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# Learning to collaborate within transdisciplinarity: internal barriers and strengths of an art–science encounter

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## Abstract

Despite the recognized importance of transdisciplinarity, including art–science collaborations, for tackling the complex challenges of the Anthropocene, little is known about the internal mechanisms of such alliances. At its best, transdisciplinarity should involve social learning with transformative potential. However, we still need evidence on how this can be achieved, specifically regarding developing interpersonal interactions and group dynamics. Our study explored the social learning processes and outcomes of an art–science encounter, aiming to highlight such a collaboration's internal barriers and enhancers. It took place within a science communication project for the European Performing Science Night 2021, which involved creating an immersive artistic installation through the collaboration of 28 artists and scientists. We analyzed the social learning processes and outcomes based on participants' profiles, individual participation, group dynamics, and the workshop context using structured interviews and participatory observation during this two-week co-creation workshop. Our insights showed that inter-relational skills were among the most important outcomes, and social learning processes varied based on group dynamics. Moreover, we identified the presence of a delicate balance between driving egalitarian and self-regulated dynamics within inclusive, collaborative processes and the need to foster non-hierarchical structures and dismantle power dynamics between artists and scientists. We discuss these findings in light of three key elements: destabilization, immersion, and materialization, which can help overcome internal barriers and leverage strengths for facilitating transdisciplinary approaches that contribute to sustainability transformations.

**Keywords** Transdisciplinary collaborations · Art–science co-creation · Social learning · Group dynamics · Transformative learning

## Introduction

Acting for a more sustainable present and future needs approaches able to tackle the complexity of the global challenges of the Anthropocene and to do so in transformative ways. A key driver of these sustainability transformations (i.e., profound systemic changes contributing to sustainability) relates to our capacity to engage in transformative learning, referring to learning processes that challenge established frameworks, taken-for-granted assumptions, deep-seated values and beliefs, and foster paradigm shifts (Mezirow 1997; Sterling 2011; Linnér and Wibeck 2021). Within this context, transdisciplinary approaches, i.e., those that bring together different actors' corpus of knowledge and practices (Popa et al. 2015), bring the opportunity to foster joint explorations of societal issues and build collective action capacity and open up learning spaces (Bieluch et al. 2017). This is specifically true for art–science encounters

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in which scientists and artists work together. Art–science experiences have proven to offer relevant insights into understanding sustainability challenges from diverse critical theoretical perspectives (Leavy 2011; Kagan 2014; Paterson et al. 2020), fostering transformations in this direction (Kagan 2015; Swanson 2015; Galafassi et al. 2018a, b); and raising innovations and new paradigms that are "*vital as we seek to learn how to live as part of a more-than-human world at a time of great change*" (Gibbs 2014, pp. 224).

However, these transdisciplinary experiences are challenged by the generalized lack of a collaboration culture among different actors and disciplines (Steelman et al. 2019). It implies that social learning is a crucial aspect of transdisciplinarity (Herrero et al. 2019), especially art–science collaborations (Westberg and Polk 2016; Renn 2021). Social learning refers to a change in understanding achieved through social interactions and iterative reflection in collaborative and participatory settings (Keen et al. 2005; Reed et al. 2010; Den Haan and Van Der Voort 2018). As Cundill and Rodela (2012) argue, the term can be associated with different processes and outcomes, ranging from deliberative interactions through which different stakeholders learn to work together and build relationships oriented toward collective action, to deliberate experimentation and reflective practice in which participants learn to navigate uncertainty and complexity through practical involvement. Embedded in art–science interactions, social learning processes can create spaces for transformative learning by stimulating creative imagination, generating new perspectives and frames of reference, or prefiguring potential futures through direct action and experimentation (Kagan 2015; Bentz and O'Brien 2019).

However, when striving to generate such learning processes from transdisciplinary experiences, the intersection between art and science faces several challenges, both external and internal to the agents participating in these spaces of encounter (Heras et al. 2021). On the one hand, external factors can limit the development of these collaborative learning processes, such as the accessibility of such collaboration and the supporting infrastructure, including funding, appropriate time frames, institutional support, and limited opportunities to disseminate the results of these encounters (Jacobs et al. 2017; Heras et al. 2021). On the other hand, internal barriers may arise from differences between artistic and scientific worlds, including their adopted paradigms, ontologies, epistemologies, and their expectations and orientation toward the encounter (process-based vs. outcomes-based). Additionally, power imbalances can influence these barriers (Jacobs et al. 2017; Wienroth and Goldschmidt 2017; Heras et al. 2021), with, for instance, scientists often taking the lead in such collaborations (Hilger et al. 2021; Harmáčková et al. 2023). Thus, finding common ground for learning between both

worlds requires institutions and individuals to self-reflect on the potentials and tensions of their own paradigms and praxis and the value and limitations of others' perspectives and epistemologies.

While several studies highlighted the relevance of social learning processes in art–science experiences for sustainability, most of them have focused on the audience's learning outcomes, leaving behind the mechanics of the collaboration that lead to them —specifically, how learning takes place between artists and scientists and what factors can hinder it (Schauppenlehner-Kloyber and Penker 2015; Hilger et al. 2021). Understanding these mechanisms is crucial because elements such as power imbalances and lack of inclusiveness influence social learning leading to transformation (Herrero et al. 2019; Heras et al. 2021). As an exception, Schauppenlehner and Penker (2015) explored how group dynamics evolve within transdisciplinary collaborative processes. They proposed a framework identifying five different phases: the *forming*, in which participants get to know each other and the project's goal; the *storming*, where power struggles and conflict resolution are present; the *norming*, where the group develops cohesiveness and has open exchanges; the *performing*, when participants function as a team and effectively cooperate toward a common goal; and the *adjourning*, being the termination of the group. Each phase has specific individual and group needs and thus types of facilitation that can be used to explore how social learning processes might occur within art–science collaborations. However, there is still a dearth of research on how individuals engage and collaborate in art–science encounters and what individual and group aspects contribute to fruitful collaborative actions and social learning processes.

Therefore, this study explores how individual participation, group dynamics, and the methodological context influence social learning outcomes and processes between artists and scientists within an art–science encounter so as to inform transdisciplinarity and sustainability debates. Our research was conducted within the European Performing Science Night project (EPSN), where artists and scientists worked together in a two-week workshop to co-create a performance for the European Researchers Night 2021 celebrated in Badalona (Spain). We aimed to answer the following research questions: (1) What social learning outcomes emerge from art–science collaboration, taking into account participants' characteristics (i.e., background, individual engagement, roles)? (2) How does individual participation shape collaborative processes in an art–science encounter? (3) How do group dynamics (i.e., composition of the group, its functioning and processes) shape collaboration in an art–science encounter? By providing empirical evidence on the internal elements that enhance or limit individual engagement and group dynamics in art–science collaborations, we seek to advance our understanding of how to

design such interactions more effectively to reinforce transdisciplinarity and sustainability transformations.

After providing insights into this encounter, namely the project's goal and the facilitation approach, we present our methodological approach and results on both social learning outcomes and processes. We then discuss our insights around three main aspects (destabilization, immersion, materialization) which can help overcome internal barriers and leverage strengths for fostering transdisciplinary collaborations.

## The EPSN workshop

The EPSN project brought together a renowned performing art foundation and seven scientific groups from France and Spain to co-create and present a performance exploring different cutting-edge scientific topics during the European Researchers Night (for more details, see project website). The art foundation was also particularly interested in fostering a joint exploration space between artists and scientists that could inspire new ideas and practices in the participants in both the scientific and artistic domains. The research groups wanted to see how their research topics might be approached from other perspectives and frames of reference, ultimately helping advance their studies. Consequently, the co-creation workshop, designed and facilitated by the artistic foundation, spanned 11 full days of immersive participation for scientists and artists from September 13th to 24th, 2021, and culminated in two presentations of the show on the final two days.

A total of 28 participants (12 men, 15 women, one nonbinary) took part in the workshop, ranging in age from 19 to 47. The group comprised 17 artists, 5 scientists, and 6 individuals with both scientific and artistic backgrounds (see Table 1). Sixteen participants had previous experience in art–science projects. The coordination team selected participants according to their professional profile, willingness to participate in a collaborative project, and full-time availability for 15 days.

The workshop was held in the foundation headquarters: a 4.000 m$^2$ former industrial warehouse converted into a creation atelier, divided into four big spaces, where participants spent two consecutive weeks of intense work (structured in 6 days in a row, 1 day for rest, and 5 more days of work). The daily schedule involved participants gathering from 10 am to 8 pm, with a break for lunch. The facilitators deliberately established this limited time frame to prompt what they called a sense of imperative collaboration for the performance's creation. Also, regardless of their profile, all participants had to engage in all the proposed activities (from discussing to performing) without predefined roles based on their backgrounds.

During the initial two days of the workshop, the participants were introduced to the workshop's objectives, the space, and the scientific topics brought by the seven research groups involved in the project. The topics were: social stigma on infectious diseases, virus dissemination, cancer, neuro-linguistic convergence, trust in information, cognitive bias and stereotypes, and climate emergency discourses and inequalities (for more details, see the project website). The participants also learned more about the methodological "essence" of the artistic foundation, which uses elements such as eccentricity, innovation, and transgression, reconceptualizes the theatrical space and the role of the public, and thus questions the established structures and systems. Physical exercises were conducted to promote trust building, teamwork, and creativity. By the end of the second day, the facilitation team divided the participants into four groups, each comprising seven members. Each group had a diversity of profiles (scientists, artists and both, and different artistic specialties) and personalities (extrovert, introvert, leaders, etc.) (Table 1). These groups were tasked with collectively brainstorming and devising ways to integrate all the scientific topics into scenes for the final performance. From the third day onward, most of the work was carried out within these groups, each having a separate space where they worked independently. Daily presentations of each group's progress were made to the entire team and facilitators, who provided their insights on the scene presented. During the last three days, the preparation of the

**Table 1** Distribution of the workshop's participants according to their background, previous contact with art–science collaboration, overall and per group

| Total | | Group 1 | Group 2 | Group 3 | Group 4 |
|---|---|---|---|---|---|
| Total | 28 | 7 | 7 | 7 | 7 |
| Artists | 17 | 5 | 6 | 3 | 3 |
| Scientists | 5 | | 1 | 2 | 2 |
| Both scientists and artists | 6 | 2 | 0 | 2 | 2 |
| With previous experience in art–science projects | 15 | 7 | 3 | 3 | 2 |

final performance implied more interactions between groups as some participants became involved in scenes from other groups (see Fig. 2). Thus, most of the time was spent working in groups to prepare the scenes, representing about 50 h out of the approximate workshop duration of 80–90 "working" hours.

Except for the initial two days, the facilitation primarily focused on artistic direction. The two heads of the art foundation played the role of directors and provided feedback during the whole group presentations. Two foundation members spent the day intermittently working with the groups, offering guidance and support, i.e., discussing the scene's content and guiding them on using materials and space, while two other members provided technical assistance. However, they did not intervene in the self-organization of the group's work or address conflicts or tensions that arose within the groups. Twice a day, after the morning physical warm-up and evening presentation, the facilitators shared tools, methods, and approaches for the creation with the whole group.

## Methodological approach

### Data collection

We used a mixed-methods approach involving surveys, interviews, and observation as data collection methods (Dowell and Weitkamp 2012; Ruiz-Mallén et al. 2018; Heras et al. 2021) (see Table 2 and Appendix 1).

One week before the workshop, we sent an online survey to the participants to gather socio-economic and demographic data, their previous involvement in art–science projects, their motivation for attending the workshop, and their expectations (see Appendix 1). We also interviewed the facilitation team on their expectations regarding the workshop and its methods.

During the workshop, four of us conducted in situ observations, following all activities throughout the process. We followed two of the four groups more closely (hereafter referred to as Group 1 and Group 4), while periodically observing the other two (Group 2 and Group 3). These observations were carried out with a specific emphasis on

participants' engagement, such as cognitive, emotional, and physical involvement during the different activities, and the interaction between participants and the facilitation provided (see Appendix 1). Additionally, for the two groups not extensively followed, two participants shared daily reports that provided insights into their groups' dynamics and individual participation. Then, one week after the workshop, participants answered an online survey in which we gathered their perceptions of the workshop and their participation, the collaborative process, and the insights they gained from it (Appendix 1). We also conducted a semi-structured interview with the facilitation team to gather their perceptions of the workshop and the strengths and weaknesses regarding participant engagement.

Before the onset of the research, we received the ethical approval of the Autonomous University of Barcelona (UAB_CEEAH_nr_5708) and obtained Free Prior Informed Consent from all participants. All the data collected at the individual level were anonymized and we coded the informants using the following format: A/S/AS _F/M/Nb_Num_ Gr_Numgr, with A = Artist; S = Scientist; AS = Artist and Scientist; F = Female, M = Male; Nb = Non Binary; Num denotes the participant's number; Gr the group and NumGr the number of the group.
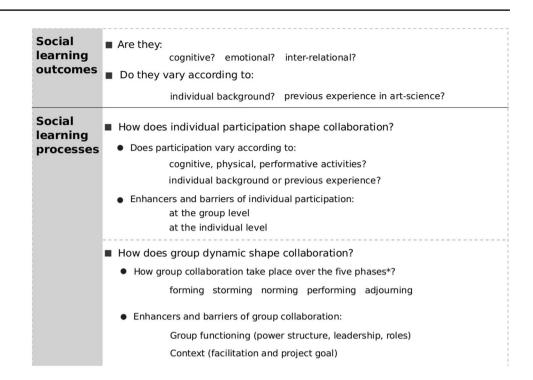
### Analytical framework

To guide our analysis, we proposed a social learning framework (see Fig. 1) based on categories of social learning outcomes broadly reported by the literature (Cundill and Rodela 2012; Baird et al. 2014, Keen et al. 2005, Den Haan and Van der Voot 2018) and on the framework provided by Schauppenlehner-Kloyber and Penker (2015). This framework explores individual learning reported at the end of the workshop as part of social learning outcomes and individual participation and group dynamics as social learning processes.

### Learning outcomes

We analyzed participants' perceptions of social learning outcomes using the answers provided during the post-workshop surveys to: "What lessons do you take away from this

**Table 2** Summary of data collection methods and sources implemented in the study

| Data source | Data collection method and implementation moment |
| --- | --- |
| Workshop participants | Online written survey pre-workshop ($n = 28$) |
| | Online written survey post-workshop ($n = 22$) |
| Facilitation team | Interview pre-workshop ($n = 5$) |
| | Interview post-workshop ($n = 6$) |
| Workshop | Non-participatory structured observation (4 observers) |
| | Participatory observation (2 observers) |

**Fig. 1** Analytical framework proposed for approaching collaborative creation through social learning outcomes and processes. Note: *phases and observable behaviors retrieved from Schauppenlehner-Kloyber and Penker (2015)



experience?" Drawing on existing literature (Herrero et al. 2019; Heras et al. 2021), we then categorized their answers into cognitive (e.g., new ideas), emotional (e.g., self-confidence), and inter-relational outcomes (e.g., teamwork). Furthermore, we analyzed whether these learning outcomes were related to individuals' background and previous contact with the art–science intersection.

## Individual participation

Since social learning is influenced by how people participate and engage in a collaborative process (Reed et al. 2010; Schauppenlehner-Kloyber and Penker 2015), we first explored how the individuals took part in the workshop. We analyzed observed and perceived participation through data gathered from daily observations and post-workshop surveys (Ruiz-Mallén et al. 2018). We examined our observations on participants' involvement in different kinds of activities proposed by the facilitators, such as cognitive (e.g., presentation of the scientific topics, scene writing), physical (e.g., warm-up), and performative activities (e.g., scene presentation and performance) (Heras and Ruiz-Mallén 2017; Ruiz-Mallén et al. 2018). Additionally, we explored the roles taken by the participants within their groups in terms of leadership, passive, or active participation. We finally examined partakers' perceptions of their workshop participation by analyzing their responses to the question: "How did you feel participating in the workshop?" We observed and reported participation according to individual background (artistic, scientific, or both) and prior experience with art–science projects.

## Group dynamics

We first analyzed the collaboration within the groups in terms of group functioning and power balance by using data from the observations and the post-workshop surveys. We also looked at the evolution of the groups' processes throughout the workshop, using the framework by Schauppenlehner-Kloyber and Penker (2015). Following these authors' categorization, we analyzed observed behaviors and social interactions to identify the different phases that the groups experienced during the workshop (especially Group 1 and 4). Specifically, we considered: (1) the forming phase, when participants showed behaviors such as politeness, excitedness, and optimism; (2) the storming phase, when disagreement, conflict, concerns, or resistance were present; (3) the norming phase, when constructive interaction and individual confidence were observed; (4) the performing phase, when participants showed empathy, commitment, and satisfaction, and (5) the adjourning phase, when participants showed signs of sadness and relief, among others (see Schauppenlehner-Kloyber and Penker (2015) for the whole list of individual behaviors and social interactions). We then crossed the groups' functioning and processes to explore whether both aspects were related. Finally, we used participants' perceptions to assess how groups' dynamics might have shaped the fruitfulness of the collaboration by analyzing the answers to "At the level of co-creation, how do you value collaboration between people within your group and with the other groups of participants? Do you think your voice has been taken into account?" and crossing these answers with the insights from the previous observations.

Recognizing that a broader context shapes these social learning processes and outcomes, we analyzed the workshop facilitation to explore how the workshop's purpose and its methodological, physical, and social context might have affected social learning processes and outcomes. We analyzed the methodological structure of the EPSN workshop (see Sect. "The EPSN workshop"), based on workshop observations, interviews with the facilitation team, and participants' answers to the post-workshop survey (question 3, 4, 5 and 7, see Appendix 1). The analysis and their results are presented in the next section.

## Results

### Perceived outcomes of the social learning process

This workshop brought about different outcomes to the participants. Most of them (19 out of 22) reported gaining insights into transdisciplinary teamwork, as shown by this quote:

> "This experience has taught me to be more understanding with the different points of view during team working and has shown that the processes of accepting/improving/discarding the ideas that arise from these teams are important for collective learning that underlies all decision-making and that these processes are necessary to synchronize the status of all team members about the object worked on." (SM1Gr3).

Fifteen participants mentioned the acquisition of inter-relational skills. These included the ability to relate to, communicate with, listen to, or understand others ($n = 7$); to be able to throw away ideas ($n = 6$); gaining or consolidating experience in group facilitation, such as mediation or conflict resolution skills ($n = 2$), leadership skills ($n = 2$), or skills for transdisciplinary processes ($n = 3$). Additionally, participants reported learning about group dynamic processes ($n = 3$).

Participants also reported having gained more self-awareness and other learning outcomes at the emotional level ($n = 13$). For instance, it allowed them to value their own contribution to the collaboration process ($n = 4$), to be conscious of their behavioral patterns ($n = 3$), or to overcome shyness and to gain self-confidence ($n = 3$) as shown in the following quotes: "*I have somewhat lost my fear of playing with physical language with (practically) strangers*" (AF1Gr2), "*to improve my self-esteem*" (SM1Gr3), and "(I have learned) *that I can trust myself and value myself.*" (AF2Gr3). The workshop also allowed participants to review perceptions of their own character, feelings, motivations, and capacities, such as one participant realizing their curiosity

toward life, another discovering their potential in art, and one reflecting on their personal development through life.

Finally, cognitive outcomes emerged from the workshop, leading to new ideas and perspectives for either the personal or professional journey ($n = 11$). Such insights related to the content of the scientific topics ($n = 2$), new ideas for participants' own projects (whether artistic, scientific or art–science related) ($n = 3$), approaches to art–science projects ($n = 2$), and specific approaches/tools shared by the facilitation team ($n = 3$). Three also mentioned that it allowed them to broaden their perspective and take out prejudices, as shown in this quote: "*As my main learning, I should never prejudge an idea, I should not expect or imagine about something, because it hardly ever resembles what it really is.*" (SF3Gr4). The workshop also allowed five participants to see the value and strength of the art–science intersection for disseminating science and facilitating collaborative processes, while two participants reported strengthening their vocation in the arts or in the intersection of art and science.

### Individual participation in collaborative creation

During the first two days of the workshop, the facilitation team led activities through a cheerful attitude, emphasizing the idea of '*we are here to play*' (reiterated several times). This approach promoted active engagement in all the activities, both scientific and physical ones. However, we noticed that seven out of 28 participants were slightly more passive than the others (5 artists; 1 scientist; 1 both scientist and artist; 4 of them with previous experience in art–science projects).

Throughout the following nine days of the workshop, individual participation was consistently high regarding scene creation and rehearsal. Yet, more variation existed during the discussion and negotiation times, with the seven slightly more passive participants being less engaged. By contrast, when the performances took place during the final days, the engagement and participation of all participants were very high.

In general, we did not observe any difference in individual participation and engagement in the different activities (cognitive, physical, or performative), according to participants' background. However, another seven participants who tended to take a more prominent role in the group dynamics (in terms of time of speaking, internal organization, and recognition by the other members of the group) had previous experience in the art–science intersection and primarily came from performing arts backgrounds, either as full-time artists, or part-time scientists–part-time artists.

When asked about their feelings regarding their participation in the workshop, while five participants reported feeling comfortable, free, or "*too much in* [their] *comfort zone*", most participants mentioned experiencing a range of diverse

emotions ($n = 11$). It included beginning from stressed or uncomfortable to self-confident and comfortable ($n = 5$), or alternating moments of excitement and high motivation to moments of frustration or tiredness ($n = 5$), or, for one participant, going from excitement to dissatisfaction (Table 3). Four participants found the experience challenging because of a lack of physical background ($n = 1$), physical and mental fatigue ($n = 1$), complex teamwork ($n = 1$), or feeling overwhelmed ($n = 1$). Two participants also reported they felt out of their comfort zone during the whole process, but an artist perceived it as a gratifying challenge.

These reported feelings regarding their engagement did not seem to be related to their profiles or previous experience with art–science collaboration, as shown in the distribution of profiles presented in Table 3.

The accompaniment and space of trust provided by the facilitation team and their group members were frequently mentioned as critical elements that fostered individual participation (mentioned in 10 out of 22 responses). Also, the presentation of scientific or performative content ($n = 10$), the performance itself ($n = 9$), and the disinhibition exercises ($n = 5$) were significant aspects that enhanced the collaboration process.

Reported barriers to individual participation were related to the dynamics of their group ($n = 7$ out of 22), while the use of different disciplinary languages posed a clear barrier to inclusivity in the creation process, as observed and reported in the post-workshop surveys ($n = 3$). Language barriers also encompassed participants whose mother tongue was not Spanish, affecting the engagement of two participants, not fluent in Spanish, who were more passive than others. The intensity of the workshop (tiredness and lack of economic retribution) ($n = 4$) and the demanding time commitment were significant limitations. Due to professional or personal commitments, three participants missed one to two half-days. Similarly, other participants had to work before or after the workshop, which was overwhelming (only seven

**Table 3** Distribution of the feelings lived during the workshop as reported in the post-workshop survey, per profile

|  | Total ($n = 22$) | Profile | | | With previous experience in science art collaboration ($n = 12$) |
|---|---|---|---|---|---|
|  |  | Scientist | Artist | Scientists–artists |  |
| Through a lot of emotions | 11 | 3 | 6 | 2 | 5 |
| Comfortable | 5 | 1 | 2 | 2 | 4 |
| Challenging | 6 | 2 | 3 | 1 | 4 |

out of the 28 participants had no current job). Finally, personal background (e.g., not being accustomed to physical or performative exercises) was also named as a barrier to individual participation ($n = 2$).

## Group dynamics of the collaborative creation

Overall, the four groups went through all the different phases identified by Schauppenlehner-Kloyber and Penker (2015) except the adjourning phase, as no formal group meeting occurred after the workshop (Fig. 2). First, participants got to know each other through the forming phase of the collaborative process during the initial two days of the workshop while engaging in activities as a whole group. From day 3 onward, the groups began to work independently and went through the forming, storming, norming, and performing phases. Yet, the process was mainly predominated by the norming phase, in which participants struggled with power structures and the establishment of their norms of action. Furthermore, the way each group went through their collaborative process and the different phases varied in the time spent on each phase, the different observed behaviors, and the power structure within each group.

Indeed, each group had its internal functioning, ranging from a more hierarchical structure with one person leading to a more egalitarian structure with members ensuring all voices were included in the activities. We detail such variability through group collaborative dynamics, both observed and perceived by the participants.

In Group 1, days 3 and 4 were mostly spent discussing the different scientific topics and how to integrate them into a scene. Participants tried to organize themselves in a way that allowed all voices to be heard and to find common working rules. However, they struggled to concretize their thoughts and ideas into a scene and faced moments of tension and excitement. Participants from Group 1 aimed to bridge cancer, virus infection, trust, and climate emergency. First, discussions were disorganized, with one or two individuals' voices dominating the conversation and not actively listening to the others. This led to a conflict between two people on the evening of day 3 and a similar situation the following day involving the same person. On day 5, another tension arose between two individuals, with one complaining about the low engagement of the other. The group was going through the storming phase and resolved these tensions internally without any external intervention. On day 6, the internal dynamic shifted significantly: conversations became more fluent, the mood improved, and participants became more constructive than previous days. They agreed that the content of their scene would be illustrating viral infection alongside authoritarianism. From day 7 onward, the whole group displayed more cohesion and proactive behaviors, established functional rules, and showed signs
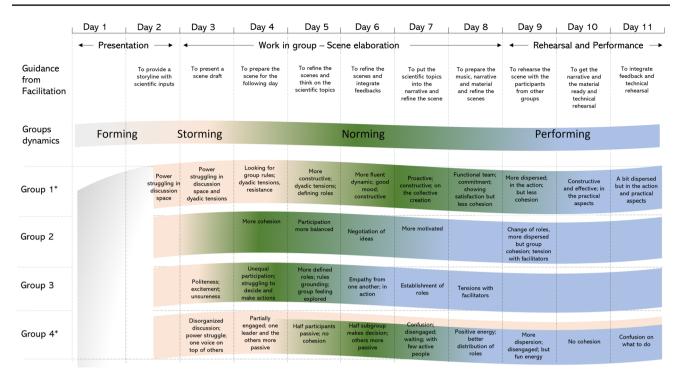
| | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 | Day 8 | Day 9 | Day 10 | Day 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ← Presentation → | | ← Work in group – Scene elaboration → | | | | | | ← Rehearsal and Performance → | | |
| Guidance from Facilitation | | To provide a storyline with scientific inputs | To present a scene draft | To prepare the scene for the following day | To refine the scenes and think on the scientific topics | To refine the scenes and integrate feedbacks | To put the scientific topics into the narrative and refine the scene | To prepare the music, narrative and material and refine the scenes | To rehearse the scene with the participants from other groups | To get the narrative and the material ready and technical rehearsal | To integrate feedback and technical rehearsal |
| Groups dynamics | Forming | Storming | | | Norming | | | | Performing | | |
| Group 1* | | Power struggling in discussion space | Power struggling in discussion space and dyadic tensions | Looking for group rules; dyadic tensions, resistance | More constructive; dyadic tensions; defining roles | More fluent dynamic; good mood; constructive | Proactive; constructive; on the collective creation | Functional team; commitment; showing satisfaction but less cohesion | More dispersed; in the action; but less cohesion | Constructive and effective; in the practical aspects | A bit dispersed but in the action and practical aspects |
| Group 2 | | | | More cohesion | Participation more balanced | Negotiation of ideas | More motivated | | Change of roles, more dispersed but group cohesion; tension with facilitators | | |
| Group 3 | | | Politeness; excitement; unsureness | Unequal participation; struggling to decide and make actions | More defined roles; rules grounding; group feeling explored | Empathy from one another; in action | Establishment of roles | Tensions with facilitators | | | |
| Group 4* | | | Disorganized discussion; power struggle; one voice on top of others | Partially engaged; one leader and the others more passive | Half participants passive; no cohesion | Half subgroup makes decision; others more passive | Confusion; disengaged; waiting; with few active people | Positive energy; better distribution of roles | More dispersion; disengaged; but fun energy | No cohesion | Confusion on what to do |

**Fig. 2** Representation of the dynamics of the groups, by phases, all along the workshop (gray: forming, pink: storming, green: norming, blue: performing) and contextual framework provided by the facilitation team, as identified by Schauppenlehner-Kloyber and Penker (2015). Note: *groups more intensively observed

of self-satisfaction. The performing phase was underway. Although there were minor tensions, they were quickly resolved. Four out of the five participants who perceived the collaboration as "rare" or "not really satisfying", or with "tensed moments", identified self-management as a potential barrier to collaboration, as illustrated in the following quote: "*In my group, there were moments of tension due to lack of assignment of roles, I think that at times this was a mishap to be able to collaborate and it demotivated us.*" (ASF1Gr1). The only group member who was satisfied with the collaboration reported, however, some nuances: "*The collaboration between people both inside and outside the group has been very good. Even so, I recognize that since there were several people with strong characters (myself included), unsatisfactory encounters have occurred sometimes during the days of creation, especially when making decisions about what to show and how to do it*" (AM2Gr1).

The other three groups did not have apparent internal conflicts despite expressing disagreements and concerns. Group 2 and Group 3 quickly established a teamwork dynamic, with standard rules and shared goals. In Group 2, participants aimed to listen to everyone's voice without any clear tensions or conflicts. Their interactions were more horizontal than in Group 1, but there was limited social and emotional engagement, showing a low internal cohesion. It led them to create a scene relating the topic of trust in information with the one of social injustice in intensive resource exploitation.

The four interviewees from Group 2 agreed that the collaboration was good, but three reported that making decisions and translating them into action was difficult.

In Group 3, the participants decided to tackle the climate emergency through a social justice lens, which was initially a goal that many of them struggled with. However, they developed their ideas and creative process through horizontal functioning and were empathetic with each other, sharing collective excitement and emotional support. Their scene exposed the social stigma on infectious diseases and the social injustices of the climate emergency. The six interviewees reported excellent collaboration, and three highlighted the synchrony in their group and the predisposition to listen to everyone. In the words of one of them: "*There was from the beginning a manifest predisposition to understanding and cooperation, and that made it much easier. Each one with our egos (which always exist), but from an attitude that left room for the group, for the common goal, I think that prevailed.*" (ASF1Gr3).

In contrast, Group 4 lacked an inclusive space for negotiation. One person's voice (scientist and artist) took the lead, leaving little room for negotiation and inclusion of others' ideas. This hierarchical organization persisted until the end of the process, with three participants active and involved and three others playing a more passive role. On several occasions, all participants of this group worked on their own, showing less engagement in group activities. Within this

configuration, they created a scene relating Fordism with the concept of neuro-linguistic convergence and cancer. While four of the seven participants considered their collaboration good, including the participant who mainly took the lead considering she "*learned to lead group dynamics*" (SF2Gr4), three reported that some voices were given more attention than others, and two felt their voice was heard only occasionally. One participant also mentioned the presence of more passive members, noting: "*The collaboration at the group level went as well as possible, with moments of little collaboration but also those who did not collaborate let things happen or take their course*" (SF1Gr4).

The participants found that predisposition to team working and having good listening skills were beneficial for group collaboration. However, the lack of role assignment, difficulty in concretizing ideas, and individual disengagement or lack of attentiveness were identified as obstacles to collaboration (Table 4). Interestingly, while participants from Groups 1–3 agreed on their perceived collaboration, more variation existed in Group 4, which might echo their own functioning and cohesion.

The internal management of power struggle impacted the groups' cohesion and their capacity to engage all the participants in the collective creation process. Despite these differences, all groups devoted most of their efforts to finding a joint agreement on how to proceed with the requested creation, and translating their ideas into a scene. Barriers to collaboration were related to the nature of the activity itself, individual and interpersonal factors, and facilitation aspects. The participants appreciated the balance between feeling accompanied by the facilitation team and having freedom in the process. However, four participants found this support challenging because they sometimes needed more clarity. At the same time, three others valued this freedom as a crucial element within the creative process. Two participants complained about contradictions in the indications given by different facilitators about expectations or feasible actions, and having a clear goal was emphasized as important for achieving a collective output and a sharper narrative.

## Discussion

Our results provide empirical evidence on social learning outcomes and processes derived from a transdisciplinary art–science collaboration and the internal elements that enhance or limit participants' engagement and social interactions within the project. This study found that individual previous experience in art–science projects and predisposition to teamwork were the most outstanding elements positively shaping collaboration, rather than individual background (scientist, artist, both). We also identified balanced power dynamics and inclusiveness as key factors in enhancing individual participation and group capacity to go over the different phases. However, this work also pointed out that internal barriers such as the lack of interpersonal skills, dominant egos, power struggles, lack of critical reflexivity, and the long time required to establish common norms—norming phase—can limit the effectiveness of the collaboration.

The EPSN project provided several outcomes to the participants, independently of their background. It facilitated cognitive, emotional, and inter-relational learning that might be key for transformative learning. Responding to the project facilitators' guidelines, all the groups related their chosen scientific topics with socio-ecological challenges (e.g., social injustice in climate emergency and natural resource exploitation; virus and cancer as metaphors of political struggles). For so doing, participants had to approach these topics from a complex systems perspective (acknowledging non-linearity, interconnections, and feedback loops), which implied cognitive learning such as bringing new ideas and perspectives to the participants and also, in some of them, a shift in their perception of scientific themes from isolated issues to embedded in broader and interconnected

**Table 4** Participants' assessment of the collaboration in their group

| Valoration | Total ($n=22$) | Group 1 ($n=5$) | Group 2 ($n=4$) | Group 3 ($n=6$) | Group 4 ($n=7$) |
|---|---|---|---|---|---|
| Very satisfied | 14 | 1 | 3 | 6 | 4 |
| Neutral | 4 | 2 | 1 | | 1 |
| Unbalanced collaboration | 2 | | | | 2 |
| Dissatisfied | 2 | 2 | | | |
| Reported barriers | | Strong egos, lack of roles, lack of consideration of participants' expertise | Absence of participants (some days), difficulty of concrete ideas | Balanced group | Fear of innovation, unbalanced listening and engagement, language, no leader |
| Reported enhancers | | | No leader, respect of opinions | Ideas acceptation, teamwork predisposition | Proactive group |

socio-ecological challenges. This bridging capacity is critical to solving current and future challenges in ways that might lead to transformative learning (Linnér and Wibeck 2021). Another important learning impact was on participants' inter-relational skills and self-awareness. This finding aligns with previous studies that suggest a diversity of individual and interpersonal learning outcomes resulting from art–science collaborations (Leimbach and Armstrong 2018; Clark et al. 2020; Paterson et al. 2020; Schnugg & Song 2020). Inter-relational skills are crucial for establishing successful transdisciplinary projects, as they involve the capacity to listen to others, the willingness to set aside one's own ideas, and to relate in more horizontal ways (Tejedor et al. 2018; Steelman et al. 2019; Tembrevilla et al. 2023). As highlighted by our study, such learning experiences affect participants on a personal level, providing them with critical personal insights that can also contribute to increased self-confidence (e.g., overcoming shyness, nurturing self-esteem), or the capacity to critically question prejudices and behaviors (e.g., being more aware of their own behavioral patterns, reflecting about their openness to other viewpoints). Thus, these insights further prove that art–science projects can foster changes in individuals' values and beliefs, which are part of transformative learning (Sterling 2011).

Vis-a-vis these insights, we have identified three design elements that can help in the development of more effective interactions, reinforcing social learning processes and outcomes, namely: (i) destabilization, as an invitation to horizontal collaborations; (ii) immersion, within a joint exploration process mediated by artistic creation; and (iii) materialization, emphasizing the importance of listening to the group dynamics needed for collective action. In the following subsections, we discuss these elements in relation to barriers and tensions to inform the design of transdisciplinary co-creation projects with transformative potential for sustainability.

## Destabilization

The first key design element relates to the heritage of the transgressive character of the foundation's artistic methodology and its application within the workshop. The coordination team's playful attitude and motivation to create a highly creative exploration sandbox resulted in a workshop design that fostered an initial stage of destabilization. Two elements were essential to this process, as observed and reported in individual participation: the transgression of disciplinary roles and group self-management.

The lack of assignment of "expert" roles according to background invited participants to step out of their comfort zone and allowed a type of participation transgressing disciplinary boundaries. The particularity of this process, rare in transdisciplinary projects (Higler et al. 2021), had

the virtue of distributing power within the group and fostering social learning, transcending persistent dichotomies found in transdisciplinary collaborations, such as experts/non-experts, scientists/non-scientists, and artists/non-artists (Hilger et al. 2021). This is also relevant as "egos" exist in artistic and scientific contexts, which has led to calls for methodological strategies dealing with this issue in transdisciplinary collaborations (Gibbs 2014; Ellison and Borden 2022). In our case, crucial to destabilize and challenge these dichotomies was the initial warm-up phase, which set a playful atmosphere and initially altered power dynamics (e.g., releasing tension, creating trust, putting participants in unconventional roles, fostering cooperative work, and informal relations between participants), and the composition of the participants, with several being both scientists and artists. In practice, this disciplinary destabilization represents an opportunity in methodological approaches within sustainability sciences to overcome participants' pre-established roles, either scientists as knowledge consultants or artists as creative actors (Dowell and Weitkamp 2012). Transdisciplinary collaborations encourage participants to display their intuition, creativity, and exploration—features inherent to both scientific and artistic research processes—without being caged in predetermined roles. These features are crucial for envisioning more sustainable futures (Curtis 2009; Wiek and Iwaniec 2014).

Furthermore, it created compelling narratives around four topics that merged scientific and artistic knowledge. Along these lines, previous studies show that undisciplined collaborations might encourage the emergence of new hybrid knowledge and practices, helping people embrace change and complexity while exploring sustainability issues (Benessia et al. 2012). In our case, we can speculate that a seed was set in this direction, with some participants reporting the inspiration sparked by the experience and their intention to bring specific transdisciplinary elements to their own practice (whether artistic or scientific). Also, merging different ways of doing (practical perspectives) and creative sensibilities provides opportunities for participants' mutual learning on life–world perspectives, a key feature of transdisciplinary collaborations (Hirsch Hadorn et al. 2008). If integrating multiple sensibilities and bridging worldviews has been identified as key in sustainability transitions (Miller et al. 2013), putting it into practice in a respectful way is often regarded as a challenge (Steelman et al. 2019).

Such destabilization was further promoted by the fact that the group, consisting of 'strangers' from different contexts and backgrounds, had to self-manage during the co-creation process. This was testified by several participants who identified group dynamics as challenging their participation. Building teamwork capacity when facilitating such encounters is thus crucial. Doing so through an inclusive and egalitarian approach has been seen as a pillar

of transdisciplinary projects (Schauppenlehner-Kloyber and Penker 2015; Wiendroth and Goldschmith 2017; Steelman et al. 2019). The integration of scientific discussions and performance development within a self-managed horizontal environment challenged participants' previous experiences. It boosted creative experimentation, creating new spaces of possibilities (Kagan 2015) and merging cultural and scientific divides. This approach echoes the concept of facilitation as a "boundary method" that can endure different meaning-making strategies for encouraging creativity at a cross-disciplinary interface rather than within a dominant discipline (Wiendroth and Goldschmith 2017).

## Immersion

Another core element of this encounter was its immersive nature within a performance co-creation process. Participants were practically disconnected from the "outside world" (Blache et al. 2022) for 11 days, and interacting almost only with each other and their creation contributed to intensifying the experience. Being immersed within a self-managed co-creation work for an artistic performance contributed to physical, emotional, and social engagement, as observed and reported by the participants, thanks to a diversity of activities coupled with formal and informal spaces, which allowed different outcomes. However, the transformative potential of these outcomes is limited when there is a lack of critical reflexivity, understood here as the building of practical competencies and reflexive capacities to engage with others, critically assess values and understanding, and question accepted behaviors (Popa et al. 2015). In both social learning processes and outcomes, critical reflexivity is crucial to contributing to social change in the long term (Cundill 2010; Popa et al. 2015). Specifically, our results suggested that critical reflexivity can be enhanced or reduced according to the level of group engagement. This was very clear in the group with a more hierarchical organization (Group 4), in which the participants valued the collaboration very differently. This shows how, when there is a low or unbalanced engagement of individuals in the group, the potential for group learning and "loop learning" is reduced (Schauppenlehner-Kloyber and Penker 2015), potentially decreasing individuals' capacity to reflect upon themselves critically. Indeed, facilitating spaces of mutual critical reflexivity, where individuals can benefit from feedback from the group, is crucial for challenging prefigured beliefs and behaviors, ultimately fostering learning outcomes with transformative potential (Popa et al. 2015; Knickel et al. 2019). In our case, while time was allocated for feedback and critical discussion about the scenes, no facilitation or design was dedicated to fostering the group's critical assessment of their collaboration. To face the challenge of integrating these reflective moments into the design of transdisciplinary

creation processes, particular tools and explicit facilitation are needed (Wibeck et al. 2022). This is especially relevant for learning processes within sustainability transformations, which urge us to critically question current development paradigms and unsustainable lifestyles and reconsider how we relate in the world (Iovino 2019). The 'more-than-rational' types of reflexivity unfolded by artistic practices, including esthetic, hermeneutic and ontological dimensions, might help in these processes (Dieleman 2008).

Nonetheless, time is a key pillar for allowing such spaces of reflexivity and the aforementioned insights, including the emotional, social, and group engagement afforded by the immersive experience. Even in a favorable setting such as ours (e.g., participants having a full-time commitment for 15 days), inclusiveness was always tensioned by participants' capacity to fully engage. Time requirements, whether in short, intensive formats like this project, or less intensive but extended projects, are still an essential issue in designing participatory projects (Schneider and Rist 2014; Heras et al. 2021). This factor should always be carefully considered, as it can unconsciously discriminate against specific profiles of participants (e.g., people with more caregiving responsibilities, like women or socio-economically vulnerable groups) and limit social learning and exchange. Institutional and financial support also affect the inclusivity of these encounters by shaping participation conditions and external motivations. Previous experiences showed that the availability of solid and sustained funding is essential to support diverse participant profiles in art–science collaborations and help the widespread occurrence of this type of encounter (see, for instance, the experience of the Wellcome Trust in the UK, in Dowell and Weitkamp 2012).

## Materialization

Finally, this study provided evidence of the group dynamics involved in social learning processes, showing (i) the importance of group functioning in the ability of groups to pass through different phases of collaboration and (ii) the predominance of the norming phase in this process. For a collaboration to be fruitful, as perceived by the participants, it seemed crucial to provide equal opportunities to all the participants, ensure a balanced power structure, and maintain inclusiveness throughout the process. Indeed, we saw that participant satisfaction with their collaboration varied according to their group power structure, with much disagreement arising in groups experiencing power struggles. So, even if a group managed to go through the different phases and produce an outcome, the collaboration process might not lead to improved learning on working in a group. In this line, we not only saw that groups' needs differ according to the phase in which they belong to, as highlighted by Schauppenlehner-Kloyber and Penker

(2015), but also most importantly that the composition of the groups and their intrinsic functioning are closely linked to their capacity to navigate the collaborative process. On the one hand, the presence of individuals with previous experience in art–science encounters might foster group collaboration and learning potential, provided that inclusiveness is maintained throughout. Therefore, while Schauppenlehner-Kloyber and Penker's (2015) framework provides relevant insights for facilitating and designing collaboration, attention should also be given to the group's internal organization for maintaining inclusiveness and fostering critical reflexivity spaces throughout the collaboration. In this line, some participatory tools might be helpful for participants to reflect critically on their collaborative process, such as, for instance, the ABACUS tool developed by Doberneck and Dann (2019). Scaling up this process to collaborations between institutional organizations might need the intervention of external actors, acting as mediators to maintain such inclusiveness and deal with individuals who might disturb the group collaboration process (Schauppenlehner-Kloyber and Penker 2015; Steelman et al. 2019; Hilger et al. 2021).

In this specific case, it was observed that the destabilization approach and a playful attitude might be useful for this aim. However, enough attention needs to be given to group functioning. Indeed, despite the diversity of group dynamics, a common trend observed in the groups was that considerable time was spent discussing ideas rather than performing them. Even when group cohesion was strong and fruitful discussions occurred, making decisions and materializing them into action was challenging. This highlights the difficulty of finding common ground and a method for the practical aspects of execution, for the "doing" and the "how", as largely reported in the literature on transdisciplinarity and sustainability research (Keen et al. 2005; Hirsch Hadorn et al. 2008; Jacobs et al. 2017). The fact that the groups needed to self-manage themselves exacerbated this difficulty and consumed much of their energy. As embodied practices with their own performative culture, artistic practices can significantly help stimulate creativity and invite action when discussions get too abstract. However, this experience suggests that these practices must be balanced with proper group facilitation. In line with insights from previous experiences (Heras and Tàbara 2014; Galafassi et al. 2018b; Pereira et al. 2019), the combination of diverse practices in the co-creation process involving the mind, body, and socio-affective interactions might be vital to fostering more creative and inclusive dialogues within transdisciplinary experiences in sustainability contexts. Embodied practices and embodied research methods have also shown great potential in this regard (Gibbs 2014).

## Conclusion

Creating collectively within the arts–science interface implies individuals reflecting upon themselves to identify their own behavior for the common purpose (purpose being the process) of creating together. It might imply profound personal reflexivity and changes as first steps toward transforming the collective. Our experience has demonstrated the potential of destabilization, immersive processes, and embodiment to foster fruitful transdisciplinary collaborations, challenging preconfigured disciplinary roles, and opening up possibilities for new relations and hybrid practices to emerge. It has also pointed to barriers tensing that potential, such as time requirements or lack of reflexivity, which can affect inclusivity and transformative outcomes of these experiences. As with any participatory process, the outcomes of this experience were highly dependent on the participation context and partakers' conditions. In this case, participation was largely fostered by groundbreaking artistic facilitation. Therefore, these elements should not be seen as always generalizable, nor as prescriptive. However, they highlight inspiring features and relevant elements to spark more horizontal and creative collaborations. In the current global context of social, political, and ecological challenges, where innovative and transdisciplinary approaches are widely recognized, further effort should be given to learning and re-inventing how we relate to others. Experiences such as art–science collaboration processes might show us other possibilities for approaching collective creation, prompting us to reconsider our goals, roles, and capacities within these creative spaces, while training active listening, mutual learning, and imaginative skills, which are crucial for building a more sustainable future.

**Data availability** Due to the personal nature of our data, raw data for observations and questionnaires are not publicly available to preserve individuals' privacy under the European General Data Protection Regulation. Anonymized data might be available upon request to the authors.

## Declarations

**Conflict of interest**  The authors declare no conflicts of interest.

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