected only via word associations, without any superstructure expected in a drama such as the building blocks of dramatic situations (Polti, 1921), more resembling a literary rather than dramatic dialogue at best, with the director and the actors needing to further interpret it for stage in the subsequent production phase. The script of the play is freely available online (THEaiTRobot et al., 2021).

Once the script was generated and post-edited, it was handed over to a professional team at Švanda Theatre, lead by Daniel Hrbek as the director (and also the music composer), also featuring a director's assistant, 6 actors, a stage designer, a costume designer, two dramaturges, a choreographer, a stage manager and a production manager.[64] The production and mise-en-scène was done in a rather standard way, utilizing human experts without any help of AI, taking some inspiration from various classics of the sci-fi genre. A decision was made to complement the showing of the play by a short foreword and an extended afterword and discussion.

64 https://www.svandovodivadlo.cz/en/inscenations/673/ai-kdyz-robot-pise-hru/3445

The director and the actors found the text extremely hard to work with, for several reasons. Apart from occasional logical gaps in the script, what they strongly complained about was the script being "soulless", as compared to a human-written script where they can try to solve the puzzle of decoding the author's motives and ideas. Here, it was clear that there was no motivation within the AI itself, there was no subtext, everything was just laid out explicitly in the script as if it were written by a naive child and there was nothing more to decode. Thus, rather than taking something from the script, the team had to give a lot from themselves to endow the script with a soul, a life, a meaning, so that they could at least try to identify with the script and the characters.

The format of the show follows the principle show – explain – discuss. The play itself has a revue format, consisting of 8 scenes, talking about the search for closeness of someone in a world where people have not known or are not able to make simple contact with each other for some time, and in which the path of one person to another is the hardest to cover. The story of the robot, which after the death of its master was left at the mercy of various individuals of human society, balances on a thin line between absurd black comedy with existential drama. The main character is a humanoid robot (all characters in the play are played by professional human actors), who wanders around the world trying to find his own place in the world, encounters various people, interacts with them in the context of some typically human problems, situations or topics (birth, death, faith, soul, love, sex, anger, burnout, job search, etc.). The play takes approximately 60 minutes, and each showing is complemented by a follow-up explanation of the process of creating the play (similar to that provided here earlier) and a discussion. For the premiere, the discussion had the format of a panel discussion with members of the project and an AI expert; however, the standard format at the repeats happening physically at the theatre is an interactive discussion of the project members with the audience.

Due to the Covid-19 pandemic, all Czech theatres needed to be closed at the time of the planned premiere. Therefore, the premiere took place without the presence of the audience, but it did not lose its theatrical character. The premiere as well as the subsequent panel discussion were freely streamed online from Švanda Theatre (in Czech language, with English subtitles/interpretation) and were viewed by approximately 20,000 spectators worldwide. A short video trailer of the premiere can be viewed on YouTube (https://youtu.be/8ho5sXiDX_A) and two photos are enclosed as Images 1 and 2. The videorecording of the panel discussion after the premiere can be viewed on YouTube in full (https://youtu.be/QnJH55yZtV4). The panel discusses many questions, including the following: Can AI write a play? How do experts from various fields of IT see it? How do theatre creators who had to deal with the text that AI created from 90% see it? How does AI work with creativity? And what other horizons does AI go to besides the field of art? The online audience had the option to ask questions via Slido (https://app.sli.do/event/4jc2vpu1, questions and answers are still accessible). We received dozens of questions towards the creation process and the interventions, the internal workings of the language model and its training data, the topics and themes in the play and their human or artificial origins, and future of the project.
After the premiere, we received a lot of feedback, both from general spectators as well as in media;

the play was reviewed by numerous Czech and foreign newspapers, including e.g. by The Times[65] or The Guardian[66]. The reviews were mildly negative, noting the play as rather weird and absurd, and generally answering the question posed by the project, i.e. whether AI can write a theatre play, with "not yet", but acknowledging some good points as well, such as some humorous points, or the general achievement of putting on stage a full-length play generated by AI which is actually watchable. For example, Arifa Akbar from the Guardian concludes: "It is all fairly puzzling and quite a relief when the hour is over. It is also instructive: even if algorithms can help us find love, recommend the perfect book on Amazon and seem to know us better than we know ourselves, a robot cannot write an original or engaging play, at least not yet."

In our view, already the fact that the generated play can be evaluated in a rather standard way rather than being immediately dismissed as a complete nonsense, which even some of the team members had feared, is a good result. Interestingly, a recurring comment both after the premiere as well as after theatre repeats is that many spectators actually find the discussion after the play more interesting than the play itself. We view this very positively, since one of our goals is precisely to inform the public about the current state of research in this field, which can be nicely done by first showing the actual play to have some solid ground to base the discussion on. We thus seem to have succeeded by using the play to entice members of the general public to learn something about the operation and current state of artificial intelligence in the context of theatre.

A month after the premiere, the creative team and the actors behind the performance got together and reflected on working with the AI's text. The consensus was that the task was unlike any other they had previously experienced. The director remarked how he managed to direct only the exterior of the play, molding it into something more coherent with the help of the dramaturge. The actors struggled with it from the very beginning, citing that it was difficult for them to read and even more challenging to interpret their characters on stage. There was a mutual feeling of an absence of the soul, the actors mentioned feeling drained by it, which is directly in opposition to the usual energy that is accessible in literature written by human authors. It felt as though the text was against them. The answer to how to deal with this type of process was to try and find subtextual meaning in each sketch. The decision to make one of the characters a robot was useful, as it immediately gave an explanation as to why the character behaved the way it did.

The director and the actors found the text extremely hard to work with, for several reasons. Apart from occasional logical gaps in the script, what they strongly complained about was the script being "soulless", as compared to a human-written script where they can try to solve the puzzle of decoding the author's motives and ideas. Here, it was clear that there was no motivation within the AI itself,

65 https://www.thetimes.co.uk/article/ai-when-a-robot-writes-a-play-review-an-eerie-glimpse-of-the-future-09b0ff509
66 https://www.theguardian.com/stage/2021/mar/01/on-the-scene-like-a-sex-obsessed-machine-when-a-robot-writes-a-play-ai

there was no subtext, everything was just laid out explicitly in the script as if it were written by a naive child and there was nothing more to decode. Thus, rather than taking something from the script, the team had to give a lot from themselves to endow the script with a soul, a life, a meaning, so that they could at least try to identify with the script and the characters.

Within the project, we have learned that theatre and science can be combined in a very intimate way, can inspire each other, can learn from each other, and such a collaboration can yield results that are interesting for the general spectator, even though the state of the art in AI is not yet mature enough to automatically generate high-quality theatrical scripts. And, probably more importantly, we have learned that incorporating AI into theatre can draw new audiences to theatre who often become intrigued and are willing to learn through the experience and the subsequent discussion both about theatre and about science.

Figures and Figure Legends

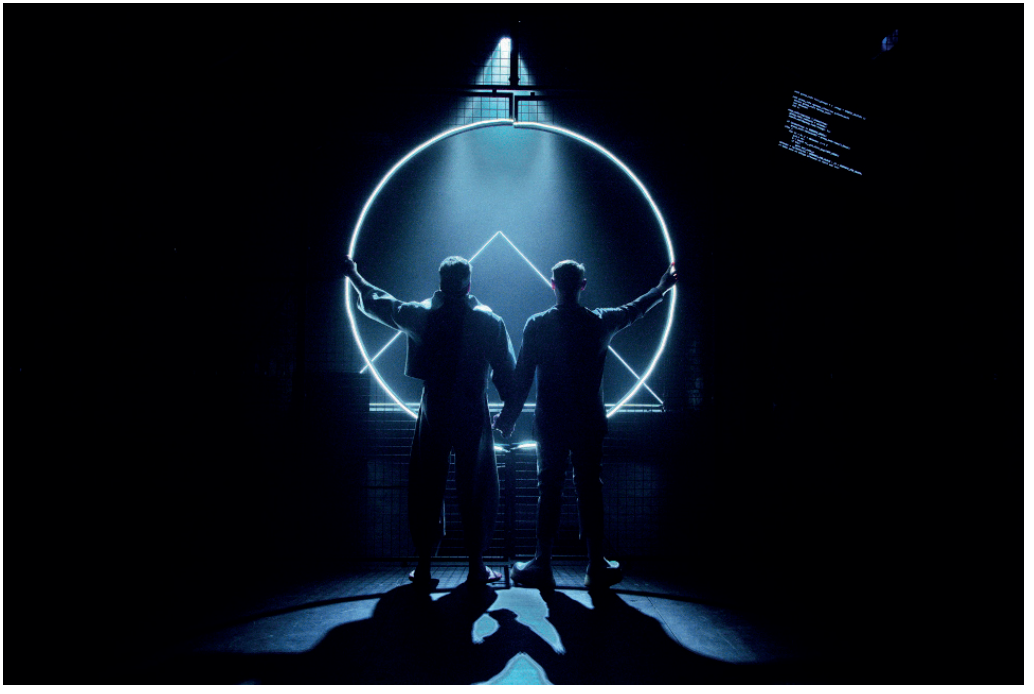

Image 1: "I think I know it." Master and Robot, from the first scene, "Death", of the play "AI: When a Robot Writes a Play". Photo by Alena Hrbková, 26th Feb 2021.

Image 1: "You didn't love her!" Psychologist and Robot, from the sixth scene, "Burnout", of the play "AI: When a Robot Writes a Play". Photo by Alena Hrbková, 26th Feb 2021.

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FROM THEATRE TO COMPUTATIONAL LINGUISTICS: ARTIST-IN-THE-LOOP ARTIFICIAL INTELLIGENCE

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The conventional relationship between theatre and science might be imagined as a directed arrow pointing from theatre to science, representing how theatre skills can empower scientists to be better communicators. However, if we invert the direction of the arrow, we can see how science itself inspires, becomes the subject of, and or a tool for, theatre. This essay examines that relationship between science and theatre with a focus on artificial intelligence (AI). We highlight how AI can play the role of a computational tool for theatrical performance artists. We also describe how AI-based language models can be employed for other artistic co-creativity.

In 2015, developments in AI-based large scale language models (Sutskever et al, 2014) prompted theatre or movie directors to try using them for writing scripts. These language models generate text given a prompt, and are trained on large corpora of text that can include theatrical plays and film scripts and that capture the statistics of narrative prose or dialogue. The results of early AI-based generation, such as song lyrics for West End musical Beyond the Fence (Colton et al, 2016), or the entire movie script for short film Sunspring[67] were nonsensical, but were made enjoyable by heavy editing[68], curation[69], and interpretation by a large cast of human actors, director, choreographer, etc. who invented meaning and subtext for the AI output.

Since then, there has been a marked improvement in the quality of the large language models. Prague-based theatre company theAItre leveraged the large GPT-2 model, open-sourced and released by OpenAI (Radford et al, 2019), to produce the 1-hour-long AI: When a Robot Writes a Play[70], whose often absurdist script[71] was 90% written by AI. Even larger (by a factor of 100 in terms of data and model size) language models, such as GPT-3 (Brown et al, 2020), made partially accessible for a fee by OpenAI, have been recently employed to generate the script of AI[72], produced in summer 2021 at the Young Vic theatre in London, or the comedic short films by CalamityAI[73].

The play AI is an interesting example of a slightly more collaborative and interactive approach to AI-script writing that involved the dramaturge, the actors and the audience. We have adopted a similar approach in our theatre company Improbotics. Since 2018, we have led workshops with professional actors playing with chatbots, inviting them to deliver, curate and reflect on the outputs of AI, on its creative capabilities and limitations, as well as on the many issues with large scale language models. As a result of our workshops, Zürich University of the Arts-based Dr. Gunter Lösel and his company, later produced Almost Human, a psychotherapy-themed improv show with chatbots (Loesel et al, 2020).

67 https://www.thereforefilms.com/sunspring.html
68 https://www.eyeforfilm.co.uk/review/sunspring-2016-film-review-by-jennie-kermode
69 https://www.theguardian.com/stage/2016/feb/28/beyond-the-fence-review-computer-created-musical-arts-theatre-london
70 https://www.theaitre.com//
71 https://www.theguardian.com/stage/2021/mar/01/on-the-scene-like-a-sex-obsessed-machine-when-a-robot-writes-a-play-ai
72 https://www.theguardian.com/stage/2021/aug/24/rise-of-the-robo-drama-young-vic-creates-new-play-using-artificial-intelligence
73 https://www.youtube.com/c/CalamityAi

Similarly to jazz music, theatrical improvisation requires human collaboration and creativity (Johnson-Laird, 2002). Performers need to adapt to a changing context, as well as to listen to and collaborate with other performers and with the audience. It is thus with the motivation of exploring the limits (and absurdist potential) of language models for writing stories, and as an improvisational challenge, that we started working on human-machine improvisation with chatbots in 2016 (Mathewson and Mirowski, 2017a). Over the years, we went from a human-machine comedy duet featuring physical robots[74], to start Improbotics, a science theatre collective and theatre company[75] featuring several dozen actors who interact with robots powered by artificial intelligence.

The AI chatbot used in Improbotics performances relies on state-of-the-art language models like GPT-3, trained on books, film dialogues, play scripts and news articles. An operator summarises and inputs the context of stage dialogue, which prompts a custom chatbot to generate dialogue used by improv actors. The goal of the human actors is to make sense from the AI generated dialogue by incorporating it into an evolving narrative to entertain the audience. Humans speak the AI-generated lines naturalistically, with appropriate timing, physicality and emotion. In turn the other performers accept these seemingly absurd "offers" while attempting to tell interesting comedic stories (Mathewson and Mirowski, 2018).

Within this improvisation convention of "justifying the offers" made by a stage partner, Improbotics developed a range of novel improvisational game formats that take advantage of state-of-the-art natural language generation tools. These include an improvisational "Turing Test" that challenges the audiences' expectations around AI (Mathewson & Mirowski, 2017b), or multilingual shows with live machine translation (Mirowski et al, 2020) that engage actors and audiences with the translation choices made by the AI.

The Improbotics format presents science as a subject for theatre, as well as an opportunity for innovation that pushes the boundaries of the artform. Working with a scientific subject like artificial intelligence on a comedic stage further presents an opportunity for audiences, as well as the human performers to engage in dialogue about AI in an informal and safe environment.

Through the medium of improvisation, Improbotics engages actors with non-technical backgrounds to explore the possibilities and constraints of AI systems, and develop intuition about them, creating a tightly coupled artist-in-the-loop interaction modality. Besides performing with the AI, the actors learn how to prompt the language model and how to curate its responses to keep only the ones they deemed appropriate, relevant or comically interesting. Through this process they become both more thoughtful and critical about the capacity of AI and the importance of engaging the public in dialogue about the misunderstandings and myths surrounding what artificial intelligence is and does.

74 https://humanmachine.live
75 https://improbotics.org

Under the lens of our artist-in-the-loop interaction, let us now more deeply examine the feedback loop that can emerge between science and theatre when we prioritise co-creativity. When human artists and such computational tools meet, playwrights and theatre directors can sample ideas and inspiration from the limits and potential of such tools (and from the broader scientific context) and then stage them in actors-led performances. Through the continued dialogue between artists (who are performing with and exploring AI tools), external critics and audiences, we can collect critical feedback on how the computational tools facilitate or impinge on the performance. That feedback on the human-machine interaction in turn becomes useful for informing future directions of scientific research. We look at three examples of interaction: gathering datasets for model training, curation of dataset and moderation of outputs, and improving long-term coherence of language generation.

Two human actors perform an improvised scene with a robot, whose lines are generated by GPT-3, voiced by speech synthesis and projected on a screen. Photo: Stuart Hollis.

One example of an artist-in-the-loop process for AI can be seen in the datasets used to train the language models (Mathewson & Pilarski, 2022). Before the advent of large language models, conversational agents were trained on datasets geared towards dialogue, like the small Cornell Movie Dialogs Corpus

and the larger OpenSubtitles[76] corpus of dialogue from 100k films. These film-derived datasets were used in research on learning large conversational models (Vinyals & Le, 2015). We used OpenSubtitles to develop conversational models for our improv theatre-specific chatbot in 2016 (Mathewson & Mirowski, 2017a). Inspired by theatrical improvisers, computational linguistics researchers curated an improv-specific dataset of "yes-and" exchanges from improv podcasts (Cho & May, 2020). They chose that dataset because it contained a high proportion of dialogue focused on building common ground, and it was making use of the "yes-and" principle to establish coherence and an actionable objective reality. Then they used it to train a "yes-and" classifier for sentences to refine other datasets and improve chatbots. We can see above works as evidence of theatre, film and improv informing AI research.

Three actors, one (in the middle) who is wearing headphones and saying only lines generated by the chatbot, sent via speech. Photo: Lidia Crisafulli.

Another example of how artistic creation informs science and vice-versa can be seen in dataset curation and model output moderation. Models such as GPT-3, trained on millions of web pages, news articles,

76 https://www.opensubtitles.org/ and https://opus.nlpl.eu/OpenSubtitles-v2016.php

seem to generate seemingly high quality text. There are trade-offs between the predictive power of large language models, and their embedded biases or their misalignment with desired societal values (Weidinger et al, 2022). For instance, these large language models can amplify negative racist, sexist or homophobic stereotypes, they can fool a user with dangerous advice and be automated and weaponised for misinformation (Bender et al, 2020).

In our Improbotics performances, where we rely on the GPT-3 language model, we take a careful approach to how we use that language model. Essentially, we do not want to offend our audience. Instead, we choose to uplift the technology and do a show for and with the audience This means avoiding cheap laughs stemming from inappropriate or offensive language model generations.

Therefore, our approach to mitigating these many biases and to the removal of offensive content relies on a combination of automated filters and human curation, performed in real time during the show. First, we remove sentences that contain known offensive words from a blocklist (Mathewson & Mirowski, 2017a), and all generated sentences are validated using multiple filters for inflammatory, hateful, or sexual content by the Perspective API[77]. Offending sentences are then replaced with generic text (e.g., "I would like to insult you"). Second, the humans who operate the system and who deliver lines generated by the chatbot have agency in both how they formulate and type the prompt, and in what sentences produced by the AI they choose to read respectively. These humans-in-the-loop are able to omit or reword parts or all of those sentences. In other words, we use language models as a curated and moderated draft that is always overseen by at least one and sometimes several human operators, who take ownership and responsibility for AI outputs. Our approach is appropriate for live performance but is labour-intensive. How could we adapt it to other human-computer interaction modalities, always leaving room for human choice? We consider the utility of automation for all stakeholders, from artists to audiences. Could such human-centric ethics inform how we approach human-facing AI models in general?

A third example of how scientific research is informed by artistic creation can be seen in the focus on long-term consistency and coherence of AI generated text. These are desirable characteristics in language generation, both linguistically (Dziri et al, 2019) and narratively (Mathewson et al, 2020). In other words, even though large language models like GPT-3 seem to generate – at a first glance, and before one starts reading carefully – plausible text, they end up generating nonsense, and rarely know "when to stop". Because they are merely trained to predict "what comes next", language models do not evaluate the quality and the relevance of their own outputs.

With that objective in mind, we tried to co-narrate stories with AI during improv scenes, as a "narrator" playing alongside the human performers and intervening sparingly (Branch et al, 2021).

77 https://perspectiveapi.com

The AI system would only "tell" the progression and character arcs while the human actors acted the dialogue in the scenes. The chatbot lines were read by a human actor with appropriate timing and intonation; to embody the AI, that actor was controlling, with their face, an animated puppet of a robot. We tested our model with four live performances during theatre festivals in England. After each performance we surveyed volunteer audience members as well as volunteer performers to evaluate how well the AI did in its role as narrator, using a 5-level Likert scale. The surveys had questions to disambiguate the enjoyment of the show from the assessment of the AI narrator. We found that audiences and performers responded positively to AI narration and expressed enthusiasm for the creative and seemingly meaningful novel narrative directions added by AI to the scenes (Branch et al, 2021). Our artist-in-the-loop research work specifically addressed the questions of evaluating the usefulness of LLMs for narration. We believe that similar hierarchical approaches to storytelling with chatbots can be reused beyond the context of computational theatre and be integrated in further research on how to get AI generative models to keep long-term consistency, akin to recent work on employing LLMs for human-in-the-loop AI-assisted book summarisation (Wu et al, 2021).

We have identified three research directions (datasets, moderation, coherency) that continue to be supported by ongoing scientific research on artistic co-creation. Future research will explore more ways that co-creative symbiosis connects science and live performance.

In conclusion, researchers in the subject of computational storytelling have defined theatrical improvisation as "real-time dynamic problem solving to collaboratively generate interesting narratives" (Magerko et al, 2009; Bruce et al, 2000). Their problem definition echoes the usual challenges faced by research in AI and in robotics, namely: how can we build systems that can generalise to unseen situations, and how can we build agents that can adapt to changes in their environment? Taking their reasoning further, digital theatre researcher Lara Martin has imagined a "grand challenge of computational improvisational storytelling" that would aim at ultimately trying to make AI systems better at perceiving, understanding and acting in the real world (Martin et al, 2016).

We do not attempt to build AI systems that write at "human-level", but rather focus on how these tools can inspire and assist human artists. Theatre is not a competitive zero-sum game like the game of Go or Chess, and does not necessarily have quantifiable metrics of success needed for machine learning – thus precluding the existence of the notion of "human-level" in theatre.

Instead, theatre is a way to express and communicate our uniqueness and humanity, as dialogue between playwrights, actors and audiences. Such a point of view echoes Aaron Hertzmann's view of art in general as an inherently social act that hence can not easily be modelled computationally (Hertzmann, 2020). By looking at the relationship between human and machine as one of collaborative enhancement as opposed to replacement, we open the door to new creative possibilities and can empower artists with new tools and modes of expression.

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DIGGING INTO HISTORY – AN INSIGHT INTO THE RESEARCH BASED THEATRE PROJECT *MAGNOLIENZEIT*

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'Faire de la recherche' in French, 'to do research' in English, 'recherchieren' in German – those three translations lead us to the very core of a practice that can be found within the arts as well as in the humanities and other academic fields: the search, sometimes for something yet unknown, sometimes for something not yet communicable nor visible.[78] Under the umbrella term artistic research a variety of artistic and creative research practices are analyzed, observed and reflected by scholars from a number of disciplinary fields (arts and culture studies, design, art history, social sciences – to name just a few).[79] To a certain extent research has always been part of creating (art) – regarding content, form or material (see Orlow, 2015, p. 202). In recent years artists have claimed research as the base or centre of their projects more explicitly (ibid.). In this report on practice I will show, that research based theatre projects can intervene in our understanding of what academic research is, but also how we go about it and how knowledge production works in academic and civic practices. I will use a research based theatre project I accompanied and co-devised as a dramaturge within a municipal theatre, the Mainfranken Theater in Würzburg (Germany), as an example. For this production we went on an extraordinary research journey and reflected that process and our outcomes within the mise-en-scène. Our research for *Magnolienzeit* (engl. Time of Magnolias) activated the whole team (actors, stage and costume designer, assistants and interns), it was at times wild and chaotic, but it was still always led by research questions. The research was not meant to be just about collecting background information but produced a multitude of valuable knowledge fragments[80] and challenged our understanding of the 'making of history':

Magnolienzeit[81] dealt with a crucial event in the history of Würzburg: on 16 March 1945, Royal Air Force bombs destroyed almost 90% of Würzburg's old town, causing approximately 3550 casualties (Baum, 2016, p. 2). Using means of documentary theatre (gestus of showing, working with factual material, playing with facts and fiction), research strategies and techniques such as narrative interviews (oral history), archive studies or comparative analysis, the team[82] investigated the local culture of remembrance. We analysed both the controversial political discourse of Jewish voices and stories, which had been neglected in that culture of remembrance for too long, and extreme right-winged groups who had been abusing the civil victims of Würzburg for their nationalistic

78 Here I refer to Uriel Orlow's depiction of the function of doing research in the field of art practices, where he refers to art as oscillating between the spheres of material facts and immaterial sensual experiences: "Kunst ist eine Grenzgängerin. Oft sucht sie nach dem Noch-Nicht-Sichtbaren, nach dem nicht direkt Mitteilbaren." (Orlow, 2015, p. 202).

79 The anthology Künstlerische Forschung. Ein Handbuch, conceived by Jens Badura, Selma Dubach and Anke Haarmann, offers an interdisciplinary overview and mapping of the field (Badura, Dubach & Haarmann, 2015).

80 Again I refer to Uriel Orlows description of the process of doing research as an exploration as well as an investigation in an intense and associative way, which aims for fragments of knowledge, "kleines Wissen" (Orlow, 2015, p. 202).

81 Note of transparency: I have used this production as a case study for a reflection on the conditions of dramaturgical labour in municipal theatres in Germany. The article "Work, Work, Work – Limits and Potentials of Dramaturgical Labour in Municipal Theatres" was published in Theatres of Labour, Platform Journal of Theatre and the Performing Arts, vol. 14/1, London: Royal Holloway (Cunningham & Unger, 2020). Thus a few general descriptions of the production's features are to be found in this report of practice as well as in the article (see Tretter, 2020).

82 The team consisted of director Tjark Bernau, stage and costume designer Karlotta Matthies, actors Bastian Beyer, Hannes Berg, Helene Blechinger, Maria Brendel, Anton Koelbl and me as the production's dramaturge.

propaganda. *Magnolienzeit* was staged as a site-specific performance[83]: at the Max-Stern-Keller, an old wine cellar below Würzburg's Old University. This space, now the cafeteria for law students, is named after a Jewish wine merchant who fled Würzburg in 1938.

Doing research was explored in multiple ways in this project and I will now take a closer look at the three dimensions mentioned above.

1 Textual: Generating the theatre script.

In the beginning there is no single text. In the beginning there are many texts, sources, fragments – photographs, films, books – memorial speeches, rituals, images – local legends, myths and sayings. In the beginning we ask rather global research questions (Who tells the stories of that crucial event? Whose voices have been neglected? How is the local culture of remembrance related to the city's self-image?), which we re-evaluate one month before the rehearsals officially start and aim to focus them on specific aspects. We organize a research week with the ensemble to prepare them for a series of rehearsals that would differ from the usual working conventions in municipal theatres for actors/actresses especially as they would become personally invested to a greater degree. They discover their roles as researchers as well. The process of co-creating the script for this project is analogue to our approach of doing research together as a team. The director Tjark Bernau and I suggest appointments in the archive, organize group walks through the city, choose around 15 interview partners (historians, teachers, testimonies of that event) and then invite other members of the artistic team/ ensemble to join us. We analyse the interview transcripts with regard to their narrative qualities, their potential to be controversial and/or clarifying, and their specific value in transferring the "then" to the "now". The director and I discuss different ways of collaging. The process of sharing selected material and re-arranging text elements continues through the rehearsals and is marked by several feedback rounds with the ensemble. Finally, the research for *Magnolienzeit* generates a collaged theatre text encompassing a guided tourist tour through the city, historical facts about the event told from various angles, different witness perspectives, archival material like "Wurfzettel" (German for a specific kind of flyers) and Municipal Notes from 1945 to today, a letter, poems, bits and pieces of newspaper articles and school book entries and excerpts of politicians' speeches about the culture and rituals of remembrance in Germany now and then. The whole process is characterized by a high tolerance for trial and error as well as a shared belief in the necessity to investigate this complex issue in depth. Looking back now I realize what is an essential condition for a research based theatre project like this within a municipal theatre: to build confidence for something to emerge through a process oscillating between facilitated theatrical experiments and academic research – and to believe in the unknown.

83 Here and in the following I use the term 'site-specific', because we engaged with the site in a "profound" way a profound way – both within the "development and execution" of the project and thereby *Magnolienzeit* matches the criteria Fiona Wilkie introduces in her study Mapping the Terrain: a Survey of Site-Specific Performance in Britain (Wilkie, 2002, p. 150). Nevertheless, it is important to note that the site was not the initial motif to start this research project. It rather was one of the crucial discoveries of our search.

2) Self-referential: incorporating the process of research on stage

As an integral part of our artistic concept we try to avoid retelling the 'chronological' story lines of the event and re-cultivating misleading assumptions. Consequently, we have to deal with ethical questions about handling historical facts and testimonies. In my position as the production's dramaturge I try to care for an alert awareness for what we are doing. This especially involves extensive context conversations with the ensemble and inviting the team to reflect on their roles as artists-as-researchers. In this pursuit I try to focus on four key aspects: How do we cope with the politics of memorialisation at play here? How can we take responsibility for our positions as theatre-makers-on-research? How do we avoid repeating story lines, such as presenting the people of Würzburg as 'victims' without acknowledging the context of the Shoa and the total war that the NS-regime initiated? How does the institution of the municipal theatre we are working for influence our research and artistic practices throughout the production's different stages? Acknowledging those ethical dimensions and the need for awareness within our research process for the mise-en-scène, we decide to make some aspects of our journey transparent for the audience. Thus, we choose to name our sources when performers cite them, we use physical research materials (books, papers, photographs etc.) on site, and we include original audio files by our testimonials – emphasizing the documentary character of our endeavour. Functioning as evidence of the realness of the sources, the audio recordings of our interview partners also add an authentic dimension to the performance. In addition, we develop a scene called *In the archive* that re-stages a typical research situation with our ensemble in the city's archive:

The actors and actresses leave behind their "representational positions" and turn into be their "self-expressive mode" (States, 1983, p. 361), put on white archive gloves, unpack the wooden boxes, look for articles and books, discuss sources, take pictures with their mobile phones to document the footage, reading a best-of of material 'not-used' and deliver small hints that connect to the facts and stories dealt with before and after this scene. In the dramaturgical structure of the performance, *In the archive* later displays the historic debates and discourses about how to analyse and judge the contexts and timing of the aerial bombing by the Royal Air Force. Conclusively, this scene not only offers a self-referential and self-ironic view into the process of actors/actresses/theatre makers doing research, but also shows how vulnerable theatre as a research machine can be: disruptions and dead ends are part of the process, too.

3) Social: sharing findings and insights

We reach out to individual experts (historians, teachers, archivists, cultural heritage hosts) as well as the municipal council for culture, civic initiatives and most importantly the Johanna Stahl Centre for Jewish Culture and History in Lower Franconia. We visit each other, exchange thoughts, ideas and texts.

Maria Brendel, Anton Koelbl, Hannes Berg, Helene Blechinger,
Bastian Beyer © Nik Schoelzel

The head of the Centre, historian Dr. Rotraud Ries, provides us with background information on the history of the Jewish community in Würzburg and the rural districts around. Another crucial partner is a school class from a local secondary school. Supported by our theatre pedagogue we develop a partnership in dealing with the 16th March 1945 and its aftermath. Throughout this partnership, the theatre pedagogue, the director and I visit the school class several times, inform them about our artistic concepts, they again tell us their perspectives (differing from ours in age and social backgrounds) on the historical contexts. We discuss how this part of history is taught in German school classes and relate it to current public debates. The pupils visit rehearsals of the theatre production and create a video documentation of the process. We as the production team receive their feedback in the final rehearsals as well as after a series of performances. This mutual exchange turns out to be a fruitful and an enriching experience of learning – for both sides. As this brief overview of partnerships of our research journey has shown, the practice of research increases the outreach capabilities of the theatre institution, opens up new contexts, builds new relations and addresses new audiences and various communities of the city. Having found the venue (Max-Stern-Keller) that is located in the centre of Würzburg's Old Town and used as a university site today supports this social dimension of our project. At the same time, the cooperation with the University of Würzburg offers opportunities for new forms of exchange and discourse, too. From the beginning, we as a theatre research team have continuously tried to keep the multitude of perspectives and the ambiguities of discourses reflected in our research process. We not only try to avoid traditional roles within our team constellation – 'the all-knowing dramaturge', 'the decisive director', 'the passive actor' – but permanently extend our understanding of who is capable to add to knowledge production – mixing academic, civic and other varied social perspectives.

Summary

I have taken a closer look at a research based theatre production, which I have accompanied and co-created as a dramaturge from 2017 to 2019. Zooming into three dimensions of exploring research within the making-of a theatre project and on stage I have shown how theatre can employ academic research strategies and how these can be combined with techniques of theatre and performance making to open up new ways of engaging with complex issues. I would argue that the tradition of documentary theatre still affects current forms of research based theatre. But the field is expanding. Research techniques we know from ethnography, the humanities or social sciences are frequently used as tools of intense exploration and played with in a self-referential way. Research based theatre projects like *Magnolienzeit* use the factuality of documents as an important source material. Moreover, they focus on the vulnerable quality of research processes as a sensual quality of theatre making. This facilitates a deep and multi-layered approach to historical, political and social circumstances. It activates different forms of knowledge, may close gaps or at least show that they exist. Thereby it generates new forms of expertise and empathy. In doing so, research based theatre affects the internal

conditions of theatre making, and demands extraordinary forms of outreach and cooperation with external partners. Such projects support the collective experience of research processes – both within the research team and in the continual exchange and sharing of material with external partners. In my experience, this is an important milestone for changing working constellations and hierarchies within the institutions – and when it comes to the inner structure and distribution of power, municipal theatres and universities share a long tradition and display similar problematic manifestations. Furthermore, those projects invite audiences to dig deeper into the making-of-knowledge through experiencing the making-of-research-processes. The objectivity of facts is challenged through the lenses of different subjective perspectives. Finally, theatre makers and audiences experience that how we understand historical events, current politics or future challenges is constructed again and again, questioned and reframed by the conditions of multi-faceted and collective processes. Thus, I would like to conclude with the words of a retired history teacher, another cooperating expert of our team, describing one of the local legends connected with the aftermath of the event:

"That was the story. It was like a fact."

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THE BOLDNESS OF SPRING.
THEATRE ABOUT SCIENCE IN THE BOTANICAL GARDEN OF THE UNIVERSITY OF COIMBRA

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We can trace the presence of modern science in theatre plays and performances since its beginnings. If, at first, the scientists and their endeavour were satirised on stage, in plays such as John Wilson's *The Projectors* (1665) or Thomas Shadwell's *The Virtuoso* (1676), in a few decades, more favourable dramatic representations of the scientist emerged, such as in Susanne Centlivre's *The Basset Table* (Montenegro, 2017a, 340). This change in the theatrical representation of science and the scientist accompanied the increase of their activity in society and the progressive increase in reputation of the scientific societies, due to their visible contributions to the advancement of knowledge and the technological consequences (Gaukroger, 2006, p. 509).

At a certain point, especially after the mid-20th century, theatre plays started to pointedly consider the moral and ethical responsibility of science, in plays such as Brecht's *Life of Galileo* (1956), Durrenmatt's *The Physicists* (1960) or Kipphardt's *The Oppenheimer case*. Theatre stood as an intellectual ground and a public space where the consequences of scientific research were pondered and discussed.

The interaction between theatre and science has stimulated a more critical behavior of society in relation to scientific practice and reinforced the idea that theatre can be an introductory vehicle for new points of view and reflection in society. Recently, theatre has been used in scientific dissemination and education environments as a communication tool that presents several advantages to convey knowledge related to science, given its ability to

> "... mobilize senses and emotions; address complex issues in an engaging way; address controversial, ethical and political aspects of science; explore the human side of scientists; deconstruct the supposed coldness of scientific activity and bring them closer to the public; and finally, stimulate reflection on the advancement of human knowledge and its implications." (Bento, Jardim, Freire, Amorim, & Ramalho, 2018, p. 35)

The relationship between theatre and science is based on a change in the pattern of knowledge production in these areas. That is, traditionally scientific practices presented the principle of the construction and interpretation of the world through inquiry and rational explanations as a basis for the production of knowledge. More recently,

> "The contemporary epistemological debate has pointed out that scientific practices are not an expression in a unique way of rationality, because in them we make use of imagination, creativity and chance as decisive factors of its production." (Florentino, 2009, p. 2)

In turn, art, like theatre, maintained a link with the preference for imagination and with the meaning that people attributed to the creative process. Nevertheless,

> "…artistic communities increasingly assume that creative processes have a reflexive and discursive component that, instead of being opposed to science, together with it constitute a general field of

> thought to carry out an open and fruitful dialogue." (Florentino, 2009, p. 2)

Thus, it is possible to affirm that the bond that has been built between theatre and science has allowed the interdisciplinary and transdisciplinary construction of knowledge, establishing a new interpretative paradigm of reality.

In this context, scientific dissemination is of particular importance. This term defines the communication interaction between science and a non-specialized public, through an accessible language. Currently, it is characterized by bringing to the debate current themes of various areas of scientific knowledge, with which the non-specialized public, as a rule, would not be confronted in their daily lives. Scientific dissemination is materialized in various ways, including through theatre.

> "Scientific theatre is the junction of the performing arts and science. It is the techniques, the feeling, the thinking, the doing, the consumption of the theatre, with history, knowledge, concepts and the experience of science." (Guimaraes & Freire, 2021, p.3)

Theatre makes sense in scientific dissemination, because one of its main functions is to communicate, and the approach of science in the theatre can be a powerful vehicle to promote the scientific literacy of larger audiences. In reality, each spectator interprets the message according to his/her identity and preferences and this "scientific communication" functions as a pedagogic action, provocative and educative, enhancing the proximity to science, and with examples that link scientific practices to everyday life (Tavares, 2018; 2019).

In this way, theatre is effective in scientific dissemination, since

> "... for all that it has that is human and sensitivity to the object treated, he is able to demystify and make people understand, in addition to provoking people by the theme and thus contributing to the formation of a scientific culture in the country." (Brito, Silva, & Silveira, 2010, p. 2)

Theatre can open the discussion on scientific topics, such as the history and philosophy of science, allowing participants to reflect on their role as citizens, leading them to rethink how their attitudes and the role of the scientist in society. (Pereira, 2018, p. 190)

Theatre about science has been gaining more and more prominence in spaces of both formal, non-formal and informal learning, from schools to science museums, such as Botanical Gardens (Tavares, 2012, 2013, 2018), and it

> "... can help in understanding and thinking about that particular subject by different audiences, causing interest and increasing scientific enculturation." (Guimarães & Silva, 2017, p. 2)

In the context of non-formal education, such as science museums and botanical gardens,

> "... Codes, formulas, and scientific subjects that are difficult to understand are presented in a playful and creative way to visitors and students. In this sense, these sites perform various functions that aggregate knowledge, configuring themselves in spaces of interaction between science and the public. According to Tânia Araújo-Jorge, a researcher at fiocruz's Oswaldo Cruz Institute, in science museums, theatre, in addition to transmitting contents from the scientific field, can help to arouse interest in science and art." (Soares, Pinheiro, & Mauro, p. 1)

In education, theatre has gained significant space, particularly in science teaching. The author Francisco Júnior states that theatre promotes cognitive development, creativity, relaxation, thus leading its audience to express their feelings in a non-formal way, leading to the construction of knowledge in a collective way. (Junior, Silva, Nascimento, & Yamashita, 2014, p. 81)

Theatre about science can be seen as a mediator in the communication of science and as a mechanism of approach to science in a dynamic, playful, and creative way, in the classroom context, within the scope of formal education, as well as outside the classroom, in non-formal teaching.

Nevertheless, theatre maintains a greater presence within non-formal education, and both can be developed in different locations and organizations. Education and theatre are based on the same principle, that is, to collaborate in order that the subjects become responsible citizens in today's world (Gohn, 2015, p. 19), by promoting the development of bonds of belonging, the construction of the collective identity of a group, the awareness of how to act in social groups, the construction and reconstruction of conceptions of the world and the formation of the individual for life (Gohn, 2015, p. 61).

In this context, the following case study illustrates the use of theatre in an informal context, a Botanical Garden, as an example of a practice of non-formal education. The study was carried out using a quantitative perspective, through the application of questionnaires collected in all sessions of the performance, to collect data from the audience, and then cross-reference results with the strategies used in the transposition of scientific themes to the script and the artistic performance.

Thus, in the context of the 22nd Cultural Week of the University, and although in a pandemic situation due to COVID19, the Botanical Garden of the University of Coimbra (JBUC), in a partnership with the theatre company Marionet, presented the theatre performance "The Boldness of Spring", having as setting the Central Square and as a dramaturgical starting point the book "Rhythms of the Botanical Garden of the University of Coimbra" (Tavares, 2012) . The book describes the transformations that occur in the botanical specimens along the year and identifies them using both the scientific and the

non-scientific names and a photo. Written in poetic text, the book is focuses in dissemination and teaching of botany considering plants as protagonists of a play, because monthly show themselves differently, contributing to a changing scenario in that square terrace.

The main metaphor, taken from the book, is that the transformations of the flora in the Botanical Garden are a theatrical performance that the plants present every year. It is divided into twelve acts, each corresponding to one of the twelve months.

Our performance took place in the beginning of Spring in 2020, and so we imagined the plants were performing an act entitled "The Boldness of Spring". The audience would circulate throughout the Garden guided by a character who had the double function of garden keeper and stage manager. This journey through the Garden would stop at several stages, where different plants would "perform" their act.

Illustration 3 - "The boldness of Spring" in the Central Square of the Botanical Garden
Credits: Francisca Moreira

With a previous scientific orientation, the script focused on the plants themselves, their names, their history, their physiology, but also in the history of the Garden, explaining its function and progressive expansion. Several species present in the Garden are exotic, typical from other places, most specially, in this Central Square, from Japan, like magnolias, maples, cedars, which inspired the playwright to include in the script small Japanese myths related to these trees. The scientific name of the plants was also referred to during the play, such as *Buxus sempervirens* or *Ligustrum lucidum*, together with their common designation, and the reason for this binomial nomenclature was explained to the public.

To maintain the audience's maximum interest during this 45-minute walk along the Garden, there was the dramaturgical option of performing the story using a diversity of theatrical devices. For instance, the part about the magnolias was performed with a puppet of a magnolia; the history of the *Cycas revoluta* (Japanese sago palm) was performed using masks; when talking about the Japanese maples, the actor would perform a dance using Noh Theatre movements and would recite haikus related to these plants. The dramaturgy of the performance was, thus, aligned with the objectives the Latin poet Horace attributed to theatre, to entertain and, at the same time, to instruct.

The metaphor used in this performance, of the Garden being composed of several stages with several plant-actors, aligns with one of the most frequent and relevant characteristics of theatre about science: the use of metaphors, whether in the dramaturgy or the acting, to convey specific scientific concepts (Montenegro, 2017b, 247). At the same time, the circuit the audience would make along the Botanical Garden might be seen as a path of study, if we consider that the original function of the Garden was precisely that of researching and learning about and so is the focus of the inspiring book for this play.
In this study, we investigated the effect of the performance on 5-13 years old children, aiming to conclude if this could be a useful approach to convey knowledge about the Botanical Garden of the University of Coimbra to a school audience. We used questionnaires, delivered at the end of the performance, to assess the knowledge gained by the children about the history and flora of the Botanical Garden.

We analysed twenty-five filled questionnaires. There was a predominance of children with the ages of 9 (13 children) and 10 (8 children). Thirteen children were girls and twelve were boys, resulting in a balanced ratio gender-wise. When asked if they had acquired new knowledge through the performance, everyone answered yes.

And when asked for concrete examples, the "name of the plants and trees" answer stands out. Next, that some plants can be poisonous, and then more individual responses such as the history of some trees and their longevity, the fact that most of the trees are Japanese, the history of the Botanical Garden, the origin of the Magnolia, among others (see Illustration 1).

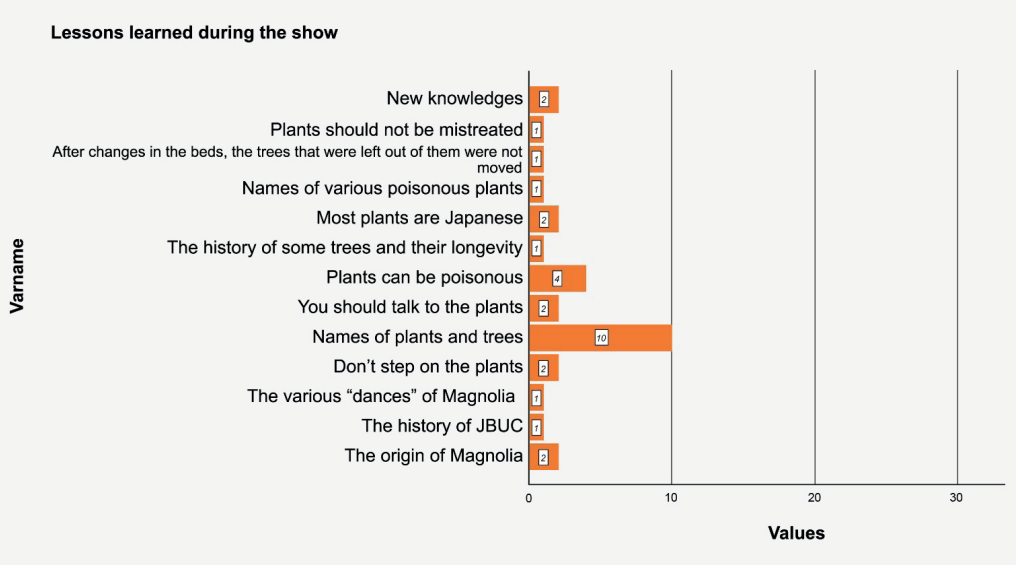

Illustration 1 - Acquired learning

One objective of this performance was to transmit knowledge about the different species of plants present in the Central Square - its main protagonists -, thus we asked the audience about the different plant species they heard about during the performance.
The plant that remained most in the participants' memory was "Magnolia", reported in 19 answers. This is probably due to the success the puppet achieved among the young audience. Other plants mentioned were, to a lesser degree, the Maple (Acer - 2 mentions), the Boxwood (Buxus - 2 mentions) and the Japanese sago palm (Cycas - 1 mention).

Significantly, three of these plants (Magnolia, Maple and Japanese sago palm) were referred to in those parts of the dramaturgy which included theatrical devices intended to captivate the audience. And the other one, Boxwood, was omnipresent throughout the Garden and was frequently referred to by the actor, for instance regarding its toxicity (which correlates in some way with the previous answers about poisonous plants).

It would have been interesting to have feedback from an adult audience, to compare with these results and try to conclude if these devices are especially effective to convey information to young audiences, or if adult audiences are equally susceptible to them.

Everyone stated they liked the performance (one said she loved it), and when asked what they liked the most, the acting and the magnolias stand out, which might suggest that presenting a magnolia puppet, with a voice, might have created a strong impression in the young audience (see Illustration 2).

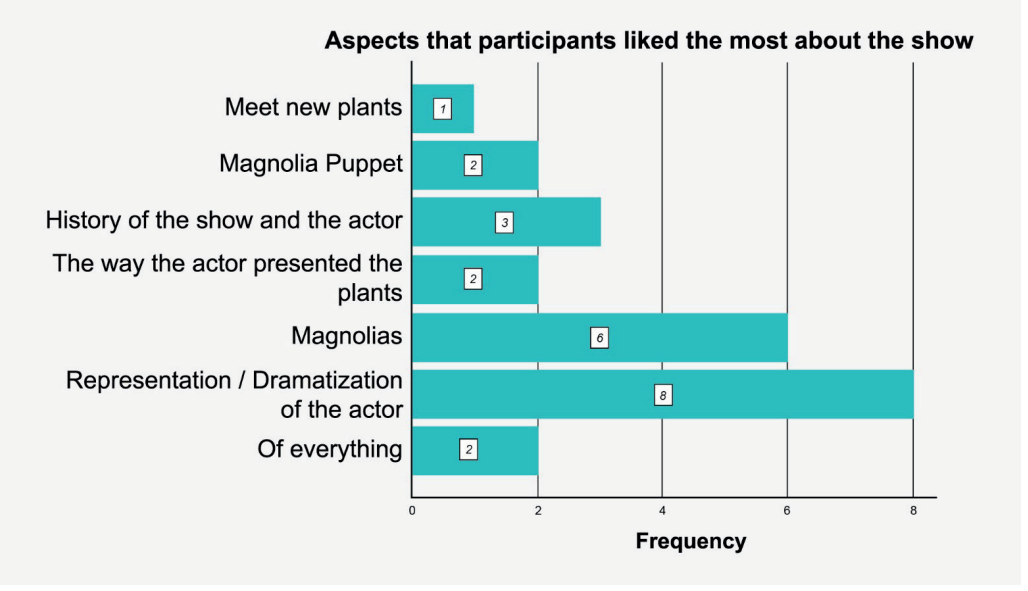

Illustration 2- Aspects that participants liked the most about the show

The performance of the play "The Boldness of Spring" reaffirmed that theatre is a powerful tool in the field of non-formal education. By the links to science performed during the play it was possible to promote the interdisciplinary and transdisciplinary construction of knowledge, outcoming to participants a new interpretation of reality.

Trough the questionnaires (Illustrations 1 and 2), it was possible to confirm the new knowledge acquired on the garden history or about specific characteristics and names of plants, while experiencing a pleasant outdoor session during the theatre performance. Some awareness and critical spirit of the participants was also evident (Illustration 1), pointing to a need of valorization of the natural scenario.

Both botanical literacy and particular plants characteristics, such as scientific versus common names, or medicinal or poisonous properties, were apprehended through a non-formal educative process, mobilizing the senses and emotions during the play.

The communication between the actor and the participants was well succeed and very positive (Illustration 2) and could enhanced new knowledge, acquisition, so broaden general and specific scientific information useful in daily lives.

Although this was a preliminary experience with a restricted sample, this case study showed that theatre about science can be a didactic, cognitive, and emotional tool, since it promoted learning, through a social interaction in a new environment. The results obtained from the questionnaires reveal a great predisposition of the participants to this type of non-formal activities in institutions such as the JBUC. They clearly recognized they learned something and at the same time they enjoyed the performance, a win-win situation.

In conclusion, we can consider that this performance, based on a book meant to teach Botany, enhanced this objective by linking public to the actor and the Garden through an alive and emotional experience, touch-to-touch. The plants were directly presented and identified, through a non-formal education context and in a pleasant and memorable experience.

The feedback from the audience also allowed us to establish significant links between some botanical knowledge gained from the performance and its dramaturgical content, which might be useful when developing future similar initiatives. A suggestion is to interpret the other eleven "acts" of the book, as plants show differences every month in that square terrace of the Garden.

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LAGRANGE PIE:
A BACK-AND-FORTH RELATIONSHIP BETWEEN ART AND SCIENCE... WITH ONLY ONE SIDE!

DANIEL ERICE
(Alioth arte&ciencia)

Hi, I'm Daniel Erice, at least in this Universe...

Well, I understand this must not be a very intuitive way of presenting myself. Or is it? Anyway, my nine year old son does take for granted that the Earth revolves around the Sun, and this is not very intuitive either.

How can he think that the very ground beneath his feet revolves around the sun at a speed of one hundred thousand kilometers per hour, without him noticing? May be even you believe the same crazy thing is happening as well.

But let's think a little bit about it.

When Galileo wanted to explain such a counterintuitive concept as heliocentrism, he didn't write a complex scientific treatise, written in latin… he decided to use theater.

So he wrote the play *Dialogo sopra i due massimi sistemi del mondo Tolemaico, e Copernicano* ("Dialogue Concerning the Two Chief World Systems" in English) in which three characters, Salviati, Sagredo and Simplicio, argue about the two main systems that disputed the explanation of the world in the seventeenth century: the ptolemaic geocentrism, and the copernican heliocentrism.

Of course, you can imagine which position Galileo gives Simplicio to defend.

And in part thanks to the use Galileo makes of theater, this new scientific concept, heliocentrism, got popularized, and gradually grew into something intuitive to us; to the point that nowadays we consider crazy a man or a woman who says that the Earth is at the center of the Solar System.

So let me start again: Hi, I'm Daniel Erice, at least in this Universe...

In fact, I wonder, can we change human's intuition about reality, as Galileo, following Copernicus's ideas, did with heliocentrism?

Can we help concepts so counterintuitive (such as the multiverse, quantum entanglement, or the relativistic view of space-time) become intuitive? Will one day my grandson take for granted that the four dimensional spacetime is curved by the presence of a mass… or an energy?

These were the questions that Alioth art&science wanted to answer in the project that I am now presenting to you: "Lagrange Pie". Alioth art&science is a multidisciplinary team made up of professionals from very different areas who are used to using both hemispheres of their brains,

at the same time! Physics, art history, music, plastic and performing arts, pedagogy and scientific communication are just some of the disciplines that Alioth uses to create educational and communication projects that explore the connections between art and science.

When we talk about this relationship, we often see just one side of the strip: how to use art for the popularization of science.

For this reason the focus of our project is on the "dark side" of that relationship.

Our goal is not to use theater to popularize science but to investigate how modern scientific concepts can change the way in which we write theater, because we believe (as Galileo did in his time) that art is the best way to make those concepts become part of human intuition.

So what did we do? We gathered a group of right-sided brain playwrights, together with a group of left-sided brain cosmologists. The group of playwrights had no specific scientific training, apart of a mere interest in science, and the group of scientists had no theatrical background.

José Sanchis Sinisterra (one of the best living representatives of Spanish theater, and recipient of the National Theater Award in 1990) was the coordinator of the group of playwrights, who belonged to the Nuevo Teatro Fronterizo, founded by Sinisterra.

On the other hand, the group of scientists was part of the Superior Council for Scientific Research (CSIC), the largest public institution dedicated to research in Spain and the twelfth largest in the world.

And then, when we had this two groups together, we introduced the main ingredient of this explosive equation: beer. But, of course, we drank it from a very scientific point of view.

Well, this is just a joke, but what is true is that our meetings didn't take place in an office, or in a rehearsal room, or in a theater… they took place in a bar.

So, around some lagers and some chips, cosmologists and playwrights together started to talk about the multiverse, about the difference between correlation and causality, about chaos theory and the three-body problem, about Schrödinger´s cat, or about travels in time... all of them very counterintuitive concepts.

Nothing was being written yet. We just talked, and talked, and talked… And the group of playwrights asked questions sometimes difficult to answer by the cosmologists. An intuition of how chaos, relativity or quantum mechanics work was starting to build in their minds.

After all these conversations we had the privilege to have Juan Mayorga on stage. Juan is a mathematician, philosopher, playwright, and the recipient of the National Theater Award in 2007. The second National Award that became part of our team... at least in this Universe.

Mayorga wrote us an initial scene full of suggestive and inspiring elements. It began as follows:

> *MARIA JOSE, a middle class, middle aged housewife. MARIA JOSE is preparing a heart-shaped cake. She seems to be following the instructions of a chef on TV, but what she is actually watching is a science program in which a French mathematician explains the theory of multiple universes. The mathematician frequently pronounces the surname Lagrange. Just as he says "Lagrange," the doorbell rings. MARIA JOSE interrupts her work and goes to answer the door.*
>
> MARIA JOSE: Samu! No, don't come closer, you'll get covered in flour!
>
> *(MARIA JOSE and SAMUEL kiss, stretching their necks.)*
>
> SAMUEL: I'd like to introduce you to my friend Toñi. Toñi, Maria Jose.
>
> MARIA JOSE: Nice to meet you.
>
> TOÑI: Same here.
>
> MARIA JOSE: But don't stand there, come in. Do you mind if we talk here while I watch the oven? (*She lowers the volume of the TV slightly, where the mathematician continues to speak.*) What temperature did he say? (*She puts the cake in the oven and adjusts the temperature.*) Two hundred degrees?

The kitchen gives off the warm smell of the freshly baked pie. But what looks like an ordinary visit of two friends, rapidly converts into an illegal gun sale between María José and Toñi.

> MARIA JOSE: (*She rearranges the cake in the oven.*) Try the Heidegger. The one with the white handle.
>
> *TOÑI takes the Heidegger.*
>
> MARIA JOSE: It shoots Jünger cartridges and has a double vee closure. It also fits well in a purse. Easy target as long as you're within ten meters.
>
> TOÑI: I don't know if I can get that close.
>
> SAMUEL: Don't you have something more accurate? Weren't you telling me about a French one with a differential?

After some haggling, Toñi decides to buy a Belgian one, the one used against the administrator of the community of neighbours. You can't miss with this even if you want to.

> SAMUEL: Maria Jose, Toñi has been making sacrifices for years.
>
> *Silence. MARIA JOSE doesn't give in.*
>
> SAMUEL: Maria Jose, I've told Toñi that you're not doing this for the money, but to help out.
>
> MARIA JOSE: I'll give you the first five boxes of ammunition for free.

TOÑI: Five boxes? I only want one bullet.
MARIA JOSE: I can wait. I'll save it for you until you can afford it.
TOÑI: I can't wait. We're celebrating our silver wedding anniversary on Saturday.

After agreeing on payment for the weapon the pie is ready.

Meanwhile, the mathematician continues to speak in the solitude of the screen. The last word he utters is "Lagrange".

And the scene ends.

At that point of the project we had just the first scene. To complete the play, this text written by Mayorga was handed to three different playwrights: Enrique Torres, Eva Redondo and QY Bazo. Each of them was given the task of continuing the story following different physical laws, as they had understood them during our conversations around the beers.

One of the playwrights should follow the theory of chaos, another one the laws of relativity, and the last one the laws of quantum mechanics.

No further help was given by the cosmologists. The playwrights had to complete their task just with the intuitions they had already built about chaos, relativity and quantum mechanics.

And so they did. After the conversations with the scientists, each playwright began to work individually and alone, carrying out personal research and investigations to resolve any scientific doubts that might have arisen. In this first creative phase there was no contact with the other playwrights so that their work would not be contaminated.

Once the first drafts of each universe were written, a meeting was held among the playwrights (without the scientists) in which the first blueprint of the play was read and commented on. The meeting was followed by a final phase of rewriting the scenes, in which minor adjustments were made.

So we ended up with a play in three acts.

The first one is composed by the initial illegal gun sale scene, and the continuation of the story in a chaotic universe. The author here worked with the butterfly effect and the concept of how a small change in initial conditions can drastically change the final results.

In this act, for example, Toñi constantly wonders what would happen if at the moment of shooting her husband, the phone rings, or a fly forces him to turn around, or a gust of wind opens a window,

or a strange itch makes him duck.... During the scene, as in the Newtonian three-body problem, the characters (and the dialogue) revolve around each other.

The second act starts with the exact repetition of the same opening scene, but now the story goes on in a relativistic universe. For this, the author worked on the concept of singularity and the possibility of time travels through wormholes.

In this act, we witness the rupture of the Aristotelian narrative structures (presentation, knot and resolution) thanks to the introduction of asides of the characters, in which they talk directly to the audience. With this theatrical device, the author reflects on the difference between the local spectator (the character) and the global spectator (the audience). The characters also show continuous lapses and failures of memory, and there are jumps in space-time, such as in the scene in which Maria Jose goes out to answer a call while Samuel and Toñi continue to talk in the kitchen. When she returns, she tells them astonished that she has just spoken with the same Toñi that she has now in front of her.

And finally, the piece ends with the third repetition of the opening scene, but in this case the story continues in an universe governed by the laws of quantum mechanics. In this case, the author worked with the superposition of states and the mental experiment of Schrödinger's Cat.

In this act, we discover that the scene of the arms sale is being recorded with a hidden microphone carried by María José, in an attempt to incriminate Samuel in a crime. But the microphone does not work properly, so, like the cat in the box, we cannot know if Samuel has been caught red-handed until we find out if the recording has been made (or not) correctly. The playwright also works with overlapping dialogues between the different characters, so that they are only understood when the spectator untangles them.

As they were written by different playwrights following their intuitions on different physical laws, the three stories had little in common. But some elements of the plot were present in all three scenes. And this resonance made the play achieve a unity that even we did not expect.

In 2013 the result was shown in the 5th Congress of Theater and Science held in Caceres (Spain), where a dramatic reading of the text was presented to the audience.

The process of rehearsals and creation of the staging was very short, lasting only three weeks, and was made possible by the loan of a part of the props and costumes by the Teatro Español de Madrid. As for the artistic decisions, we sought a simple and metonymic set design, in which an oven and a table were enough to signify a kitchen. In the background, projected on a panorama, the colors red, green, and blue, one for each of the acts to indicate their complementarity. The naturalistic costumes

helped to create contrast with the unrealistic situations that the characters lived. Finally, the decision was made that the three repetitions of the opening scene written by Mayorga would not be exactly the same. Small changes were introduced in actions (a coin that Samuel throws in the air falls to the ground in the third act), in costumes (in the second act Maria Jose wears a transparent apron), or in the performances (the relationship between Toñi and Samuel is different in the three acts).

Unfortunately some family and health problems prevented us from continuing with this project, but now we are planning to resume it and convert it into a radio theater play, with the support of the Institute of the Spanish Radio Television.

In any case, our goal with this project is not at all to explain the counterintuitive concepts on which the script is based.

As Galileo did with his "Dialogues", we just want to experiment if we can help to build a global intuition about the new scientific paradigms, and to investigate the other side of the strip that represents the relationship between art and science.

Although now that I think about it, the Möbius strip is a very counterintuitive object as well. Who would think that a single-sided, single-edged figure could even exist?

But then, maybe, and just maybe, the relationship between science and art is, like the Möbius strip, a single sided shape.

So let me end this article with the first sentence of the text "Lagrange Pie":

"I am Joseph-Louis de Lagrange, at least in this universe …"

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Figures

Fig. 1. Costume sketch of the character Mª José,
designed for the play 'Pastel de Lagrange' by Daniel González.

Fig. 2. Three scenes from the performance of 'Pastel de Lagrange' that took place at the Sala Trajano in Mérida during the 5th Scientific Divulgative Theater Conference, in 2013.

THEATRE ABOUT PHYSICS: HOW METAPHORS AND ANALOGIES FROM PHYSICS CAN HELP CREATE STORY THEATRE

ANNEMARIE HAGENAARS

My 45-minute monologue *The Story of The Einstein Girl* inspired by Philip Sington's novel *The Einstein Girl* is set in the early 1930s. Sington's story is told from the perspective of the protagonist, psychiatrist Martin Kirsch, who treats a young woman after she is found unconscious in the woods outside Berlin. She has no papers except for a handbill advertising a lecture by Albert Einstein. As Kirsch searches for the truth about who the 'Einstein Girl' is, he falls in love with her and then discovers that she appears to be Albert Einstein's daughter. Sington's story is fictional, but based on historical facts. Einstein and his first wife, Mileva Maric, did have a daughter before they were married. In 1986, a significant time after Einstein's death, letters were found in which he wrote to Mileva about Lieserl: "Aber siehst, es ist wirklich ein Lieserl geworden, wie Du es wünschtest. Ist es auch gesund und schreit es schon gehörig?"[84] No one knew anything about her until then. She was born in 1902 and it is not clear what exactly happened to Lieserl. She might have been adopted or she died.

As a writer and performer, I was curious about the theatrical effect of choosing the woman's perspective instead. *The Story of The Einstein Girl* is the story of Elisabeth Einstein a.k.a. Lieserl[85]. It starts in spring 1933 at the train station where Elisabeth is reunited with her daughter Anna. We next go back to October 1932 when she is at the clinic in Berlin suffering from amnesia. She then slowly remembers who she is and what happened to her in the woods. Eventually we go further back in time to the end of September 1932 at Einstein's summer house in Caputh, where Elisabeth confronts him with the fact that she is his daughter. This confrontation is so traumatic that she loses her memory and ends up in the clinic.

What would it be like to experience memory loss? And how would I communicate that lived experience to an audience? I opted to use metaphors from quantum mechanics and relativity theory; two theories in which Albert Einstein played an important role. The metaphors became the foundation of communicating physics through this play.

Analogical thinking is one of the fundamental cognitive processes of the human mind. It consists of dealing with a new situation by adapting a similar familiar situation. We learn in school that a basic function of analogies and metaphors is the transfer of emotions. Analogies provide a way to create specific and complex emotions for the reader (or listener) of the text that cannot be described without them. We learn when we are moved. We gain new knowledge by using analogies that map information from a familiar domain (source domain) to a new domain (target domain). These mappings however do not occur one-to-one, but through conceptual blending, a theory of cognition developed by Gilles Fauconnier and Mark Turner. The source and target domains are two input spaces which may initially very well be incompatible. They can be merged together in our mind by selecting certain elements from these input spaces and map those onto each other. From this blended output space the mind creates a new integrated concept. Eventually, all learning and thinking consist of

84 Translation German to English: "But you see, it has really turned out to be a Lieserl, as you wished. Is she healthy and does she already cry properly?"

85 'Lieserl' means 'little Elisabeth'

blends of metaphors that can be traced back to simple and concrete bodily experiences.[86] For example, the conceptual metaphor "Life is a journey" connects the abstract concept of life (target domain) to experiences one has when going on a journey (source domain). A journey has certain elements of time, a destination, a road map, unpredictable events, delays, etc. The elements from both "life" and "journey" blend together and we learn about the concept of life through this metaphor. Conceptual blends and metaphors were used in the script to enhance the story telling.

In the first hospital scene Elisabeth makes sense of her amnesia through the metaphor of a black hole. I chose this image because the black hole immediately speaks to the imagination. It is an astronomical object that has such a strong gravitational pull that everything falling in cannot escape, not even light. Once a light ray crosses the so-called event horizon (a black hole's "surface" or the point-of-no-return) we cannot observe it anymore. Just like memories that are hidden by the brain[87] and cannot be consciously assessed, the light rays are sucked into the black hole and get trapped in its deep infinite core. Using this metaphor, audience members might have learned something new depending on which domain was familiar to them. If they were familiar with the feelings of memory loss (source domain) they might have learned something new about the abstract concept of a black hole (target domain): "light rays" map onto "memories" and "(the unconscious part of the) brain" maps onto "black hole". For physicists in the audience who might have been more familiar with black holes than with the concept of amnesia, this might have been the other way around. In that case, (as is the case for the protagonist Lieserl who is a physicist herself) the black hole would have been the source domain and the experience of memory loss would have been the target domain. Audience members who might have been unfamiliar with either amnesia and the black hole, might have used the more familiar metaphor of a mirror that turns black and does not reflect any light, which is mentioned in the script as well. Therefore, different conceptual blending might have occurred in the minds of different audience members. What is important to creating story theatre specifically, is that the visual metaphor of the black hole helped the character in the story express the emotional distress of her memory loss and transfer these emotions to the audience.

> "The one in the white coat must be a psychiatrist. He says I suffer from amnesia.
>
> AMMMNEEEESSSSIAAAH.
> A black hole.
> Light cannot escape.
> Memories stick to the inside of my skull.
> Pulled back by gravity to the center of my head.

86 Embodied cognition is the idea that cognition is shaped by aspects of the body or the body's interactions with the environment. The sensory-motor system forms the basis of the representation of the abstract concept (target domain), because of a concrete bodily experience from the source domain.

87 Note that the wording "memories hidden by the brain" is already a conceptual blend in itself.

Are they still there?
I can't catch them.
They're invisible.
Hidden behind the horizon
where behind the event horizon time and space switch roles and nobody sees it"

Towards the end of the play, after remembering what has happened to her, Lieserl shares with us her experience regarding the uncertainty about her identity. Besides the black hole metaphor for amnesia, I also use references to quantum mechanics (QM). This theory of physics describes the behavior of particles at the atomic level, which is different from the classical world. We are used to objects being measurable at a certain place at a certain time moving with a certain velocity. QM describes the position of a particle being both in place A, place B, etc. at the same time with a certain probability. Once you measure the position of the particle, you cannot know the velocity and vice versa. This counterintuitive behavior is described by the wave function and Heisenberg's uncertainty principle. The thought experiment often used to illustrate this is Schrödinger's cat trapped in a box with poison being released if a radioactive atom decays. Before the observer is peeking into the box, the atom has both decayed and not decayed (radioactivity is a quantum process). Does that make the cat both dead and alive at the same time? Einstein tried to "solve" this problem of QM not knowing position and velocity at the same time by introducing the hidden-variable theory, and stating that QM was only a statistical theory, not a complete theory yet, and thus insufficient to describe the exact position of the particle. All the above references to QM became metaphors for the woman's identity crisis:

"My life is a quantum story
Both true and not true
He[88] doesn't believe in quantum mechanics.
That something can be and at the same time cannot be

He hates the uncertainty
He wants to measure me.
His measures will transform the wave function in such a way that it no longer oscillates, but spikes.
As long as he hasn't looked into my head, I am both perpetrator and victim.
Both good and bad
Both dead and alive
He cannot stand the idea that I'm not one or the other
He doesn't know me
And not because he lacks information[89] about me,
but simply because I am all there is to know."

88 Reference to Albert Einstein who denied both the existence of quantum mechanics the way it was presented by physicists at the time and the existence of his daughter in the play.

89 Reference to the hidden-variable theory proposed by Einstein, Podolsky and Rosen.

I also combined both metaphors, for example in this excerpt:

> "I don't exist, do I?
> I'm dead, aren't I?
> I'm dead and I'm alive
> I am and I am not.
>
> He gave life to me and now he denies me.
> He wishes I had never been born.
>
> Is light only light if it is being observed?
>
> I'm going in.
> My head first.
> It falls into the hole much faster
> than my feet.
>
> And I'm gone.
> Invisible to the outside world.
> Infinitely far away.
> Trapped in the black hole
> that is my brain."

I performed the script in two different ways. I worked with Dutch director Sylvia Weening first and then later with American director Michael Luggio, who had opposing approaches to creating theatre. Besides minor adjustments in the script, the major differences were in stage lighting, stage setting, blocking, music and the acting style. The different directions of *The Story of The Einstein Girl* have both been performed in Dutch and English.

Under Weening's direction, the lighting design was inspired by the image of the past and future light cone.[90] I would walk over from one spot on stage to another depending on the time and place in the story. During these transitions, there was music. The stage was empty. The acting was towards the audience, the storytelling balanced and modest. We minimized the use of illustration in image and setting, because the content of the script is very dense and philosophical. We focused on the pace and rhythm of the words and on the vocal technique that was necessary to tell the story in a clear and efficient way.

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90 At one point in space and time, a light ray can travel all the paths that are represented by the cones from the past, into the future.

On the contrary, under Luggio's direction there was initially no design concept.[91] There was a train station bench, a mirror, and I was carrying a suitcase. The focus was on a more realistic and cinematic way of acting that included the so-called fourth wall[92], similar to Method Acting. It was about the internal drive of the character and how to physicalize this as the actor by actions.[93] It was less focused on the vocal technique of the actor. The acting also guided the initial blocking and then later choices were made about my movements on stage.

The creation of my show was never intended to be an experiment. It organically grew into one. Responses about the performances at the Amsterdam Fringe Festival 2012 and the Woudschoten Physics and Didactics Conference (where 600 physics teachers attended), and amongst students at secondary schools all over the Netherlands, made me see the value of what the The Story of *The Einstein Girl* meant for physics communication and how well it was perceived (see figure 2). The performance made "difficult physical concepts visual" and brought "feelings to physics".

If I had initially set up the theatre project as a practice research, I would have conducted a thorough written survey amongst audience members at the festival, the conference and the schools to be able to show in statistics what the effectiveness was of the metaphors and analogies in communicating scientific concepts. I would have asked them to fill out the survey after they had seen either the Dutch version or the American version. I would have asked more in-depth questions about the metaphors from physics that had been used and those results might have taught me more about the learning that happens through conceptual blending. I would have clearly defined the different domains of the conceptual blend in the survey and I would have then related multiple questions about these blends to aspects of the different versions. Currently I do not have all the significant data to draw strong, specific, and justified conclusions about which version worked better to communicate the metaphors and in what way. However, the feedback I received from audience members did teach me that depending on how the metaphors were presented to them in terms of acting style, staging, light plan and sound design, images from physics came across stronger in either one version or the other depending on the individual. The American version was more 'like a film' and the Dutch version more 'as if reading a book':

"In the Dutch version I liked the modesty and way of telling the story. You could really form your own images of spaces and situations. In the American version, the emotion you showed was especially beautiful. I preferred the Dutch version."

91 Music and a light plan were added later when working with a local technician at the different theaters.

92 The fourth wall is an imaginary wall separating the actors from the audience. The audience can see through this wall onto the stage. The actors act as if they do not see the audience watching them.

93 The technique of living the character by building emotional layers, was founded by Konstantin Stanislavsky and further developed by Lee Strasberg, Stella Adler and Sanford Meisner.

"I like the American version better than the Dutch version. I very much enjoyed the more cinematic influences in the American version. The whole piece now seemed a lot less abstract than in the Dutch version."[94]

At the secondary schools, I would give a 45-minute introductory lecture about the creation of the show, the historical setting and the basics of quantum mechanics and relativity theory by referring to the metaphors I used in the play. This lecture integrated the courses CKV (Arts and Cultural Education), history and physics. *The Story of the Einstein Girl* became a school project that could also be used for credits by students for the course CKV.[95]

From this report on practice it follows that metaphors and analogies from physics can help create story theatre. They can provide strong symbolic and emotional images to build the story and help audiences understand the abstract parts, such as memory loss and the experience of an identity crisis. Without analogies these concepts are difficult to translate into words. The metaphors also inspired audiences to learn more about the background of the play. They were not only curious about the novel *The Einstein Girl* by Philip Sington, but also about the physics on which the metaphors were based: the black hole, relativity theory and quantum mechanics.

The play was written by using two different metaphors from physics, the black hole as a metaphor for the (unconscious) mind and different aspects from QM, such as the uncertainty principle and Schrödinger's cat, that provided a poetic way to communicate the woman's questions about her life and existence.

The metaphors and analogies from physics proved to be effective in communicating the story, because audiences responded that difficult physical concepts were made visual and that feelings and physics came together. This result is also supported by cognition studies in conceptual blending. Whether or not the metaphors made audience members more knowledgable about the theories themselves remains a question to be researched.

Through use of metaphors and analogies artists can create an inviting learning environment for the audience by choosing their source and target domains wisely, inspiring curiosity to look further into the science and concepts presented. *The Story of The Einstein Girl* proved to be a unique case study to demonstrate that the practice of theatre can be deeply enriched by drawing inspiration from the sciences while simultaneously providing a form of physics communication.

94 Responses from two different audience members Laura de Bonth and Tijl Kindt respectively at the Amsterdam Fringe Festival. They were amongst those who saw both versions.

95 I became a Culture Card Acceptant. My theater production company was recognized as an organization offering educational shows. It also made it easier for schools to book my show, and use money that was provided by the Dutch government for the course CKV in particular.

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YOU SHOULD BE OLD ENOUGH NOT TO BE AFRAID OF SPIDERS

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The high incidence of spider fear and phobia persists although spiders are not actually very threatening to humans in modern industrialised societies (LoBue, 2010). Nentwig et al. (2022) present a quick overview of the impact of fear in humans and, according to their work, an estimated 25–50 % of people in developed countries loathe spiders and about 5 % of the population is genuinely afraid.

Several reasons are often pointed to explain such fear. A study by New and German (2015) showed that spiders demonstrated a singular ability to surmount inattentional blindness and capture viewers' attention despite a very brief, unexpected, and peripheral appearance. This bias of enhanced visual attention is present as early as in preschoolers (LoBue, 2010), and is supported by either the increased pupillary dilation recorded in 6-month-old infants (Hoehl et al., 2017) or the presence of a basic perceptual template for spiders in 5-month-old babies (Rakison & Derringer, 2008). Spiders seem to constitute an evolutionarily relevant threat that humans were not only biologically prepared to fear but also reflexively perceive (New & German, 2015), constituting an inherited cognitive category shared by humans based on co-evolution (Landová et al., 2021).

Mediaeval superstitions may also have played a role in the perpetuation of myths and misconceptions when it comes to spiders (Nentwig et al., 2022). Particularly in Europe, spider induced disgust related to illness dissemination became popular from the tenth century on. These arthropods were associated with the spread of several devastating epidemics that mortified the old continent from the Middle Ages onwards, suggesting an important role of culture in the persistence of fear among Europeans (Davey, 1994, Nentwig et al., 2022). Nowadays, social networks contribute to a fast spread of sensationalistic media reports, not so seldom containing scientific errors. Moreover, a bias towards the dissemination of fake news regarding spider bites may also play an important role in the misconception of the real threat posed by spiders (Mammola et al., 2020, Mammola et al., 2022).

Finally, a reduction in nature relatedness, i.e., the connection of humans to nature, may also play a role in the increase of fears and phobias, namely towards spiders (Zsido et al. 2022).

But is it worth it? Spiders are old creatures, endemic to all continents, except the Antarctic[96], and occupy a plethora of different habitats, from terrestrial to marine environments, from places with an absolute minimal temperature of -71.2ºC to areas reaching 56.7ºC ground temperature, from 418 m below sea level, to over 6000 m above sea level (Mammola et al., 2017). Due to their ballooning abilities, they are excellent dispersers (*e.g.,* Kuntner & Argnasson, 2011) and account for the batch of early colonisers of numerous environments (*e.g.,* Soto et al., 2017). From an ecosystem service perspective, spiders do play very important roles, from pest biological control in agricultural landscapes (Birkhofer et al., 2018, Cross et al., 2015) to local scale indicators of ecosystem disturbance in forested

96 World Spider Catalog. http://wsc.nmbe.ch
See https://eol.org/pages/166/maps and https://www.gbif.org/species/1496

landscapes (Pearce & Venier 2006), coastal sand dunes (Bidegaray-Batista et al., 2017) or riparian environments (Reyes-Maldonado et al., 2017). It is possible to find inspiration for technological innovation upon spider's locomotory and sensory systems (King, 2013, Kang et al., 2014) or to attain medical and pharmaceutical innovations by studying these eight-legged arthropods' venom (Saez et al., 2010, King & Hardy, 2013).

In fact, spiders hold an outstanding number of world records and curiosities (Mammola et al., 2017) quite suitable to be used by educators and science communicators under an informal approach set to help transform fear into curiosity.

Working with spiders since 2004, the author Rui Carvalho was many times presented with the gap between the perceived and the peril they pose. On exchanges with Andreia Valente, who had a strong background in science communication and education through art, a project that aimed to bridge this gap was born.

Science communication as a form to willingly bridge scientific knowledge to the general audience has many forms, of which theatre is one of them (Brake & Weitcamp, 2009). With education being a relevant part of their mandate, museums, universities and research institutes have conveyed knowledge to the audience in appealing and effective manners with long lasting effects through theatre (Weitcamp & Almeida, 2022).

Under that perspective, considering a concrete science communication need, and to tackle the previously set challenge of helping people surpass their fear and make them in awe of spiders' capabilities, we decided to approach the audience through this form of art.

The play "You should be old enough not to be afraid of spiders" is based on the three minute talks taken to the semi-final and final of the science communication contest FameLab of 2019, where Rui Carvalho played the role of a small girl afraid of spiders in the semifinal, and in the final as a grieving spider mourning a deceased relative. It was not aimed to deconstruct the specific phobia regarding spiders (arachnophobia), but to address the all too generalised dislike these arthropods provoke, while inciting the viewer's admiration around such a substantially diverse and creative group of animals. The story was built on the assumption that a careful use of humour may serve as a powerful tool to convey scientific information (for a review on the matter, see Riesch, 2015), predisposing the viewers to connect with the characters' flaws and inner questions, even if for a moment the character is a spider. The spider was a very lovable customised homemade XXL fluffy doll with a radius of about 3m, inspired in a children's book that Andreia had previously illustrated, telling the story of a Pholcidae spider who decides to travel around the world. In the process of creation of the play, it should be noted that both the idea of the doll and the seed for the play were set by the challenge of scientific peers.

The overall play structure was set while working side by side, but the real writing happened online, as the authors were living with half an ocean between them.

The script was created in two steps. First, there was the specific intention of inviting the viewers to contemplate the uselessness of the fear triggered by spiders. Then, the audience was presented with the facts we believed to have the highest potential of creating admiration towards these animals. The text came to life in blocks that were worked on separately, and smoothed by permanent feedback. The choice of jokes was, first of all, based on what made both authors laugh. The introduction of music was inspired by the work of the comedy double Sammy J and Randy[97]. The play was taken to the stage in May 2019, at the Centre of Science of Angra do Heroísmo (CCAH), Azores, Portugal, after a couple of weeks of online rehearsals Although our target audience were children - and therefore the whole dialogue was appealingly infantilised - we felt the urge to involve their families. It was important to try to dissolve the emotional barrier of many parents who actively and indiscriminately fear spiders, allowing for a potentially new household perception of these arthropods, reducing the potential internal friction from this new mindset about spiders.

The play tells the story of a 5-year-old girl named Vanessa who starts a hunger strike to convince her family not to kill the Pholcidae spider living in her room. Through her long and difficult 37 minutes of food deprivation, she meets Dr. Vasques, an arachnologist all too willingly to talk about spiders with whomever may listen, yet unable to communicate with laymen. Along the play, Vanessa dismantles the scientist's jargon into a comprehensible language, while learning from him about the amazing world of behaviours and survival strategies spiders possess. She understands their importance in the ecosystem, not forgetting that they are wild animals. The remaining fear Vanessa felt towards spiders becomes curiosity and the little girl can now actively talk her parents into respecting these animals, while naming her roommate "Hope".

After the play, participants were invited to observe real Pholcidae and *Steatoda* sp. specimens that had been placed in sealed jars for the purpose, with the help of magnifier lenses. The safety sensation provided by the impossibility of the contained spiders coming out of their jars allowed nearly all participants to accept this final extra challenge.

In order to measure the impact of the overall activity in the emotional perception of spiders, all participants – children and adults – were invited to share their views by placing a vote in one of three jars marked with happy (3), neutral (2), or sad (1) smileys. This method was repeated before and after the initiative. Two voting papers with an equal number were handed to each participant before the play and a colour code distinguished child from adult votes.

97 https://www.youtube.com/watch?v=E6K66u9kWks&list=PLbBADJCHntK1wBxbJAxbc9kyM9 96A64aq

A total of 42 child and 62 adult valid responses were collected. Average mean perception of spiders was positive in both groups, though higher in adults when compared to children, both before (m_{ad_b}: 2.39 vs. m_{child_b}: 2.14) and after the play (m_{ad_a}: 2.81 vs. m_{child_a}: 2.67). Although age and its related life experience seem to play a role in the deconstruction of spider-related fear (Nentwig et al., 2022), it is worth to note that a relevant share of the adult public had some scientific background, which may contribute to some degree of bias in the results.

The ANOVA shows that a significantly positive evolution occurred in the emotional perception, both in children ($p=0.0189$) and adults ($p=0.0087$). Results were considered significant for *P-value* < 0.05.

In addition to the statistical evidence, it is also noteworthy to add the array of positive feedback received from the play's viewers. Comments like "I still don't like them, but I started putting the spiders out of the house whenever spotted" further support our conviction that theatre was extremely relevant to the success in conveying the desired message. The tone set, its musicality and funny core all along an unexpected chain of events might have turned the dice on the success side. Also, the viewer's feedback allowed for the identification of the text vulnerabilities that ought to be addressed in future presentations.

Despite the encouraging results, the pandemic situation has put on hold the feasibility of this project. We expect to resume this play in a near future, along with other science related activities, to further contribute to the undoing of fear regarding spiders.

Figures

Fig. 1 – Poster of the play

Fig. 2 – Vanessa and Dr. Vasques interacting

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