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Inter- and transdisciplinary reasoning for action: the case of an arts–sciences–humanities intervention on climate change

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Abstract

Inter- and transdisciplinary (ITD) approaches represent promising ways to address complex global challenges, such as climate change. Importantly, arts–sciences collaborations as a form of inter and transdisciplinarity have been widely recognized as potential catalysts for scientific development and social change towards sustainability. However, little attention has been paid to the process of reasoning among the participants in such collaborations. How do participants in arts–science collaboration reason together to overcome disciplinary boundaries and to co-create interventions? This article investigates how *inter- and transdisciplinary reasoning* (or ITD reasoning) unfolded in a collaboration involving experts from the natural sciences, humanities, and the arts. We studied how collaborators reasoned through different understandings and experiences of climate change as well as through multiple ways of fostering motivation to take action via two co-designed artworks, HOMONEXUS (a participatory textile and acoustic installation) and GLACIER NEX US (a performance staging a dialogue between a melting glacier and a glaciologist). Our conclusions are threefold: (i) ITD reasoning can increase participants' capacity to navigate often-unpredictable situations by cross-fertilizing ideas and overcoming blind-spots; (ii) humanities in arts–science collaborations can foster a more nuanced understanding of the differences and similarities of different knowledge systems as well as a deeper ecological understanding of sustainability problems; and (iii) the aesthetic experiences stimulated by arts–science interventions may help to raise awareness about the climate emergency and sustainable actions by providing pleasant and positive or dazzling and negative aesthetic experiences.

Keywords ITD · SciArt · Epistemology · Aesthetic · Science communication · Research teams · Sustainability

Introduction

To address complex social-environmental problems of contemporary societies, such as the climate emergency, multidimensional approaches are necessary. Research collaborations mobilizing diverse disciplines and knowledge systems are one of the approaches that may support sustainability actions and interventions (Chambers et al. 2021). These collaborations are often challenging also because of the numerous asymmetries that characterize them, which are due, among others, to differences in methods, intellectual resources, and practices as well as to power differentials of disciplines in academia (Poliseli and Leite 2021). Yet, collaborative research may support pluralistic processes of knowledge co-production that engage knowledge both from academic disciplines (interdisciplinarity) and from society (transdisciplinarity) (Norström et al. 2020; Pereira et al. 2018). These two are often mixed and it is possible to talk more generally about inter- and transdisciplinary (or: ITD) research (Bammer 2005; Freeth and Caniglia 2020). An example of ITD work representing a potential catalyst for social change is arts–sciences collaborations (Edwards 2008; Root-Bernstein 2000; Root-Bernstein and Root-Bernstein 1999, 2004).

By connecting knowledge from the arts and from many other disciplines, artists and scientists together can contribute to addressing the climate emergency, among others, by

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articulating the interconnections of environmental, social, and cultural values, by creating visions of alternative futures, and by mobilizing alternative perceptions and experiences (Bentz 2020; Galafassi et al. 2018a, b; Heras et al. 2021; Tosca et al. 2021). Collaborations of this nature can scrutinize the cultural divides separating the arts, the natural and social sciences, and the humanities (Hulme 2014, 2016a; Page 2021). Further, it is increasingly clear that bringing together methods, practices and theories from the arts and different sciences can increase explanatory power as the two approaches are complementary rather than exclusionary when interrogating, exploring, and understanding complex real-world situations and challenges (Cardenas and Rodegher 2020).

However, little attention has been paid to how participants in collaborations across arts and sciences reason together when dealing with the numerous divides characterizing arts–science processes (Cardenas and Rodegher 2020). Considering that conventional scientific methodologies do not entirely grasp the reasoning that characterizes such arts–sciences collaborations (Dunbar 1995), most work on ITD has focused on scientific collaborations where the involvement of perspectives from arts and humanities are often peripheral (Hulme 2018). Therefore, there is a lack of insights about how reasoning unfolds and how knowledge is generated and deployed in these collaborations, especially considering the many asymmetries they present. In this paper, we use the case study of an art–science–humanities collaboration, that involved artists, scientists, and philosophers: the project *Evolving Futures: Owning our Mess* (henceforth: *Evolving Futures*). We specifically investigated how *inter- and transdisciplinary reasoning* (or: ITD reasoning) unfolded leading up to the co-design of two artistic interventions: HOMONEXUS and GLACIER NEX US. We understand ITD reasoning as a collaborative practice that consists in giving reasons through discourse and dialogue for the sake of coordinated decisions and actions (Laursen 2018). ITD reasoning thus encompasses communication across different perspectives, standpoints, and positionalities in a process of mutual learning. By unfolding the ITD reasoning, we chronicled and explained how participants conveyed their own knowledge and dealt with disciplinary differences when co-creating interventions.

This paper is structured as follows. First, we explain the theoretical and methodological approaches used to reconstruct the ITD reasoning in an art–science–humanities collaboration. Second, we present the case *Evolving Futures* and the two products of the collaboration (HOMONEXUS and GLACIER NEX US). Third, we present the results of our analysis through a narrative that captures salient trajectories of the ITD reasoning through a conceptual map. Fourth, we discuss how knowledge of ITD reasoning can improve ITD practices, the role of the humanities in arts–science interventions, and the potential of aesthetics experiences to nourish reflections about the climate emergency. Finally, we conclude by arguing for the importance of furthering our understanding of reasoning processes in ITD collaborations more generally.

Theoretical and methodological approach

This paper investigates ITD reasoning as a central epistemic process of ITD work. Thus, here we start by presenting the current debates about the role of reasoning in collaborative research as well as how focusing on reasoning can disclose important dynamics of arts–sciences work before introducing the mixed-methods approach that allows us to capture the profusion of features necessary to understand the complexity to ITD reasoning in arts–sciences collaborations.

Theoretical approach: ITD reasoning in arts–sciences–humanities collaborations

To understand how participants in ITD navigate disciplinary boundaries, we focused on the epistemic process of ITD reasoning, that is on the thought progression and reasoning taking place during a collaboration which might include moments of differences, disagreements, convergences, integrations (Pohl et al. 2021; O'Rourke and Crowley 2013), and mutual learnings (Freeth and Caniglia 2020). In providing a theoretical framing, we rely on works that have conceptualized reasoning (Wright 1995) and collaborative reasoning as: (1) *goal-directed*, such as when aiming to co-design and co-create interventions or to generate better understandings of a phenomenon (Laursen 2018); (2) *embedded in multiple communication acts*, from linguistic (e.g., an explicit argument) to non-linguistic (e.g., as embedded in artifacts or protocols) (Campolo and Turner 2002); (3) *enabled by (and enabling) coordinated efforts*, such as through the development of shared language, agreed-upon objectives, or intersubjective standards of reasoning (Laursen 2018); and (4) also as intrinsically characterized by *aesthetic dimensions* (Wood 2014). However, we also point out that reasoning together with arts–science–humanities collaborations present peculiar features in all four respects.

First, in relation to its goal orientation, arts–sciences collaborations in the field of sustainability have transformative goals (Bentz et al. 2021; Galafassi et al. 2018b), differing considerably from other kinds of research that aims to develop explanations. Hence, their purpose is not much to provide better explanations or understandings of phenomena, but rather to co-create interventions that may support shared agency and potentially motivate towards sustainable actions (e.g., leveraging emotions to motivate people and generate change). The inclusion of the humanities

(especially philosophy of science and science studies) within an arts–science collaboration also provides opportunities for reflexive contextualization that contribute to shaping the goals of the ITD collaborative reasoning (Eigenbrode et al. 2007).

Second, because of the specific arst–sciences–humanities nature of this collaboration, the ITD reasoning includes more tacit, non-linguistic, embedded, and embodied forms of knowledge (Heras et al. 2021; Tosca et al. 2021). The specifics of the arts–sciences collaboration permeate the collaborative reasoning allowed, such as through complementary understanding of systems thinking that also includes aesthetic dimensions (Kagan 2014) or through the use of design practices for the visualization and development of abstract concepts and theories (Peukert et al. 2020).

Third, the standards of ITD reasoning in an intervention-oriented collaboration differ from those of explanation-oriented research (Laursen 2018). When aiming for the co-design of an intervention, rather than for the explanation of phenomena, art–science collaborations require the negotiation of standards that enable practical forms of reasoning towards the generation of *multivocal* interventions (Caniglia et al. 2021). *Multivocal*, in this case, refers to how ITD reasoning may inform the co-design of interventions that embed a multiplicity of knowledge and perspectives in ways that do not look for agreement, but rather capitalize on difference, recognize incommensurabilities, and embed dissonances (Gehman et al. 2018). *Practical standards of reasoning* refer here to the process and capacity of agreeing on what reasons count as adequate when deliberating about what to do (e.g., how to design and implement and intervention together) rather than about what is true or false, valid or invalid. These standards might be set in advance (e.g., in the conception of a project by the organizers) or might emerge during the collaboration (e.g., when dissonance and conflicts emerge). They are embedded in the process of answering questions, and providing reasons for our answers, such as: Who is entitled to share their opinion about what should be done? How can we decide what aspects of a research or artistic practice may inform an intervention? What constitute a good intervention? The practical standards of reasoning (emerging when addressing such questions) in an intervention-oriented and multivocal collaboration may be made explicit in statements such as: everyone participating in the project is entitled to share their opinion about an intervention; or take into consideration everyone's knowledge and research or artistic practice when developing an intervention; and a good intervention (i.e., one that fulfills intended goals) will incorporate the best of everyone's insight.

Fourth, aesthetic dimensions are present throughout science (i.e., thought experiments, beauty, imagination, creativity, and so on) (Ivanova and French 2022). They help scientists to create explanations, develop theories, test hypothesis, and understand phenomena (see Poliseli 2020; Poliseli et al. 2022). However, in arts–science collaborations focusing on environmental emergencies, the aesthetic dimension can also serve as catalysts for intrinsic motivation. As famously asserted by Herbert Marcuse: "art cannot change the world, but it can contribute to changing consciousness" (Marcuse 1978, p. 33). In this sense, beside the entertainment side of it, artistic approaches can offer profound (although often temporary) reminders by imagining future environmental scenarios (Klaver 2014). Thus, art–science work can enable, provoke, solicit, and seduce collaborators and participants to become aware that some of our habits denigrates people's quality of life and downsizes nature and the environment (Wood 2014).

Methodological approach

Following the ITD reasoning as a collaborative endeavor implies reconstructing how reasoning unfolded in specific moments. In the context of an art–science collaboration, it is thus important to consider that ITD reasoning aims at generating interventions rather than explanations and it is often highly embedded, embodied, and tacit (see above in the section "Theoretical approach: ITD reasoning in art–science–humanities collaborations"). Thus, to capture these complexities, we adopted a methodological approach that rests on the premise that we need to think, practice, relate, and know, in unhackneyed ways, also adopting methods that are slightly unusual (Law 2004). Hence, we used a mixed-methods approach combining ethnographic tools, content analysis (CA), and conceptual mapping together with philosophical and sociological reflections. This mixed-methods approach allowed us to reconstruct and narrate the (intervention-oriented and embedded) process of ITD reasoning related to climate change, sustainable actions, and intrinsic motivation in the collaboration.

Data from this collaboration were collected through participant observation, questionnaires, video, and audio recordings from workshops, collaborative dynamics, field notes, personal communication, grant report, and moderators' materials over a period of 3 months. The > 7 workshops were video and audio recorded, and further transcribed. The questionnaires were applied previously to the start of the collaboration and after the end of the collaboration. Both questionnaires were semi-structured (Mattar 1994) following a strict composition of questions that allowed us to gather information about the collaborative participation, conceptual aspects of Water–Energy–Food nexus/climate change, and the limits and benefits of integrating arts and sciences.

CA (Bardin 1977) was adopted to structure and organize data collected from all distinct instruments above-mentioned. CA was applied due to its set of communication analysis techniques that allows to obtain indicators helping

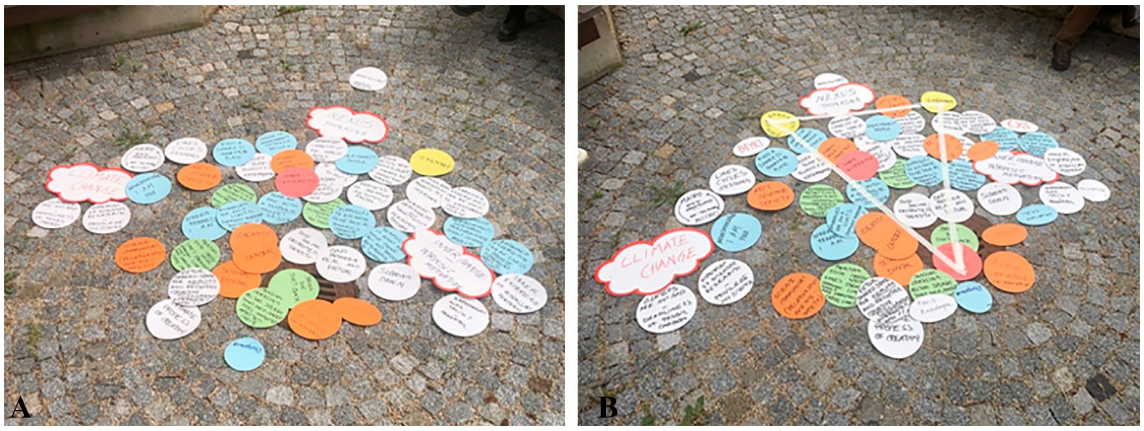

Fig. 1 In the *Theoryssage*, the core concepts of the project were visualized through white-red clouds; white and light-blue circles represent insights that emerged from the exchanges during the collaboration; orange and red circles represent new conceptual clusters that emerged during the whole process (**a**). The geometric form emerged during the activity to represent potentially new ways of considering the interconnections characterizing discourses around climate change and inner transformation (**b**)

in the inference of knowledge regarding the conditions of reproduction/reception (inferred variables) of the messages. This is possible by selecting meaningful data and rejecting non-significant data: separating and uniting; hierarchizing and centralizing the information received. It finds a series of meanings that are further categorized. To code or characterize a content is to place it in one of the defined equivalence classes, based on the meanings, depending on the coder's judgment. These categories are organized by themes according to shared elements. Therefore, CA was used to systematize and identify more than 80 subcategories of analysis that emerged during the workshops and questionnaires. These categories were subsequently clustered in ten thematic groups in relation to the major themes involved in the discussions during the collaborations. The triangulation of those thematic groups occurred at the *Theoryssage*.

The *Theoryssage* event took place a week after the two interventions (HOMONEXUS and GLACIER NEX US) and aimed at identifying conceptual clusters emerging from individual and collective reflection regarding climate change interventions (see the section "Goals and organization of the collaborative process"). It was a structured process of reflection on participants' main contributions during the co-production and mutual learning process. The topics that emerged that seemed to be essential in generating inner transformation in relation to climate change were identified (through colored paper circles), presented by the participants, and then organized spatially in relation to one another (see Fig. 1). The insights gained through this exercise were triangulated (Patton 1999) and compared to the thematic categories that emerged through CA improving their robustness in the elaboration of a conceptual map (see Fig. 4).

A *conceptual map* (Ausubel et al. 1980; Novak 1998; Novak and Gowin 1999) was constructed after these categories were identified and triangulated, to display the process of collaborative reasoning. The reasons to choose conceptual and mental maps were three. First, both are schematic structures that represent a set of concepts immersed in a certain propositional context (Tavares 2007) which amounts to diagrams that show conceptual significances, relations, and hierarchies. Second, they help us to see the progression of concepts and ideas (Powell 2010) as they can be processual and representational (Gieseking 2013) but never complete (Kitchin and Dodge 2007), helping to reflect on the process-oriented approach used in the designed workshops. And third, although there were epistemic asymmetries between the knowledge background and skills among the participants (which is expected due to the nature of ITD approaches), no disagreements, or collaborative impasse occurred during the workshops, only the expected tensions from the discussions induced by the process-oriented approach bounded by the theoretical space of *Evolving Futures*.

The collaboration in *Evolving Futures* embraced the emergent nature of learning and knowledge co-production (Norström et al. 2020; Pereira et al. 2018), which does not require the elaboration of a previous hypothesis or theory-testing process, as it would occur in more conventional processes of knowledge production in the natural and social sciences. Thus, the insights generated through our mixed-methods approach were purposely situated, context-sensitive, and multivocal (Galafassi et al. 2018a, b). In this sense, and as often within arts-based research, the construction and assessment of the ITD reasoning followed an inductive approach to data generation and analysis that allowed us to grasp the complexity and open-ended nature of such experience.

The case study: *Evolving Futures: Owning our Mess*

*Evolving Future*s, our case study, allowed us to capture and reconstruct the specificities of ITD reasoning. The project was initiated by the think-tank *artEC/Oindustry* and jointly developed with the Konrad Lorenz Institute for Evolution and Cognition Research (KLI) under the fund StartClim2020. The initiative took place for the most part online during Winter 2021 and in the last phases in hybrid form in the Spring. *Evolving Futures* crafted an experimental space that combined arts, sciences, and the humanities (especially philosophy of science, cognitive science, and science studies) to generate interventions to contribute to nurture regenerative and transformative approaches in addressing climate change.

Goals and organization of the collaborative process

Evolving Futures aimed at finding ways to co-create art–science interventions that could generate intrinsic motivation and agency for climate awareness and behavioral change in the audience while also relying on understanding complex relationships connecting behaviors and the climate emergency. The ITD team was composed of 2 artists (Artist 1 and Artist 2), 1 climate scientist and glaciologist (Scientist), 2 philosophers of science [one ethnomusicologist (PoS 1) and one participant observer (PoS 2)], 1 sustainability scientist (Moderator 1), and 1 art historian (Moderator 2). The general design of *Evolving Futures* drew on frameworks and approaches from ITD sustainability research (e.g., Bammer 2005; Haider et al. 2018). The project especially crafted a collaborative space of knowledge co-production and mutual learning. Reflections on moments of comfort/discomfort (Freeth and Caniglia 2020; Chambers et al. 2021) and agreements/disagreements (Poliseli and Leite 2021) supported mutual learning and joint ITD reasoning (for more details, please, see Table 1).

Topics and co-design of the artistic interventions

Evolving Futures addressed two topics: (i) climate change through the interconnected perspectives of climate science and of the Water–Energy–Food nexus (Biggs et al. 2015; Simpson and Jewitt 2019); and (ii) the challenges of fostering inner motivation for change and the potentials of embodied cognition (Newen et al. 2018). The topics were discussed first in theory and then in relation to artistic practices towards the co-design of the final artistic interventions. The focus was on learning from each other, by exploring tangible and intangible, locutionary and illocutionary, constative and performative aspects of art–science understandings of climate change. The engagement with the topic of climate change started with climate and earth-system sciences, through key terms and concepts (such as planetary energy balance, greenhouse effects, coupled system, forcing, and feedback). Examples were mainly brought in from glaciology. Further, considerations from sustainability sciences were discussed, especially those providing a complexity-based understanding of social–ecological dimensions of climate change (Caniglia et al. 2023). Through the Water–Energy–Food nexus, it was possible to focus on the challenges that emerge when attempting to understand and manage often-competing interests and trade-offs across basic resources, such as water, energy, and food, while ensuring the integrity of social–ecological systems (Biggs et al. 2015; Simpson and Jewitt 2019).

To foster conversations about behavioral change, *Evolving Futures* mobilized theories of *intrinsic motivation* that explain how people find motivations to change their behavior (Deci and Ryan 2013). Discussions revolved around how these theories can help to support autonomy, competence, and relatedness towards enhanced performance, persistence, and creativity. Besides, ideas from *4E cognition* were explored as entry points to understand the human mind as enacted, embodied, extended, and embedded (Newen et al. 2018). The 4E cognition framing allowed for discussing how cognition and action are closely related and how collaborations involving artists and scientists could contribute to the integration of interdisciplinary perspectives.

Intervention, installation, and performance: HOMONEXUS and GLACIER NEX US

The exhibition took place in Spring 2021 as a non-recorded "on-live" event during one single day, and lasted two hours. We refer to the event as *on-live*, because it occurred during COVID-19 semi-lockdown. Due to safety measures, the audience participated online. Two artworks were created: the installation HOMONEXUS and the performance GLACIER NEX US. The artworks explored new ways of experiencing the intricate relationships that tie our lives to climate change through nexus thinking. The embodied experiences aimed to create motivation and agency for critical engagement with climate change at the intersection of digital and analog, virtual and real. While GLACIER NEX US was entirely virtual and live-streamed, HOMONEXUS was live-streamed from the Konrad Lorenz Institute, so the audience could join only online. The program included: 15 min for welcoming, with short trailer videos from the website (https://climartlab.space/about/) (Moderator 2); 30 min for introduction to *Evolving Future* (Moderator 2); 45 min dedicated to the artworks that took place simultaneously in 2 breakout rooms. Each performance was staged twice (20 min each),

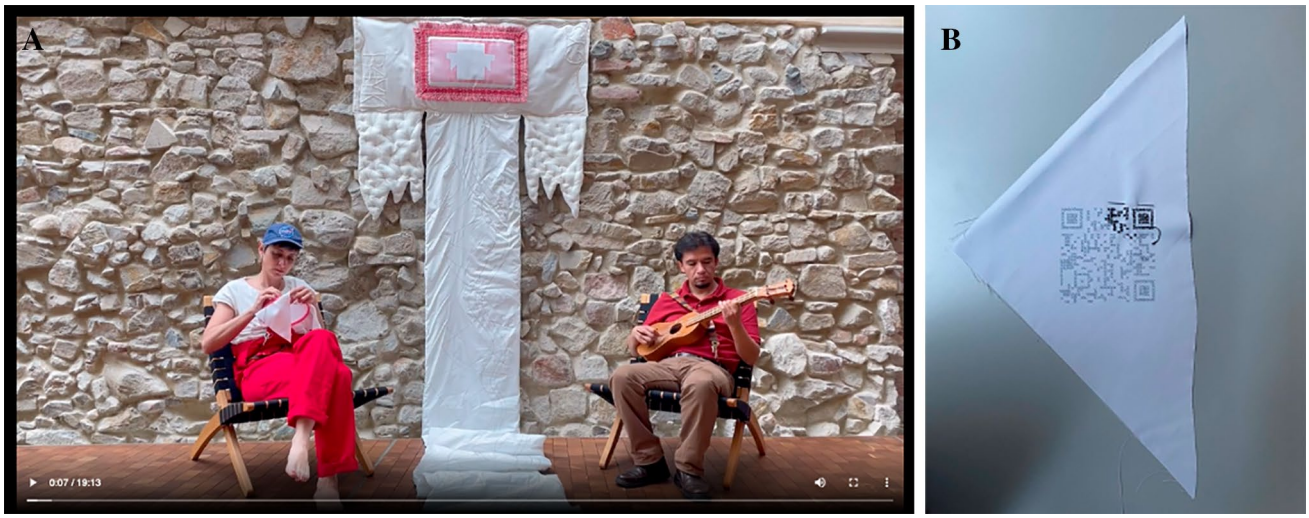

Fig. 2 Screenshot capturing a moment of the performance of HOMONEXUS (**A**); example of the QR code used during the performance by participants (**B**)

so people in distinct breakout rooms could join separately. At the end of each performance, there was space for interactions and discussions with the audience to reflect on their experience; the final activity (45 min) consisted of scientific inputs on the project (Moderator 1), open comments, and Q&A. Details about each performance follow.

HOMONEXUS was a participatory textile installation in digital and analog spaces combined with a Fandango soundtrack performance (Fig. 2), between Artist 1, PoS 1, and the audience. While Artist 1 embroidered, PoS 1 who is also a musician, played guitar. The audience could join the embroidery using material they would have available at home. The traditional craft of embroidery was used as input for collective meditation, where the installation embraced an embodied and collective approach to cognition and motivation in relation to the emotional challenges that climate change presents. The participatory aspect involved a deep collaboration through the co-creation from the seven members of the *Evolving Futures* team during the workshops but also through the engagement of the participants of the exhibition, with a particular focus on the activity of a collective embroidery through a QR code pattern. The QR code was a metaphor for nexus, for the connectivity aspect of our society, and when accessed would lead the audience towards information of Climate Change, Water–Energy–Food nexus available through the *Evolving Futures* website. Elements of the installation emerged during the workshops and were then manually transferred on the textile sculpture through the use of different, collected, and recycled materials, sewed abbreviations and acronyms from the digital language (CYS, B4YKI). The sculpture created a totem incorporating beliefs, methodologies, misjudgments, wishes, and targets in relation to climate change. The installation and collective embroidery were accompanied by a Fandango soundtrack of *Son Jarocho*, performed by PoS 1. Fandango is a traditional type of music and dance from Mexico. In Fandango, participants can join the ensemble of musicians during celebrations by playing distinct roles (e.g., playing a musical instrument, singing, dancing, cooking, distributing meals and drinks among the participants, etc.). This musical practice promotes intergenerational encounters among individuals and fosters a strong feeling of social bonding among the participants.

GLACIER NEX US critically engaged with arguments from glaciology and climate sciences in connection to themes of personal and zoom identity, pandemic technocracy, patriarchy, disturbance, and social change in combination with mantra performances. The core of the online performance consisted of a dialogue, an online meeting, between a melting glacier and a glaciologist (Fig. 3). This dialogue playfully enacted care and despair between humans and more-than-human entities through the caring glacier–glaciologist relationship, while at the same time contrasting it with the despair of humankind towards non-humans, in this case the glacier. An important part of the performance consisted in singing a mantra, also performed online. The script of the mantra (see below) was composed by Artist 2 using Sanskrit words about the snow and cold of a glacier and human experience. After the mantra was performed, the melting glacier disappeared (or melted) in a digital and technological world. A crucial aspect of GLACIER NEX US was the appeal of the personified glacier. The embodiment of a glacier through 'virtual identity disruption' catalyzed a kind of environmental imagination that puts into perspective the human–technology–nature relations. The dramatic end of the dialogue (similar to when someone loses connection during a virtual call) allowed the imagination to

Fig. 3 Virtual details of GLACIER NEX US: The embodiment of a glacier in the virtual environment (**A**); The sign of disconnection at the end of the dialogue (**B**)

access a (not so) fictional scenery of a society that thrives in its technological dimension while nature ceases to exist. In this way, GLACIER NEX US suggested that, when the world nature is over, what lasts is only technology and the question: 'What now'?

śīna शीन (ice)
śītala शीतल (cold, cool, cooling)
haimana हैमन (relating or belonging or suitable to winter, winterly, wintry, cold)
pruṣvā प्रुष्वा (a drop of water, hoar-frost, ice).

Unfolding ITD reasoning in *Evolving Futures*

To understand how the participants reasoned together in the different phases of the collaboration (see Table 1), first, we present the conceptual map showing three main trajectories of ITD reasoning (the section "Categories and conceptual map"); second, we reconstruct these three trajectories as exemplary cases of the complexities of ITD reasoning in an arts–sciences–humanities intervention-oriented research (the section "ITD reasoning unfolding: three trajectories").

Categories and conceptual map

We represent the ITD process through a conceptual map (Fig. 4). To build this map, we used some of the categories that emerged during the collaboration. Although there were around 80 categories, the thematic groups were triangulated with the categories from the *Theorys-sage*. Thus, we focused on those topics that were recurrent or relevant according to the design of the collaboration and which informed the co-design of the two artistic interventions. In this sense, not all themes that emerged were influential in how the collaborative reasoning unfolded over time during the workshops. For instance, *identity and gender* were topics that prominently appeared in a few moments but did not explicitly enter the design process. Other themes that also emerged in a tangential way were *colonization, minorities*, *experimentation*, and others.

As the workshops of *Evolving Futures* were co-designed according to a specific theme and goal (see the sections "Theoretical approach: ITD reasoning in arts–sciences–humanities collaborations" and "Goals and organization of the collaborative process"), the analytic categories emerged in relation to those conceptual trajectories (see the section "Topics and co-design of the artistic interventions"). Thus, the collaborative reasoning was, in some ways, oriented around three main trajectories:

Trajectory 1: *Science communication:* Dealing with dissonance through ITD reasoning.
Trajectory 2: *Water–energy–food nexus:* Navigating reductionism and holism through ITD reasoning.
Trajectory 1: *Sustainable actions:* ITD reasoning for the collaborative design of interventions.

The conceptual map possesses a non-linear, non-chronological character as it does not portray the workshops in a temporal sequence. Despite being presented through three main trajectories, the themes were iteratively discussed all through in a dialectic, dynamic, and process-oriented way. This means that, although the workshops were thematic, the three trajectories do not belong to one or other specific workshop, but represent the most frequent themes that emerged in distinct moments of the collaboration.

Table 1 Main phases, workshops, and activities of *Evolving Futures*

Phases	Summary	Workshops | themes | participants	Activities
Design of the collaboration and building of the team	Design of the framework establishing the activities, aims, and selection of artists from an open call. Reflections on the disciplinary background of the team members	[M1 and M2]	Previous to workshops with the participation of the Moderators
Discussing the theoretical foundations	In several online workshops the participants discussed topics related to climate change, climate science, glaciology (W3, W8), intrinsic motivation, embedded and embodied cognition (W4), sustainability transformations, art–science research (W1), mutual learning (W2), artistic approaches (W5)	(W1) *Kick-off meeting: getting to know each other* [All participants + guest lecturer]	Getting to know each other by sharing personal and collaborative experiences across participants Invited guest lecturer about SciArt work in sustainability sciences, more specifically on Climate Change and Social Change
		(W2) *Mutual learning and knowledge co-production* [All participants]	Discussing dimensions of transdisciplinary collaboration and notions of comfort and discomfort Reflecting on hidden assumptions (e.g., about what is research and what is a valuable contribution) that underpin the work of the team members
		(W3) *Climate science and nexus thinking* [All participants]	Learning and discussing issues and topics related to Glaciology and Earth System Science; action-oriented sustainability science: transformative changes, transitions, mitigation, and adaptation
		(W4) *Intrinsic motivation and embedded cognition* [All participants]	Learning and discussing issues and topics related to theories of intrinsic motivation, and theories and practices of embedded cognition
		(W5) *Putting ideas together and the experience of art* [All participants]	Both artists present their artistic style, methods, and approaches that serve as input for the co-creation of the exhibition

Table 1 (continued)

Phases	Summary	Workshops | themes | participants	Activities
Co-design and performance of the artistic interventions	The team explored new approaches at the intersection of arts–science to generate intrinsic motivation, co-designed (discussing format, implementation, and framework), and performed the interventions together	(W6-9) *Co-design process* [All participants]	Co-creation and exhibition preparation through several online meetings to discuss format, implementation, and framework Separated meetings between participants (Artist 1 and PoS1) (Artist 2 and Scientist) to refine the two performances
		Exhibition evolving futures: owning our mess	Welcome and Check-In (trailer videos of artworks and link to website) short introduction of what will happen in the experience Short presentation about our project: what are the main concerns in climate change awareness, participation, intrinsic motivation, and artworks? Breakout rooms for personal experience (each room is assigned for then switches breakout rooms) 1. Artist 1 and PoS1: embroidery and music. PoS1 plays while Artist 1 and the audience stitch 2. Artist 2 and Scientist: short performance of glacier as embodied identity Community Nexus: detailed scientific input on the project, networking, Q&A, and chatting
Reflection of the process and theory building	After the exhibition, reflection on the collaboration, as well as towards the theoretical development, was performed in a *Theorys-sage* gathering	*Theoryissage* [All participants]	Reflection on the main theoretical contributions that had emerged throughout the whole co-production and mutual learning process

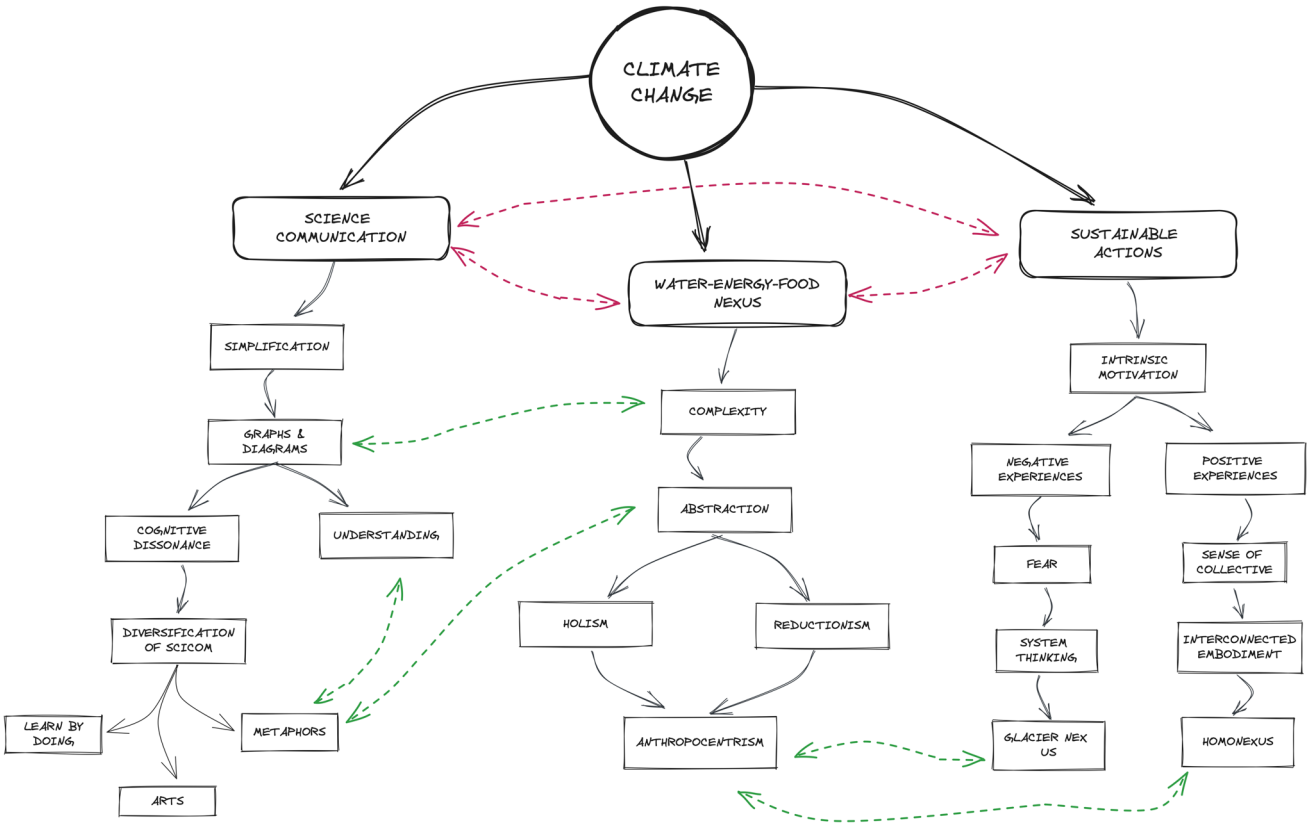

Fig. 4 Conceptual map representing the interdisciplinary reasoning during the workshops. The upper circle (climate change) represents the main theme of *Evolving Futures* and the square boxes underneath visualize the three main trajectories (science communication, Water–Energy–Food nexus, and sustainable actions). Dotted red arrows signify that participants interwove the conversations across the main trajectories and the Green dotted arrows signify that such conversations took place at multiple time and engaging with multiple topics

ITD reasoning unfolding: three trajectories

Relying on the conceptual map, we now reconstruct focal points of the three trajectories. In this way, we highlight the peculiar nature of ITD reasoning in an intervention-oriented collaboration which is embedded in linguistic and non-linguistic exchanges and that enables the coordination of multiple perspectives (see the section "Theoretical approach: ITD reasoning in art–science–humanities collaborations"). In reconstructing each trajectory, we emphasize aspects related both to the content of what was discussed and to the peculiar nature of ITD reasoning that emerged.

Trajectory 1: dealing with dissonance through ITD reasoning

Climate change is a *complex* phenomenon, meaning that its causal underpinnings and systemic dimensions are not easily captured (Hulme 2014, 2016b, 2018). Further, to make complex issues understandable to society, science communication also simplifies complex scientific knowledge through the use of diagrams, mechanisms, and graphs. While, for scientists, this is perceived as an epistemic virtue, since it can help provide an understanding of such phenomena through visualization (de Regt 2017), for artists in *Evolving Futures*, the contrary appeared to be the case. **Such "diagrammification of knowledge"**, as coined by Artist 1, **only evokes *cognitive dissonances* but no clarification whatsoever** (Fig. 5). Below, we can follow both the arguments defended by the scientists in favor of diagrammatic visualizations and those presented by the artists during the workshops.

> [...] this idea of graphic representations, diagrams, graphs [and I agree with artist 2 that] I cannot grasp in a satisfactory way. [...] It is always something that takes me a bit far away from the problem. I made this funny graph, so we can have fun. The idea is the more the abstraction, the more the incomprehension [...]. So, then I started to think [...] something that can maybe describe this sort of feeling, [...] the idea of dissonance. So, representing the problem with graphs and diagrams is always like "ok, what should I do with that?" [...] They look somehow in a way like a stranger,

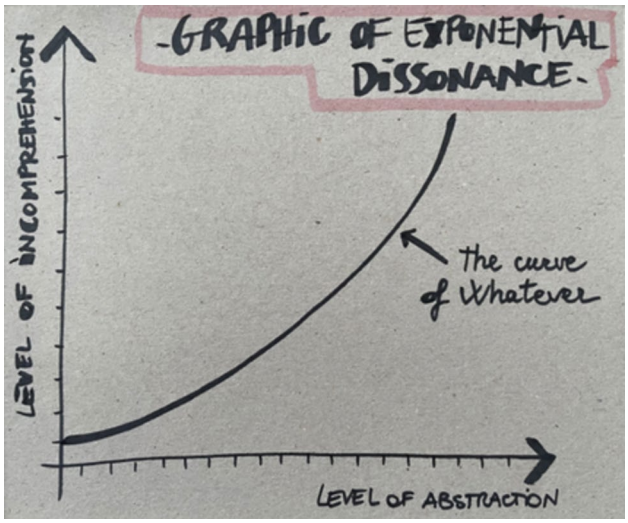

Fig. 5 "Graphic of exponential dissonance" and image as presented by Artist 1, during **Workshop 5**

> and it's difficult to take, to catch the information. They have something, I don't know, it came into my mind this idea of dissonance, sort of dissonance effect. And then I looked at the word up, I just stumbled into this "cognitive dissonance". (Artist 1, **Workshop 5**)
> I remember when both [artist 1 and artist 2] had really strong responses to "diagrammification of knowledge", right? And yet, as a scientist, I love that! [...] For me, that can be an extremely good way of understanding what's expressing a concept. And I think, it's obviously not art at all, but I think visual scientific communication and visual communication is super important for conveying complex ideas. And I was quite surprised that they both hate it, like graphs and diagrams so much. [...] I didn't know that [...]. I was like "Oh God, everyone loves graphs and diagrams and they don't like it at all!" (Scientist, **Workshop 8**)

A possible resolution for the cognitive dissonance was the need for a diversification of how scientific knowledge is communicated to society. An example brought by Moderator 1 (**Workshop 8**) reflected on the plurality of knowledge representation used in science: "a glacier can be expressed and understood through a picture, through a diagram, through an experience, through many different tools". However, the focus, whenever this discussion occurred, was on **how to represent knowledge in a way that is different from those usually used by science**. In this sense, what emerged as solutions against the downside of communicating complexity through scientific diagrams was the use of three tools: metaphors, arts, and learning by doing. Although metaphors were also described as an instrument capable of simplifying complex knowledge, arts were brought up as skillful in informing knowledge through an experiential way. Learning by doing, meanwhile, was depicted as a form of procedural knowledge connected with the intervention.

> This is also connected to the idea of climate change. The idea that we want to change, [...] but we still keep doing things that we know is bad, [then] we experience this kind of dissonance somehow. So, how could be a possible approach to reduce this cognitive dissonance? Yeah, of course, learning by doing. I was thinking of a collective ritual, where it is possible to share also knowledge, and experience, [with no] hierarchy, no pressures, [...] reducing the dissonance [...]. This is a very interesting quote from Confucius which basically is resuming what I think about the problem "We hear, we forget. And then we see, and we remember. But when we do, we understand". And this is to me, like a basic kind of principle". (Artist 1, **Workshop 5**)
> I'm thinking about how people could participate [...] without going through this kind of very complex scientific discourse. I mean, of course, it is important, it can be addressed for another community but maybe to address a broader audience we can use [...] metaphors together to think about how nexus can be compared when people are producing something like this, something related to what [Artist 1] was thinking to do. (Philosopher of science, **Workshop 6**)

Trajectory 2: navigating reductionism and holism through ITD reasoning

Another major trajectory of discussion was centered on the theoretical side of the Water–Energy–Food nexus. The nexus was central for several inputs and in most conversations. The reason of this focus was that this framework provides a non-linear and complexity-based approach to understand human impact on nature as well as how different kinds of societal configurations may impact climate change (e.g., Biggs et al. 2015). **Workshops 2 and 6** introduced climate sciences and climate change by the Scientist and the Water–Energy–Food nexus by Moderator 1. However, one of the complaints from this discussion was that the complexity represented by climate change was, again, abstract. While the Scientist described how equations and numbers are extremely useful to render and measure glaciers despite the adversities of a non-controlled environment, Moderator 2 (**Workshop 6**) raised an argument about how the interpretation of such a condition-unconditional knowledge could be similar to a phantasy, since it is neither haptic nor graspable. A way around was to focus on the Water–Energy–Food nexus which seemed more material to grasp.

Nevertheless, nexus thinking continued to be controversial, not due to distrust or denial regarding its scientific premises, but due to **how *reductionist* such an approach seemed to be in relation to a phenomenon extremely systemic and complex, such as climate change.** This discussion raised again another debate, mostly triggered by Moderator 2, concerning the distinctions between artistic and scientific reasoning. The main idea was that science possesses limitations ascribable to its reductionistic capacities, whereas arts were depicted using holistic approaches due to their creative capacities. However, this discussion did not prolong once Moderator 1 stated how both approaches can actually be complementary instead of exclusionary. As it follows:

> I'm wondering what is water-food-energy nexus. [...] Actually, this idea is where science clashes. Because is very strict, kind of boundary, scientific boundary. Water, Energy, Food without the complexities within it [...] and then you try to [...] connect these containers with each other. [...] For us, it is interesting as a project because we come from the arts where you have a much more loose connection to a lot of different things, and then you clash with this kind of very scientific terminology and ways of seeing. [...] It might be interesting to our project to see this problem, you know, the missing gap, the flexibility, the left out of the chaos, [...] the connecting containers without being fluid - although they pretend to because you have to show that all these relations are important. (Moderator 2, **Workshop 6**)
>
> I think this polarization [...] is agency blocking. On the one hand, everything is connected and everything is so complex [that it] doesn't inspire and inform agency. At the same time, a true reductionistic analytical way of understanding this complexity is [...] not appropriated to understand or intervene in complexity. [...] One has to think about something in between [...]. The complexity and the reductionism finding a middle ground that allows for understanding, for agreement, for establishing differences, to then understand and move on. [...] Once I acknowledge that everything is connected then I have the need to reduce the complexity, once the complexity is reduced, one needs to bring back the complexity. [...]. [...] In this dialectical thing between chaos and order that something can emerge and that we can deal with. (Moderator 1, **Workshop 6**)

Once this dynamicity was settled, **a second concern about the Water–Energy–Food nexus emerged regarding the *anthropocentric* bias of this concept.** According to the Scientist, Water–Energy–Food nexus is useful for governance planning and management purposes, but it is not a concept for understanding the Earth system's connectedness, which is the nexus per se. It is highly restricting, because it ignores relevant components of this network, such as planetary boundaries, biodiversity, society, etc.—even in IPCC[1] reports, the anthropogenic impacts are assessed as an external force on the climate system. This is just one stepping stone for obstructing the understanding of the intrinsic connectedness of climate change, and most importantly the role of humankind as an important element due to its impact on the earth system. All participants shared this position, and being a collective concern, both moderators invited the participants to scrutinize gaps and limitations to be explored during the intervention, from a critical point of view. In addition, the focus was also on how the adoption of such a perspective could help generate motivation towards more sustainable actions. An outstanding and harmonious way out was not to ignore the anthropocentric aspect of the nexus but, instead, use it as its own Achilles' heel, that is, to reinforce the centrality of humans as the causes of climate change, hence their obligation in taking responsibilities of its own past and future actions.

> I don't think I understand why these three things [Water-Energy-Food] were pulled out. Because these things are key to human survival? [...]But maybe we should take inspiration from the nexus because [...] that's not something we have to be critical about, we want to play with this, and I think what's important about it is the interconnectedness because this is [...] what is fundamentally missing that people are forgetting in the climate system, we are a component of the climate system, [...] we are part of the biosphere. And what we're doing is part of this system[...]. This is the nexus that I think we don't recognize or respect. (Scientist, **Workshop 6**)

Trajectory 3: ITD reasoning for the collaborative design of interventions

The question "How do we generate intrinsic motivation?" scaffolded the general design and framework of *Evolving Futures* as explained in the sections "Theoretical approach: ITD reasoning in art–science–humanities collaborations" and "Goals and organization of the collaborative process". The strategies that emerged to address this question were on no account consonant between the participants. From one side, some of the collaborators (Scientist and Moderator 2) suggested that people are more motivated when an experience triggers negative feelings, the fear of death for instance. On the other side, the other participants (PoS, Artist 1, and Moderator 1) were reluctant. They thought about motivation

[1] The Intergovernmental Panel on Climate Change (https://www.ipcc.ch/).

with a shared and positive feeling of being connected and integrated. Artist 2, meanwhile, conveyed that people would feel the motivation once they experience the passion exhilarated through experiences.

Artist 1 was allured to adopt an approach that used embroidery as a metaphor for the interconnectedness representing the nexus. The activity of sewing was an invitation to slow the pace down. Slow the food chain, slow the energy consumption, etc. Considering that Artist 1 uses embroidery to express her artistic work, sewing, not only in this context but also in others,[2] is then perceived as a political act, and in this case, against the Water–Energy-food nexus.

> I think that slow-down activities can bring the introspection we need to process the information and reduce our inner dissonance. [...] But how to change? [...] The change is already there somehow [...] it cannot be perceived straight away but it is already happening. [...] When we plant a seed we don't go there removing the soil each hour to see if it's growing. We water it and wait until the plant manifests itself. So it's like, it's also like somehow an act of trust, and yeah I put another quotation about sewing because I think it is a very interesting activity and it can really be [everywhere] else and is a very political activity. "The great change we are willing to see in the world passes literally through our hands and body" (Artist 1, **Workshop 5**)

In addition to sewing, the Philosopher of science suggested that sensorial inputs could add to fostering motivation. Considering his background as an ethnomusicologist, he acutely proposed using music to create an atmosphere of collective meditation while embroidering. Such proposal was connected to Ingold's (2016) ideas of a world interwoven and interconnected through lines. For both Artist 1 and Philosopher of science the idea of the textile sculpture, as the collective embroidery were examples of how these collective embroidered lines could be perceived as metaphors for the interconnectedness of the Water–Energy–Food nexus while at the same time inspiring a collective reflection through practical knowledge. By doing so, as stated by the Philosopher of science, 4E cognition would set the ground for an act of interconnected embodiment. This gave rise to the theoretical foundation of the HOMONEXUS performance, as explored in the section "Topics and co-design of the artistic interventions".

> We have very important information coming from scientific work but also maybe art can help us to transmit it in a more experiential way [...] as a means to create some kind of experience that makes us aware of what is going on. I guess this can be endorsed by this theoretical framework which is embodied cognition. [...] What I can see from this collaboration is [...] to make explicitly embodied cognition and also this idea of experiential knowledge that is coming from the experience. Knowledge, not from the ideas inside our minds, but something that emerges from our experiences. [...] I was thinking about something related to distributed agency, I mean, because it is not only an exhibition but we are trying to promote some changes in the behavior of people direct for certain purposes. So, maybe what we are looking for is this [...] idea of distributed agency which connects science, arts, but also the tools, the materials that people are going to be manipulating in order to create a situation that may enhance some kind of behavior that we are looking for. (Philosopher of science, **Workshop 7**)

The motivation that generated the GLACIER NEX US performance was moving towards an impersonation of a glacier. What does it mean to be a glacier? If we could talk to a glacier, what would it have to say? If people need to feel connected but at the same time experience fear for our environment, what is better than to talk with an endangered glacier? The Scientist and Artist 2 gathered together to compose a dialectical performance where Artist 2 personifies a glacier. As a consequence of humanizing nature, it brings the spectator closer to the Anthropocene, reflecting upon nature in a way where there is no place on Earth entirely pristine. As an example of this debate, Moderator 1 uses Groß (2017) concerning the modifications in which mountains as socio-ecological systems surpass throughout the years. GLACIER NEX US intended to explore the relatedness of humans to the environment while at the same time bringing a systems-oriented approach.

> Behind this, we tend to [...] think about the poor glaciers that are dying, and therefore you have a loss feeling [...] we care that the glaciers are gone, and will impact us [...] and I thought that was quite an interesting thing about the sort of collecting ideas of ecological grief with responsibility. [...] We are dealing with an issue of glacier loss driven by climate change [...] we are exploring different ways of relatedness, trying to look at the whole and at the impacts from distinct perspectives. (Scientists, **Workshop 9**)

[2] Artist 1 (**Workshop 5**) displayed several artistic works of women artists from Global South and Global North that also combine embroidery with a political standpoint, for instance, Catharina Cibulka, Teresa Margolles, and Thalia Campbell.

Recurring themes: the role of practical standards of reasoning in the three trajectories

A recurring theme from the reconstruction of the three trajectories is the need to pay attention to how ITD reasoning is embedded in moments of friction, disagreement, and misalignment, such as in relation to: visual representations of knowledge in Trajectory 1; broader assumptions about the value of abstraction and reductionism versus concreteness and holisms in Trajectory 2; and how diverging ideas may motivate people to engage in sustainable action in Trajectory 3. Friction and disagreements did not always follow the art–science divide. The project's focus on co-designing interventions opened the possibility for the collaborators to appeal to their own personal motivations and emotions when explaining their own reasoning processes beyond disciplinary belongings. The moments of friction were negotiated through an appeal to practical standards of reasoning that enabled decisions about what to do, that is about how to design and implement a multivocal intervention together.

More specifically, in all three trajectories, the ITD reasoning was pushed ahead by the will and need to, on the one hand, maintain the plurality of approaches of the participants (multivocal), while on the other hand, create interventions together (integrative). The reconstruction of how ITD reasoning unfolded in the three trajectories records several ways the participants made an integrative decision to pursue a multivocal intervention. In Trajectory 1: "…what emerged as solutions [integrative] against the downside of communicating complexity through scientific diagrams was the use of three tools: metaphors, arts, and learning by doing [multivocal]". In Trajectory 2: "this dynamicity was settled [integrative] … An outstanding and harmonious way out was not to ignore the anthropocentric aspect of the nexus but instead, use it as its own Achilles' heel [multivocal]." In Trajectory 3: "The Scientist and Artist 2 gathered together [integrative] to compose a dialectical performance [multivocal]…". Underlying the unfolding of ITD reasoning in these instances were *practical standards of reasoning* as the process and capacity of agreeing on what reasons count when deliberating about what to do (the section "Theoretical approach: ITD reasoning in art–science–humanities collaborations"), though not always made explicit. An example of practical standards of reasoning here is: "Take into consideration everyone's knowledge and research or artistic practice to acknowledge complexity (e.g., by overcoming reductionism) while finding creative ways that allow for developing a shared intervention (e.g., combining diagrammatic representations and metaphors)". Another example is "A good intervention, that is one that fulfills intended goals (e.g., generating motivation for change), will emerge from dialogue and incorporate the best of everyone's insight in different forms (e.g., through a dialectic performance)".

Discussion

The role of ITD reasoning for multivocal interventions

In *Evolving Future*s, the ITD reasoning unfolded through a continuous interweaving of arguments, examples, visualizations, and (il)locutionary acts. The dialogic dynamics required participants to be able to engage with more tacit dimensions of their own knowledge and expertise, within and beyond their disciplinary affiliations (Newen et al. 2018). This was the case, for example, when participants engaged in more theoretical conversations about the Water–Energy–Food nexus and its perceived inadequacy to capture the complexities of climate change (Caniglia et al. 2023). In this instance, the conversation engaged simultaneously with aesthetic and epistemic values, such as simplicity and systematicity or communicative power and generalizations (Peukert et al. 2020). The ITD reasoning also involved emotional dimensions, such as feelings of frustration towards ways of thinking that were perceived by some as hindering people's motivation for change.

Importantly, however, it is in the co-design of the artistic interventions that the ITD reasoning allowed for the integration of multiple perspectives, while maintaining a plurality of stances and positions. Artists, scientists, and philosophers could engage in one line of action without the need to agree or resolve their different perspectives, but still safeguarding the capacity to contribute from their own perspective while generating something together. The ITD reasoning supported an integrative process that resulted in *multivocal* the two artistic interventions that emerged from shared decisions and resolutions that evolved from the often-conflicting views of those involved (Gehman et al. 2018). The two artistic interventions were multivocal as they embodied multiple perspectives, values, and ways of knowing, from those of climate and sustainability sciences to those of the arts and the humanities.

The role of the humanities in arts–science collaborations

Even though climate change research requires the integration of knowledge from distinct disciplines (e.g., meteorology, hydrology, ecology, etc.), most art–science collaborations on climate change tend to privilege the knowledge generated in the natural sciences (e.g., climate and earth-system sciences) (Heras et al. 2021; Tosca et al. 2021). Yet, an important perspective in the discussion of how arts–science collaborations contribute to the understanding and addressing climate change comes from the humanities

(Hulme 2014, 2018). Reflexive approaches from philosophy of science and science studies thicken our understanding of the multiplicity of relationships across scientific, artistic, and local knowledge of climate and environmental change (Hulme 2016b; Haraway 2016).

In *Evolving Futures*, similar considerations helped to modulate the way in which participants could grapple with different perspectives due to their disciplinary training. In this respect, reflections from philosophy of science and science studies problematized how scientific knowledge is generated and represented as well as how epistemological differences across disciplines could be overcome. Further, cognitive science and psychology played a fundamental role in the creation of artistic interventions engaging with deep layers of human life to foster inner change and transformation (Woiwode et al. 2021). The engagement with theories of intrinsic motivation and 4E cognition, for instance, thickened the understanding of climate change by stimulating reflection on the deployment of value-heavy concepts and by fostering reflections on tacit and embodied dimensions of behavior, knowledge, and action.

The role of aesthetics experiences for sustainability

There is often a tendency to look at the arts instrumentally as means for the communication of scientific results. However, this attitude relies on an underestimation of the potential of how arts can contribute to redirect and inspire further research as well as to create societal change and transformations. As the experience provided by ecological artworks relies on sensory/perceptual, and imaginative and emotional interactions, it can generate a particular ethical position towards the natural world as it reflects upon distribution of agency during these interactions (Brady et al. 2018). In projects that aim to empower people to deal with the climate emergency, it is important to include arts-based practices, since the purely scientific ones, from diagrams to scientific papers, are often insufficient to address these topics in other dimensions of society.

Considering that aesthetical and ethical reflections can help us to recognize the weight of our interactions with the environment (Brady et al. 2018) and to provide an understanding of it (Elgin 1993), the idea of both interventions was to provide a meaningful engagement with the climate change entangling human and beyond-than-human, the environment, and its interconnectedness. In this sense, both interventions aimed to provide contradictory relationships between humans and the climate emergency by leading the spectator to have a positive and negative (i.e., conflicting) aesthetic experience, respectively. For instance, HOMONEXUS meant to enable a beautiful, meditative, and reflexive experience about Water–Energy–Food nexus by focusing on slowing down activities provided by a virtual-collective embroidery altogether with a calm musical ambience, which we refer to as positive aesthetic experience. Meanwhile, GLACIER NEX US approached the climate emergency with different lenses. Through the personification of an endangered glacier, this performance amalgamated and reassured the interconnectedness of the human with more-than-human entities in contrast with an anthropocentric world view by providing a dramatic conversation between a melting glacier and a glaciologist, which we refer to as negative (or contradictory) aesthetic experience. In this sense, and because artworks can convey information by generating responses that make a difference (Hoelscher 2021), aesthetic experiences as distinct as they might be, can help shape the form we connect to the environment (Brady 2003) by instantiating our relations to it.

Conclusions

In this paper, we chronicled the process of collaboration in the case study *Evolving Futures: Owning our Mess*, which involved natural scientists, artists, and philosophers of science. We captured how ITD reasoning surfaced in relation to particular topics and issues through multiple perspectives and expertise. We also emphasized the importance of involving perspectives from the humanities as they can provide a unique level of reflexivity about how scientific knowledge is generated, its limitations, or how it relates to other kinds of knowledge. Finally, we focused on the role of aesthetic experiences, which are often overlooked, because we tend to focus on ways of reasoning from the natural sciences. Overall, our analysis of ITD reasoning enriches the existing understandings of integrative ITD approaches. Once we abandon the aspiration to achieve consensus and agreement across often-incommensurable perspectives, ITD reasoning can help to navigate often-unpredictable and emergent situations by capitalising on and leveraging differences. We hope that, by clarifying the role of practical standards and of aesthetic dimensions of collaborative work, our work may help those setting up similar endeavors to improve both the processes and the outputs of their collaborations in ways that partakes different knowledge and expertise needed to understand and foster creative action for change.

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Data availability Raw data were generated at Konrad Lorenz Institute for Evolution and Cognition Research (KLI). Derived data supporting the findings of this study are available from the corresponding author GC on request.

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