Climate adaptation game design to foster transdisciplinary and intercultural collaboration

Ingrid Vigna[1], Aida Arik[2,3], Jelmer Jeuring[1], Isabelle Ruin[2]

[1]Norwegian Meteorological Institute, Bergen, 5007, Norway
5 [2] IGE, Université Grenoble Alpes, CNRS, IRD, Grenoble INP, F-38000, Grenoble, France
[3]Now at: LESSEM, Univ. Grenoble Alpes, INRAE, Grenoble, France

Correspondence to: Ingrid Vigna (ingridv@met.no)

Abstract. Addressing the complex challenges of climate adaptation requires transdisciplinary collaboration that bridges diverse knowledge systems across cultural and disciplinary boundaries. This paper presents insights from the "Climate Action Transdisciplinarity in Education and Research" (CATER) project, which implements game co-creation as an educational tool to foster transdisciplinary and transcultural collaboration on climate adaptation. Through annual schools, participants from diverse scientific, professional, and cultural backgrounds engage in an immersive learning process that integrates theoretical lectures, field visits, and collaborative game design. Participants develop games addressing real-world climate adaptation issues, including agricultural resilience, probabilistic forecast communication, and resource conflicts, thereby translating complex concepts into immersive, educational applications. In this paper we reflect on the co-creative process as it took place during two schools in 2023 (Kenya) and 2024 (Tanzania), and discuss game co-creation as boundary work, how it facilitates mutual learning and applies soft skills, while participants negotiate power dynamics, knowledge integration, and group facilitation challenges. A complementary evaluation using Q-methodology assessed changes in participants' perspectives on transdisciplinarity and co-production, revealing a shift from disciplinary viewpoints toward greater appreciation of collaborative, inclusive approaches in climate adaptation strategies. The findings highlight game design as an effective medium for experiential learning and transdisciplinary boundary work, although challenges remain regarding power imbalances, language barriers, and group dynamics. Importantly, the combination of game co-creation and systematic evaluation with Q-methodology offers a promising approach to enhance and assess transdisciplinary collaboration. Future CATER schools will allow us to refine these methods.

1 Introduction

Facing climate adaptation challenges is becoming an everyday reality for many (Banholzer et al., 2014; Hoppe et al., 2014; Berrang-Ford et al., 2019). Adapting to the multi-scaled impacts of climate change requires collaborations that transcend science-society boundaries and that integrate perspectives, knowledge and capacity into transdisciplinary strategies that are both robust over time and resilient to shocks.

30   To facilitate such collaborations and knowledge sharing, there is a need for co-productive modes of interaction between researchers and stakeholders which not only allow for different expertise, backgrounds and priorities to be brought to the table, but that allow for co-production of knowledge that is more than the sum of its parts (Bremer & Meisch, 2017; Hilger et al., 2021). To do so, innovative methodological tools are needed to foster synergetic knowledge co-production at a pace and intensity (Costa et al., 2022) suitable for a given adaptation context.

35   Co-producing suitable strategies for climate adaptation is, however, not a one-off exercise. A potential future with unstable, extreme and high-impact climatological conditions suggests a continuous need for science-based adaptation. This also means that there will be an ongoing, and likely growing, need for future professionals that are able to understand the complexity of these issues and who can promote transformative collaboration (McClure et al., 2024). In other words, climate adaptation requires self-reinforcing collaborations that not only feed off transdisciplinary capacity, but simultaneously nurture it from the

40   bottom up.

In this paper we explore the potential benefits and challenges of a multi-method approach based on game co-creation to foster and assess the transfer of transdisciplinary and sustainable knowledge about climate adaptation. The approach has been implemented within the context of a series of schools as part of the project "Climate Action Transdisciplinarity in Education and Research" (CATER). The project aims to create transdisciplinary cooperation for mutual learning between global north-

45   south contexts, linking science to action, and building leadership and confidence of students, early-career professionals, and practitioners on the frontlines of climate action. The paper gathers evidence from two schools; one organized in Kenya in November 2023, and a second in Tanzania in October 2024 (more details follow in the next section), with participants from primarily African and European countries.

As a key pedagogical structure of the schools, we developed and implemented an approach that combines immersive game-

50   based exercises, where participants are both creators and players of games focusing on climate adaptation challenges. With the term "game", we refer in this work to what has often been defined in the literature as "serious game" - i.e. game with a purpose other than just entertainment. Serious games have been used for a variety of objectives, such as research, raising awareness, promoting social learning and enhancing collective discussions among different stakeholders (Speelman et al., 2018). Their use in sustainable resource management contexts has been widely documented as a means to explore socio-ecological system

55   complexity, facilitate conflict mediation and promote collective decision-making through simulation (Madani et al., 2017; Rodela et al., 2019; Ruankaew et al., 2010; Wesselow & Stoll-Kleemann, 2018). Furthermore, games are increasingly being used to support climate change research and practice, with an emphasis on decision-making for climate adaptation across various timescales and sectors (Flood et al., 2018).

Within the CATER schools, the process itself of co-creating a game is an educational tool to foster transdisciplinary

60   collaboration. Co-creating a game involves participants putting themselves in others' shoes, taking on different roles, and integrating diverse knowledge and perspectives into a shared understanding of complex social and ecological systems, made tangible by the game format (Kriz, 2004; Lankford & Craven, 2020). This approach prompts them to anticipate various outcomes that can arise from a process of playful, yet profound learning (Arnab et al., 2019; Morini et al., 2022). The game-

based exercises created a format for exploring challenges and opportunities for science-society interactions around climate
65   adaptation at a micro-level. By engaging in collaborative game design, CATER school participants delved into the complexities
of climate adaptation, negotiating power dynamics, and enhancing their critical thinking and problem-solving skills in real-
world contexts. The main goal was to evoke transformative learning experiences, in order for participants to internalize
transdisciplinary interactions and enabling application of learning outcomes in their respective professional spaces.

However, the outcomes of game experiences are often difficult to measure and drawing conclusions about their added value
70   is a major challenge (Den Haan & Van der Voort, 2018). Several papers on game approaches identify a need for combining
gaming with a more systematic evaluation approach that allows for assessing the knowledge co-creation process and its impacts
(e.g., Mayer et al., 2014). In our approach, we complemented the game-based learning with an assessment based on Q-
methodology (Brown, 1993). Q-methodology is a valuable tool for eliciting systematic insights about people's subjective
assessments about virtually any topic of interest. It is especially useful for identifying underlying structures of subjectivity
75   (Zhou & Mayer, 2017) on topics of which people may have diverging views (Eden et al., 2005). As such, systematic
assessments of 'messy' co-productive learning processes combined with structured reflections can contribute to a robust
foundation for further research and transdisciplinary collaboration. Thus, the purpose of the Q-method assessment was to
evaluate the school's impact on the participants' sense of transdisciplinarity, co-production and power dynamics in the climate
adaptation space. In particular, we aimed to test the hypothesis that divergent perspectives will have a tendency to converge
80   after attending a CATER school, as participants learn about climate services from multiple disciplines and learn from their
peers.

In the following subsection, we describe in more detail the context and the transdisciplinary approach of the CATER schools.
Then, we present our methodology by describing the co-creative game exercise, the observations and debriefings conducted,
and the assessment procedure of the impact of the school on participants perception. In the Results section, we analyse the
85   game prototypes produced by the participants, we reflect on group dynamics in the game co-creation process, and we show
the results from the Q-method assessment. Our reflective discussion highlights how game-based exercises provide a means of
engaging in transdisciplinary boundary work, how co-creating game-based solutions are both challenged by and benefiting
from cultural, social, disciplinary and individual variety, and how learning outcomes emerge at personal, group and school
levels. We wrap up with an outlook towards limitations of the approach and implications for future schools that will be
90   organized in our project, as well suggest relevant lessons that can guide other initiatives that aim to build on game-based
learning as a method for enhancing sustainability transformations.
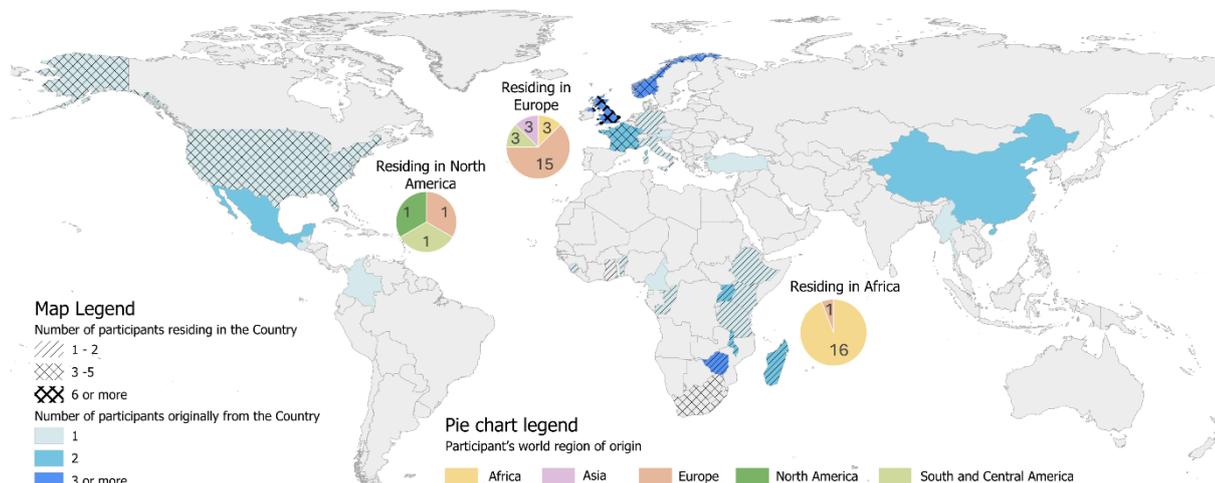
1.1 The CATER school

The CATER project (2023–2028) gathers scientists involved in co-developing climate services with stakeholders from both
private and public sectors in Africa and beyond. The aim is to create "an environment where students, early-career researchers,
95   lecturers, and practitioners across disciplines and sectors can together learn, discuss and re-interpret the latest knowledge at
the forefront of climate risk resilience and action in Sub-Saharan Africa" (www.caterschools.net). The rationale behind the

project is a belief that transdisciplinary and co-production processes are key to nurturing social engagement, equitable power distribution, inclusivity, socially legitimate, context-driven and decision-relevant services, while forging a much-needed closer relationship between science and society. CATER is funded under the INTPART programme (https://hkdir.no/en/programmes-and-grant-schemes/intpart), which is administered by the Norwegian Directorate for Higher Education and Skills and the Research Council of Norway. Its partners are from Norway, France, and South Africa, and the programme is linked to the Norwegian government's PANORAMA strategy for cooperation on research and higher education with Brazil, Canada, China, India, Japan, Russia, South Africa, South Korea and the USA (cooperation with Russian partners was suspended in 2022).

Throughout the project period, CATER organizes annual 10-day schools. These schools gather about 10 lecturers and 20–25 international students. Having both students and lecturers immersed in a multicultural environment allows for exploring pathways for successful transdisciplinary collaborations through the co-creation of games. Moreover, the school schedule fosters interactive activities combining theoretical, methodological, reflexive sessions with field trips, where participants are encouraged to share their experience and knowledge (local, tacit, and practical) to enhance understanding between the physical, socio-economic, and cultural aspects of climate change mitigation and adaptation. Although climate risk governance is context-based, challenges related to linking science to action are often similar across contexts, with opportunities for mutual learning within local contexts and across continents.

1.1.1 Diversity of the participants' profiles

The CATER school participants were selected by the school organizing committee based on their motivation, capacity to contribute to and benefit from an English-language work environment, as well as criteria ensuring a balanced diversity in terms of gender, nationality, professional status, scientific background and experience with inter- and transdisciplinary collaborations. In terms of cultural backgrounds, the first two editions of the school gathered participants worldwide, but mostly from English-speaking African countries, and western Europe, in particular Norway and the United Kingdom (Fig. 1). Although most of the 44 total participants were residing in Europe (24) or Africa (17) when they applied to the schools, a large majority of the participants have experience living or working in one or multiple countries other than their country of origin.

Figure 1: Countries of origin/residence of the 2023 and 2024 school participants.

The geographic distribution can be largely explained by the CATER project partners' locations and professional ties with these countries. Additionally, with the English language advertising and application submission, most participants speak English as their first language or master it as a second language through living or studying in an English-speaking country (Fig. 2a).

In terms of scientific and professional backgrounds, the majority of participants were either PhD students, postdoctoral researchers, or master's students, evenly distributed between social and physical sciences disciplines. The distribution varied according to the participants' country of residence, with practitioners being less numerous but more predominantly based in Africa (Fig. 2b).
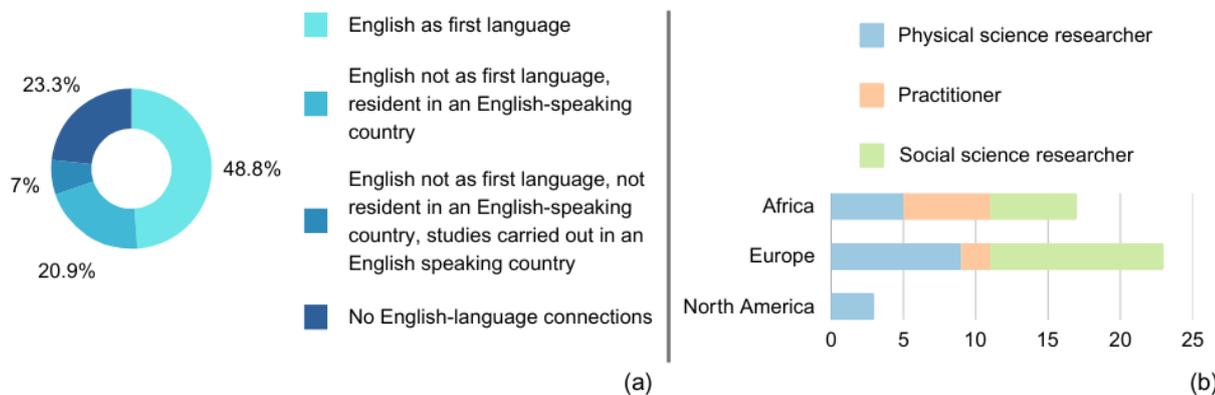
Figure 2: Participants' characteristics, including (a) the percentage distribution according to their proficiency in the English language, and (b) the distribution of their professional fields across different regions of residence.

In summary, the origin of the participants in each of the school sessions reflects the cultural and professional diversity that often characterizes transdisciplinary collaborations. This diversity is a source of richness for its plurality of knowledge, life

experiences and viewpoints, but it is also a challenge in dealing with language and cultural barriers and unbalanced power
135   dynamics that may cause misunderstanding and tensions.

1.1.2 School organization and content

The overall school program alternated between theoretical and practical modules encompassing climate science, social science
and the humanities (see the 2024 version of the school program in Fig. A1 in the Appendix). Moreover, it aimed to co-create
a common knowledge base and toolkit to develop transdisciplinary soft skills. The learning sessions aimed to provide space
140   for self-reflection on current practices, as well as practical exercises using techniques building on collective intelligence, such
as writing a set of shared behavioural guidelines for group activities (Galesic et al., 2023). Self-reflexive sessions spurred
discussions around principles, ethics and values in climate services, of transdisciplinary approaches to climate services, as well
as climate justice and power issues. Even though the school's curriculum only skimmed the surface of the range of knowledge
and skills specific to these subjects, the aim was to cultivate openness, sensitivity and curiosity of these elements in a climate
145   adaptation context.

As an introduction to game co-creation, the participants played previously developed climate-related games during the first
days of the school. This served as an example of how games can be used in climate adaptation processes, thus inspiring group
work both practically and thematically. Two games were played during the two first school editions: "AnyCAT", an adapted
version of "ANYCaRE" (Terti et al., 2019), a table-top collaborative role-playing game to explore the value of probabilistic
150   forecasts on emergency management decision-making and communication strategy; and "Melkeværet" (Vigna et al., 2024), a
board game coupled with a digital interface on weather forecast information for agriculture.

2 Methods

2.1 Game co-creation

On the first day of the schools, participants were assigned to groups of five or six people, to co-develop a game that addresses
155   a climate adaptation challenge. The exercise was intended as a common thread during the course of the school, linking the
school's learning activities and enhancing critical reflection on the content. The participants were encouraged to integrate
content, insights and reflections from the school lectures into their games. The groups were pre-selected by the school
organizers to maximize internal diversity in terms of scientific expertise, professional skills, gender, and cultural background,
to simulate real-world exposure to challenges and opportunities of a transdisciplinary co-production process.
160   An introduction to concepts and approaches in game design was provided at the beginning of the schools. The guidelines
structured the game development process into four steps, adapted from the Triadic Game Design approach (Harteveld, 2011):

1. Setting the aim of the game, the target audience and the format (board games were encouraged). This step mainly refers to the "meaning" component of the game as described in the Triadic Game Design approach, i.e. the effect that the game is meant to produce in the real world;

165
2. Conceptualizing the socio-ecological system represented. This step refers to the "reality" component, i.e. the representation of the real world inside the game;

3. Building the mechanics of the game, such as defining the players' roles, the characteristics of the board, and the rounds' structure. Here we referred to the "play" component, which involves the elements of the tool itself and is directly connected to the game design discipline;

170
4. Defining the structure of a game session, such as the number of participants and their arrangement in the room, or a list of predefined questions to lead the debriefing following the game-play. This step targets the implementation of the game and is meant to ensure the correspondence between its "play" and "meaning" components.

The groups were given time each day to work on their game design. Since the focus of the activity was to learn through the co-design process and not on the final output itself, the groups were not expected to develop a completely finalized and

175 operational game, but rather a working prototype that could potentially be further developed in the future.

The two editions of the school resulted in eight board game prototypes (four each) focusing on different challenges related to climate adaptation (Table 1). The topics included communication of climate and weather information, climate-induced conflicts over resources, international mitigation and adaptation policy negotiations, power imbalance in climate adaptation systems, integration of scientific and traditional knowledge, and agricultural adaptation strategies to a changing climate.

180 **Table 1: Overview of games created by participants of the CATER schools in 2023 and 2024. The information in this table was collected by the authors based on the participants' presentation and game-test session held at the end of the school.**

School	#	Game title	Topic	Format
Kenya, 2023	1	Grazing Grounds	Conflicts between communities of pastoralists and farmers in Ethiopia.	Role-playing game with three roles (farmer, pastoralist and NGO representative)
	2	Wanna Be @ COP28	International negotiations on resources for climate change mitigation and adaptation.	Board game focusing on negotiation. The players represent countries with different needs and interests.
	3	Pastoralist Cater Land	Challenges faced by pastoralists in East Africa in relation to exposure to drought, which pushes them to search for resources.	The players represent pastoralists and move physically on a room-sized map drawn on the floor.
	4	Land of the GOAT	Collective decision-making under climate uncertainty and limited shared resources, in the context of goat farming	Board game focusing on decision-making related to the interpretation of seasonal forecasts.

			in East Africa.	
Tanzania, 2024	5	-	Seasonal forecast probability communication and plurality of knowledge sources, in the context of agriculture and farming adaptation to variable conditions.	Board game inspired by poker mechanics.
	6	-	Suitability of different forecast time leads and communication channels for climate events preparedness.	Board game where the players represent different weather information providers.
	7	The Crop Survivor	Importance of crop diversity for resilience to different climate events in Malawi.	Board game where the players represent farmers, focused on crop variety choices in relation to seasonal forecasts. Coupled with a digital forecast simulator.
	8	(Do Not) Exploit the Farmers	Power imbalances between farmers and extension officers	Role-playing game where one participant plays the role of an extension officer, while the others assume the roles of farmers.

2.2 Observations and debriefings

The game prototypes were not evaluated per se but instead a final game session was organised at the end of the school. Each group ran a short test session of their prototype involving the other groups' members as players or observers. After each game demonstration, a debriefing session allowed to collect feedback from both participants and lecturers on how to improve the games and reflect on the challenges and strengths encountered by the participants during the game co-design process.

In addition, the school's outcomes were analysed with the help of several evaluative elements. Firstly, observations of the group work activity, as well as informal feedback from group and break-time discussions, were noted and discussed among lecturers after each school day. These staff discussions were aimed at making any needed adjustments for the next day's content or structure, but also provide a daily summary of positive and negative outcomes of the day. Second, one group each day was expected to take daily notes which provides a record of the activities and discussions. Finally, on the last day of the school, a debriefing session dedicated to a general evaluation of the school experience was conducted. The debriefing was carried out through a collective discussion guided by the lecturers, during which we encouraged the participants to share their feedback on the school content, the resources made available and the game group work. We also asked them to share their thoughts about their main takeaways and the aspects of the learning content that aligned with their previous knowledge and experience. Although everyone was encouraged to share, participation in the discussion was voluntary. Lecturers took notes of the contributions.

2.3 Perception impact assessment

One outcome of the 2023 edition of the CATER school was the recognition of a need for a more formal and objective way of
200   evaluating the impact of the school learning environment for participants. Although survey instruments can often be used to
evaluate learning objectives, we wanted a tool that better enabled us to evaluate how ideas shift relative to peers. In line with
this, during the 2024 CATER school we employed a Q-method assessment before and after the school to understand how
perceptions of climate challenges and transdisciplinarity changed over the span of participating in the CATER school
curriculum. The aim was to test the hypothesis that divergent perspectives will have a tendency to converge after attending the
205   school.

Q-method is a mixed-method approach used to study subjectivities in many subject areas, including conservation and
sustainability research (Sneegas et al., 2021; Zabala et al., 2018) and educational research (Lundberg et al., 2020). Certain
other studies have also similarly mobilized the Q-methodology for assessing impacts of interventions (Davies and Hodge,
2012; Freie, 1997; Walton, 2013). For our assessment, we asked school participants to rank 23 opinion statements related to
210   climate services according to a forced semi-normal grid. The statements were related to transdisciplinarity in climate action
and developed based on semi-structured interviews with six international subject specialists, as well as from literature and
media sources. The original 72-statement concourse reflected a heuristic framework of tensions in method (product vs.
process), knowledge (scientific vs. local), and expertise (technical vs. interpersonal), capturing stylized extremes of
transdisciplinary climate adaptation practices. The final set of statements were selected to represent diverse themes without
215   redundancy and refined for clarity and relevance to the subjects covered during the school. Participants were asked to rank
autonomously the statements by means of a guided online procedure before and after attending the 2024 school, which was
then used to observe changes in perceptions.

To carry out the Q-sorting process, we used TD-assess, which is the online application of our Q-method protocol built from
the EQ-Web-Sort open-source code (Banasick, 2023). The first step of the exercise is to read through the 23 statements and
220   do an initial sorting into three piles: "tend to disagree," "no strong feelings," and "tend to agree". These cards are then color-
coded and arranged by the initial sort to help with the next step of sorting the cards onto the grid (see Fig. 3). The next screen
after the sorting is completed asks the participant to provide commentary on the four statements they ranked the highest and
lowest (i.e., -3 and +3). Finally, a short survey captures the participant's high-level demographic characteristics. The online
application was verified for compliance with the EU's General Data Protection Regulation (GDPR).
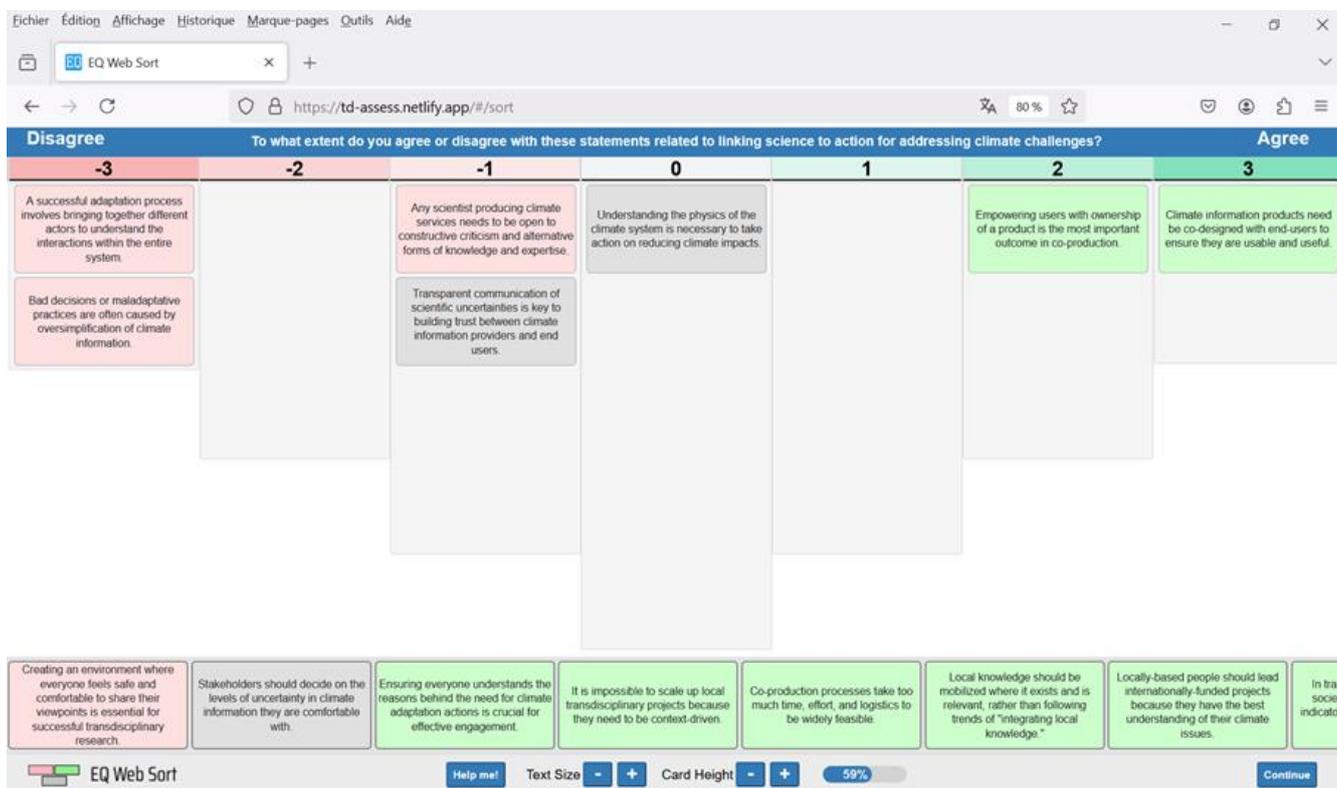
Figure 3: Example screenshot of the final sorting step of TD-assess. The final sorted set of statements and their associated ranking is called the "Q-sort."

We analysed the captured Q-sorts from the TD-assess exercise by first looking at the raw ranked data of those who participated in the TD-assess exercise before and after the CATER school. We then analysed all the Q-sorts through a Principal Component Analysis (PCA) to identify groupings of perceptions within the dataset. The exploratory analysis provides insights into changes in viewpoints of participants coming into the school and after participating in the school.

3 Results

In this section we first analyse the game prototypes produced in 2023 and 2024. Game content and linkages with the school curriculum are highlighted, as well as how the participants' background may have inspired game prototypes. We then reflect on group dynamics in the game co-creation process, based on authors' observations, and on participants' feedback collected throughout the schools and the final debriefing session. Finally, we show the results from the Q-method assessment.

3.1 Games' prototypes as artefacts of the diversity of co-production experiences

The topics and characteristics of the games reflected both the participants' personal experiences and the content of the school lectures. For example, one group, which included a member with experience related to the United Nations Climate Change

240 Conferences, developed a game on international mitigation and adaptation negotiations (see game 2 in Table 1). Similarly, the games focusing on agricultural adaptation strategies were inspired by the direct experiences of some participants, particularly those based in Africa, who had deep knowledge of context-specific challenges (see games 1, 3 and 8 in Table 1). Additionally, a circumstance that unintentionally influenced game creation occurred during one of the first evenings of the 2023 school, when we screened the film "Between the Rains" (https://www.betweentherains.com/). The film depicts tribal conflicts over

245 resources near Lake Turkana in Kenya and we believe that it partly inspired games 1, 3, and 4 in Table 1.

We observed that the presence of at least one practitioner in each group enhanced the work by providing examples of contexts to apply the game methodology, thus making the exercise more concrete and relevant. As an example, The Crop Survivor (game 8 in Table 1) was developed by the group as a tool to be potentially used by a participant based in Malawi, who support farmers in enhancing their resilience to climate change by diversifying their crops. On the other hand, both the content provided

250 during the school and the schedule of the lectures contributed to shaping the group work. Although a balance between social science and natural science-related topics was sought, more space and time was actually dedicated to decision-context aspects of climate adaptation. This was particularly evident – and highlighted by participants' feedback – in 2023, where only one day was dedicated to climate science and climate risk drivers, while the rest of the lectures explored the complexity of decision-making and the existence of a plurality of knowledge systems, the theory of transdisciplinarity, and issues of power, ethics and

255 social justice. This led to a stronger emphasis on conflicts and climate justice issues in the games: games 1 and 3 had references to conflicts between livestock farming and agriculture over scarce water and land resources, exacerbated by changing climate conditions, while game 2, already mentioned, focused on COP consultation among countries with different negotiation power. Drawing from the experiences from the 2023 school, the 2024 school incorporated more physical science content by balancing the lecture hours more equally between climate science and risk-related topics, and power, justice and transdisciplinarity

260 reflections. For the latter, we attempted to reduce the theoretical burden by referring to existing projects and real-world challenges. We observed that the game topics were highly influenced by the initial focus on climate modeling and communication. For example, the games addressed topics such as selecting the right communication channels to reach climate information users, understanding the relevance of different lead times in forecast products, and the challenges of communicating probabilistic forecasts (see games 5, 6 and 7). This distribution of game topics was a result of our emphasis on

265 physical science in the lectures, although it may also have been influenced by the students' backgrounds. These findings suggest a connection between curriculum content and the practical application of lessons learned, which is made explicit through game co-creation.

Along this line, although each produced game focused on a specific aspect or challenge related to climate adaptation, it is interesting to note how the participants were able to integrate multiple disciplines, as well as insights from both scientists' and

270 practitioners' experiences. One particular example was a game developed in the 2024 school, inspired by poker mechanics and focusing on the interpretation of probabilistic forecasts (see game no. 5 in Table 1). During each round, the players received a seasonal forecast in the form of probability for above-normal, normal and below-normal precipitation and had to decide on the crop or livestock type best adapted to the season's conditions. A row of hidden playing cards represented the actual seasonal

11

precipitation. The other deck cards were distributed to the players, who could then get a partial overview of the cards that were

275   not included in the seasonal precipitation draw. This game mechanic was a metaphor for local or traditional knowledge of players, which helped the participants to forecast the seasonal conditions but only gave a partial view. The use of local knowledge was further simulated by allowing the players to receive additional hints by asking the community elders' council for advice (i.e., revealing some of the other players' cards). While the communication and interpretation of probabilistic forecasts were thoroughly discussed during the climate science lectures, the importance of recognizing different ways of

280   knowing and the necessity of bridging traditional and scientific knowledge were recurring themes throughout the week in discussions on transdisciplinarity.

The 2024 edition of the school included a field visit day, thanks to the collaboration with local representatives. The participants visited a Maasai settlement in the region to discuss local climate adaptation challenges and strategies with a Maasai elder, as well as the Arusha Climate and Environmental Research Centre of Aga Khan University, which focuses on sustainable

285   agriculture research. We observed that the visit to the Maasai village had an impact on the creation of the games. For example, the visit influenced the poker-inspired game group (game 5) in setting the players' decision-making challenge on the adaptability of different livestock typologies to water availability. Overall, a large number of school participants gave feedback that the field day was the most impactful part of the school. Since it was scheduled during the second week when groups were already well into the creation of their games, the reflection on the shared immersive experience of the field day served as a

290   'reality check' for the games that were under development. Based on the experiences described above though, we hypothesize that if the field trip had occurred at the beginning of the school, the groups might have opted to gamify the experience of that particular climate challenge.

In general, the participants provided feedback that expressed strong appreciation for the game co-creation as a transdisciplinary group exercise. They emphasized the potential for games as a tool to help tackle complex issues, work as boundary objects

295   among different stakeholders and facilitate communication of scientific knowledge. Some of the participants expressed willingness and confidence to apply the method in their future work. This included both further developing their CATER school game prototype and also designing new games for their specific cases. We know from evidence that at least one attendee of the 2024 school already designed and implemented a game in their work.

3.2 Group dynamics in game co-creation

300   The exercise of co-creating a game (Fig. 4) as a group is designed to act as a microcosm for experiencing the transdisciplinary dynamics that characterize the complexity of climate adaptation.

(a)   (b)
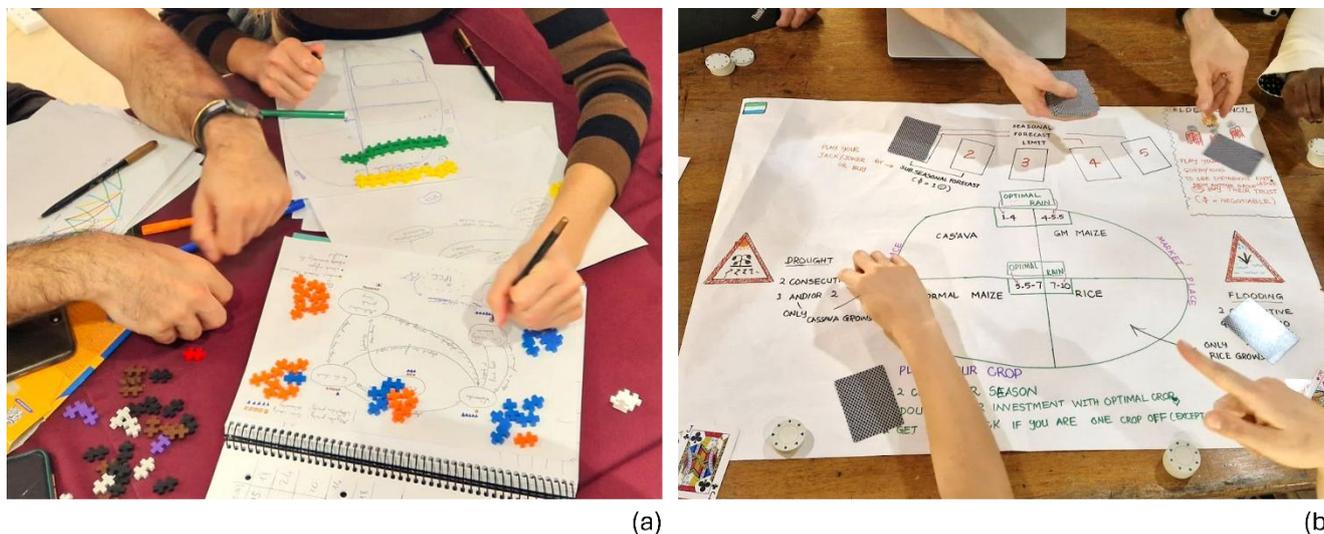
Figure 4: Two moments of the game co-creation process: a) a group is modeling the mechanics of the exchange of resources between countries in the COP consultation game (game no. 2, Kenya, November 2023); b) the poker-based game on probabilistic forecast communication is being tested at the end of the school (game no. 5, Tanzania, October 2024).

As prior experience in game creation was minimal and everyone had some degree of familiarity with playing games, the exercise placed all participants on equal footing. This helped to limit some participants from developing a dominant role in group dynamics due to a greater familiarity with game design. However, similarly to transdisciplinary processes in climate adaptation, there were challenges and opportunities to navigate as a group, each of which affected, but mostly enhanced the game design learning experience.

Acknowledging these dynamics, one goal of the CATER schools is to foster a safe environment while making participants aware that power dynamics exist in group settings. In order to work through these issues constructively, time was specifically reserved at the beginning of the group work for collectively reflecting on personal needs, barriers and inclusion strategies. This reflection was framed around collectively agreeing to a set of values or ground rules and experimenting with facilitation techniques to enhance everyone's capability to listen actively, respect each other's ideas, build confidence, and create safe spaces to foster creativity and constructive exchanges. The group work provided the opportunity to put such collective intelligence techniques into practice.

Nevertheless, and not dissimilar to 'real-world' transdisciplinary and transcultural collaborations, power dynamics could be observed in the group work (Fritz and Binder, 2020). The exercise of game co-creation played a crucial role in making these visible, allowing us to observe the transfer of unconscious power dynamics into the setting of the group. These dynamics often included dominant roles that emerged between male and female participants, extroverts and introverts, and those with game experience versus those without game experience.

The inherent challenges and opportunities of the multicultural nature of the working groups were typically implicit within each group, but became visible at various occasions. For example, as most participants coming from Africa tended to be practitioners, and given the setting of holding the school in Africa, these participants were often contributing with contextual

knowledge based on their expertise. Similarly, there was a tendency for participants with a prior passion for gaming, often coming from European or North American countries, who took on the role of gamifying the context provided. Language barriers also posed significant challenges for participants less comfortable with speaking English, contributing to unequal level of contribution of the participants during the exercises. Since all school activities were carried out in English and, as described

330 in Sect. 1.1, about half of the participants, as well as many lecturers, were native English speakers, this created an imbalance. Non-native speakers faced greater difficulties in engaging in collective discussions, which made their participation more demanding and, sometimes, limiting their ability to contribute fully.

Considering the interactions between the lecturers and the participants, we observed a general struggle for the lecturers to find the best posture in relation to the working groups. In addition to the general supervision of game design experts, each group

335 was assigned one or two lecturers from the school program to support their work. However, they were not given strict guidelines on how to approach their 'supervisory' role. This is in line with the general school setting, where all lecturers have always participated in the activities, sometimes as lecturers of the specific session, sometimes as participants themselves. The lack of strict guidelines resulted in very different approaches: some of the lecturers participated in all the initial group discussions as observers, some were more involved in the discussions themselves and partly participated in the co-creation

340 process, and some joined the groups only if specifically asked by the students for help (or retreated if groups expressed that they did not need help). Most of them also adapted their approach throughout the two weeks, for example by trying to be more present in case of group struggles. From the student feedback, this resulted either in a feeling of lack of guidance or a perception of too strict directions. In addition, the lack of even geographical and gender representation among the lecturers, the majority of them being of European origin and male, may also have contributed to making the interaction with the groups challenging.

345 **3.3 A framework for exploring perception change**

We present here the exploratory findings of the Q-method assessment as an abductive framework for identifying and understanding the ways in which the CATER school and the game co-creation play a role in shifting perspectives. In total, we captured 25 Q-sorts (i.e., sorted statement sets) from the TD-assess exercise. Seventeen out of 22 school participants took part in the exercise, from which there were 7 respondents who repeated the exercise both before and after. In total, there are 16 Q-

350 sorts from before the school (one of which was a first-time CATER school lecturer unaffiliated with the Q-method assessment) and 9 after. The demographics of the TD-assess respondents well reflect those of the CATER school: evenly split between genders, a diversity of disciplines, mostly early-career, and highly multicultural. Although Q-method studies are not meant to be generalizable and therefore offer flexibility in the participation rate, it is crucial to ensure a solid representation of viewpoints (Brown, 1980; Sneegas et al., 2020). In our study, we recognize that the sample may not fully capture the diversity

355 of views among all CATER school participants, especially in the post-school dataset. However, these findings offer a general indication of the perspective shifts from which we can explore further by repeating the Q-method assessment in future schools. We applied a PCA with Varimax rotation (Akthar-Danesh, 2016) to the full dataset of 25 Q-sorts, including both pre- and post-school assessments, using the Ken-Q analysis platform (Banasick, 2023). To ensure meaningful comparison and retain all data,

360   we pooled the pre- and post- school datasets in the analysis. This preserved a shared principal component space that allowed us to trace participant-level changes more precisely. Through this, we identified three analytically meaningful factors. That is, the factors identified meet a set of quantitative checks as are often used in Q-methodological studies, including the number of flagged Q-sorts per factor ≥2, Kaiser–Guttman Criterium of eigenvalues ≥1 per factor, the variance explained per factor ≥10%, and the combined variance explained of all extracted factors ≥35% (Moser and Baulcomb, 2020; Tafel et al., 2022; Watts and Stenner, 2012). The factor outputs also made sense in the context of what we observed and the commentaries provided through

365   the TD-assess platform.

A mix of twelve pre- and post-CATER school Q-sorts correlated significantly to Factor 1, five pre-CATER school Q-sorts to Factor 2, and four post-CATER school Q-sorts to Factor 3. There were also four pre-CATER school Q-sorts that did not correlate significantly to any of the factors. Of those who repeated the exercise pre- and post-CATER school, there was no 'out-migration' of Factor 1, but there was 'in-migration' to both Factors 1 and 3. Factor 2 was bipolar as a result of one Q-sort

370   with a significant negative correlation, and was thus split into two Factors that have somewhat opposite views. Figure 5 shows the plot of factor correlations with their positions and movements before and after attending the CATER school. A composite Q-sort was created for each factor based on weighted values of the respondent Q-sorts that correlated significantly to the factors.

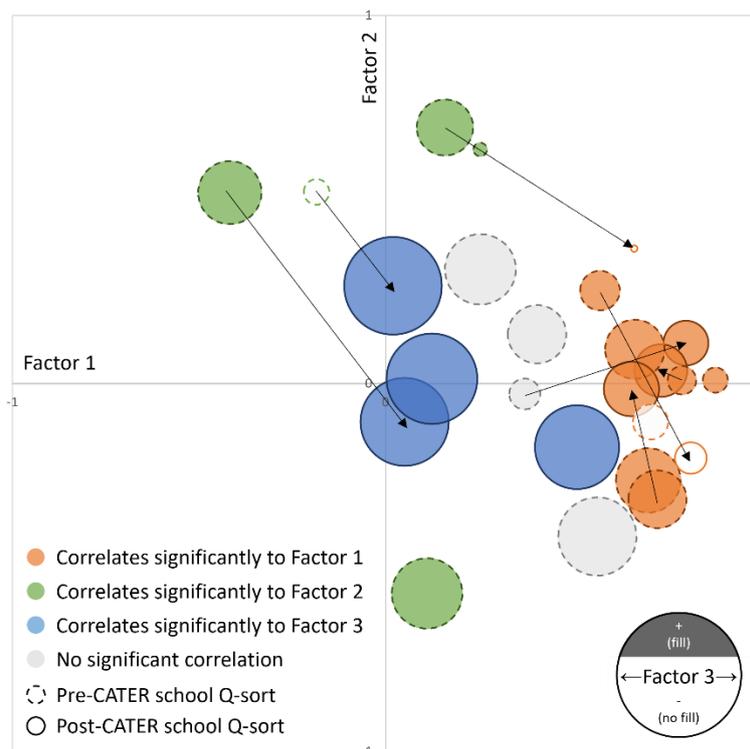375   **Figure 5: Plot of factor correlations. The spread of points along the horizontal axis represents the Q-sort correlation to Factor 1. The horizontal spread represents the correlation to Factor 2. The size of the bubble represents the correlation to Factor 3, with positive correlations represented by filled bubbles and negative correlations with no fill. Q-sorts that significantly correlate to factors**

1, 2, or 3 are shown in orange, green, or blue, respectively, and grey for no significant correlation to any of the factors. The bubbles with dotted outlines represent Q-sorts from before the CATER school and solid lines for after. Arrows indicate Q-sorts of the same participant pre- and post- CATER school.

380

The composite Q-sort for each perspective allows us to see the main ideas that differentiate the factor compositions, as well as consensus ideas. Distinguishing statements are those that are identified by their statistical uniqueness ($p < 0.1$) within the composite Q-sort compared to the other factors. In addition, we look at salient statements for each perspective, or those statements that rank +2 or above and -2 or below. Table 2 shows the salient statements that were unique to each factor. Further

385 statements had shared or similar values between perspectives. For brevity's sake, full composite Q-sort rankings are provided in Appendix B, as well as more detailed information on the Q-method assessment. The entirety of the output data was used to interpret the general typologies of the perspectives from each Factor.

Table 2. Salient statements (i.e., ±2 or ±3) unique to a particular factor. Asterisks (*) indicate statistically distinguishing statements for given factors at $p < 0.01$.

#	Statement	F1	F2a	F2b	F3
Factor 1 Salient Statements - Agree					
19	Transdisciplinary approaches are key to rebalancing of power dynamics through equal consideration of different perspectives and priorities.	2*	-1	0	-1
21	Transparent communication of scientific uncertainties is key to building trust between climate information providers and end users.	3	0	1	1
Factor 2a Salient Statements - Agree					
18	Traditional knowledge and indigenous spiritual systems must be at the base of climate adaptation because they are rooted in centuries of respect for the land.	0	3*	-1	1
9	Effectively bridging science and society requires trained intermediaries to support scientists and local officials to engage with each other.	0	2	1	0
14	Local knowledge should be mobilized where it exists and is relevant, rather than following trends of "integrating local knowledge."	0	2	0	-1
Factor 2b Salient Statements - Disagree					
8	Creating an environment where everyone feels safe and comfortable to share their viewpoints is essential for successful transdisciplinary research.	1*	-1	-2	-1
12	In transdisciplinary research, societal relevance is a better indicator of 'quality' than scientific robustness.	-1	1*	-2	0
Factor 3 Salient Statements - Agree					
20	Transdisciplinary approaches for climate adaptation help break down silos which helps avoid maladaptation.	1	1	0	2*

4 Discussion

This section reflects on the overall process and findings of the game co-creation activities. Drawing from the school outcomes, we explore how the co-creation exercise shaped collaboration and learning, as well as how perceptions evolved through this process. These reflections aim to deepen understanding of how co-creation unfolded in a microcosm of diversity across disciplines, professional roles, and cultural backgrounds and what this reveals about the potential of games in transdisciplinary education.

4.1 Game co-creation as boundary work

The simultaneous presence of very diverse aspects in the games, such as probabilistic forecast communication and interpretation, forecasts' lead-time, climate models and traditional knowledge, indicates that the group work was a meaningful space for experientially based discussion based on collective elaboration of the lectures' content. The game co-creation exercise offered the opportunity to connect the school curriculum content to the practical application of lesson learned. Our findings also suggest that the exercise led the participants to share their disciplinary and personal perspective, to create connections among disciplines and connect scientific expertise and practitioners' experience on the ground. Based on this evidence, the observation of the group work activity and the feedback from the participants, we argue that co-creating a game worked as a boundary object between disciplines and between researchers and practitioners, enabling communication and mutual learning (Lundgren, 2020; van Bruggen et al., 2019). It encouraged the participants to meaningfully contribute to the transdisciplinary exchange despite different backgrounds.

Moreover, through the group work, the participants could discuss among peers any disciplinary topics that may be difficult for neophytes. Translating complex topics into clear game mechanics enhanced the learning process for everyone and highlighted the ability of games to capture and convey complexity while avoiding inadequate simplification of real-world phenomena (Flood et al., 2018). As an example, during the evaluation session of the 2024 school, a participant reported that the lecture on weather forecasts was hard to follow, but that co-developing a game on communicating probabilistic forecasts helped them understand more clearly the concept and the related challenges.

4.2 Negotiating struggles and progress in game co-creation

As described in the result section, we could observe a transfer of unconscious power dynamics in the group settings during the game co-creation exercises. Power imbalances were visible, for example, between male and female participants, extroverts and introverts, and between native English speakers and non-native speakers. The latter, in particular, mirrors and reproduces the disadvantages encountered by non-native English speakers in English-dominated spaces in their career development, as is especially the case in many science fields (Amano et al., 2023).

Though the process and the roles taken on by each participant in their group were by-and-large constructive, there were some groups where these dynamics may have formed barriers to contribution. On the one hand, this served as an opportunity for

17

mutual learning; on the other hand, it could serve to mirror historical hegemonies within the group dynamic. In other words, it was critical to develop awareness of latent patterns of power dynamics (based on gender, geography, discipline, etc.) and associated contributory roles in order to recognize and start to break these patterns in the group setting; however, time constraints often prevented the groups from fully breaking these dynamics in favor of accomplishing the task at hand.

425 Nonetheless, despite these complex dynamics, the approach of co-creating a game in a highly transdisciplinary and multicultural group fostered an overall positive atmosphere of collaboration. It provided the opportunity for the participants to put the collective intelligence techniques addressed at the beginning of the group work into practice, and to develop a range of soft skills alongside diversified disciplinary knowledge. Such skills are crucial for a successful transdisciplinary process, where active mediation of tensions or conflicts are needed to ensure the consideration of all perspectives and the legitimacy of the

430 process among experts and decision-makers (Cash et al., 2003).

The positive atmosphere was further enhanced by the shared goal of producing a tangible outcome, with the short-term aim of testing it among peers at the end of the school. The need to bring creativity into play was also a crucial aspect, which stimulated the collective experimentation and the synthesis of interdisciplinary knowledge. The game co-creation exercise thus constituted a space to exercise and develop group creativity, an important means in tackling complex challenges that cross geopolitical

435 and disciplinary boundaries, such as climate change (Edgell and Lee, 2023).

4.3 Assessing perception change from transdisciplinary co-creation

We found the TD-assess exercise to be an advantageous way to assess changes in perceptions of CATER school participants without judgement of knowledge retained or feedback reflecting on the school itself. The findings indicate that participants moved away from what could be classified as more disciplinary views (i.e., Factors 2a and 2b) to views that better emphasize

440 the transdisciplinary process (i.e., Factors 1 and 3). In Table 3, we summarize the perspectives based on the composite Q-sorts from this initial analysis. Notably, Factors 2a and 2b, which we named the "Community Knowledge Advocates" and the "Scientific Information Advocates," were only present among the pre-CATER school perspectives. Factor 3, the "Actor Involvement Advocates," were only present among the post-CATER school perspectives. Factor 1, the "Collaborative Process Advocates," were present among the pre- and post-school perspectives. We use this framing to help identify aspects of the

445 game co-creation process and the school overall that could lead to shifts in perspectives. In other words, given our observations and feedback from participants, we look for ways in which the game co-creation experience may move participants away from being "Community Knowledge Advocates" or "Scientific Information Advocates" and towards "Collaborative Process Advocates" and "Actor Involvement Advocates."

Table 3. Summary of composite Q-sort ideas that comprise the different perspectives identified through the Q-method analysis of

450 **the 2024 school.**

Factor	Summary of perspective (based on composite Q-sort)

Factor 1: Collaborative Process Advocates	Believes successful climate adaptation requires transdisciplinary approaches, transparent communication of scientific uncertainties, and co-designed climate information products with end-users. They emphasize understanding system interactions and ensuring everyone comprehends the need for climate adaptation actions. **Unique to their perspective is the focus on policy mechanisms and the scalability of local transdisciplinary projects.** *Presence of pre- and post-school Q-sorts*
Factor 2a: Community Knowledge Advocates	Highlights the importance of traditional knowledge and indigenous spiritual systems in climate adaptation, along with trained intermediaries to bridge science and society. They stress mobilizing local knowledge and empowering locally-based individuals to lead internationally-funded projects. **Their strong emphasis on traditional knowledge and indigenous systems sets them apart.** *Presence of pre- school Q-sorts*
Factor 2b: Scientific Information Advocates	Advocates for co-designing climate information products with end-users and believes empowering users with ownership is crucial. They emphasize that climate inaction is more due to a lack of understanding of policy mechanisms and stress the importance of comprehending the reasons behind climate adaptation actions. **Their focus on practical co-production and user empowerment distinguishes them from the other factors.** *Presence of pre- school Q-sorts*
Factor 3: Actor Involvement Advocates	Believes transdisciplinary approaches are essential for breaking down silos and preventing climate maladaptation. They emphasize bringing different actors together, empowering users in co-production, and understanding on-the-ground climate vulnerabilities. **Their particular focus is on breaking down silos through transdisciplinary approaches and preventing maladaptation.** *Presence of post-school Q-sorts*

If we pay particular attention to the statements that had the most movement in rankings among the seven participants who repeated the exercise both prior- and post-CATER school, the participant's viewpoints clearly shifted from prioritizing societal relevance over scientific robustness toward a more balanced or critical view. They increasingly viewed co-production processes as requiring a lot of time, effort, and logistics, making them less feasible than initially thought. This change in perspective is also reflected in the game group work as a microcosm of navigating a transdisciplinary process, which was common feedback in the post-school surveys and comments. School participants were able to see first-hand some of the challenges and opportunities involved in co-creating in transdisciplinary spaces. Additionally, the necessity of understanding physics for taking action on climate impacts was downplayed after the school, indicating a shift toward other approaches.

There was also a heightened appreciation for the importance of bringing different actors together to understand system
460   interactions and the role of transdisciplinary approaches in breaking down silos and preventing maladaptation.

The collective effort to think systematically about a problem through the process of co-creating a game helped the participants value the complexity of climate adaptation, leveraging playfulness and imagination to explore reality (Pedercini, 2017, Morini et al., 2022). Thanks to games' ability to promote perspective-taking (Dishon and Kafai, 2020), the process made participants re-evaluate the prioritization of climate change over other societal challenges, recognizing the importance of addressing a
465   broader range of issues alongside climate adaptation. Overall, these perspective and idea shifts reflect a growing skepticism toward sector-specific assumptions and a stronger appreciation for collaborative and integrative strategies post-CATER school. The preliminary TD-assess findings also gave us another layer of empirical support for the observations we made during the schools and feedback we received from participants. The structure of co-creating a game allowed participants to share their knowledge in a non-competitive and cooperative way that puts the emphasis on the transdisciplinary process (Morini et al.,
470   2022). There are several elements in the CATER school meant to foster a positive experience that can be recreated in larger transdisciplinary processes. First is to create a space that is comfortable for mutual learning. The perspectives we observed through the TD-assess before the school indicate that participants were coming into the school with a specific set of ideas that may have reflected their disciplinary or experiential backgrounds. However, the perspectives that were observed after having participated in the school reflect a positive transdisciplinary experience fostered through the setting of the school. It could be
475   imagined that a negative experience where participants were pushed to defend their point-of-view could lead to entrenchment in their disciplinary perspectives.

4.4 Limitations and future work

Despite the specific attention devoted to group dynamics, soft skills and facilitation tools, we observed several practical and methodological limitations related to the game co-creation process. The transfer of unconscious power dynamics into the group
480   settings posed a challenge that deserves further attention. These power dynamics were linked to cultural diversity, gender, and personal attitudes of the participants. Although such dynamics are not uncommon in transdisciplinary collaborations (Bremer & Meisch, 2017), more work is needed to explore how to better guide the participants through these challenges within the time constraints of a fully packed school curriculum. Importantly, this also implies crafting a more clearly defined role for the staff lecturers in the co-creation exercise.

485   Another methodological challenge pertained to language barriers. With English as a working language during the school and a high proportion of native/fluent speakers among participants and lecturers, those with more limited language skills faced challenges in expressing their insights and participating equally in the game co-creation process. Future schools should consider additional strategies to facilitate linguistic equity.

The first findings of the TD-assess tool are encouraging and provide the basis for designing future versions of the assessment
490   tool that better encourages participation. One major limitation in our implementation was the participation rate post-school. From informal feedback received minor changes can be incorporated to better encourage participation, such as reducing the

overall time required for completing the exercise by removing some statements and steps. Also, further tailoring statements to better reflect the cultural diversity of participants can improve engagement and, in turn, data quality (Sneegas et al., 2021). Finally, allowing dedicated time to the exercise while participants are still gathered for the school would improve participation

495   rates.

5 Conclusions

This paper presented a multi-method approach to foster transdisciplinary collaboration for climate adaptation. Implemented within the context of a series of schools, the approach combined the co-creation of games by groups of culturally and professionally diverse school participants with a structured assessment of its impact on the participants' perspectives on

500   transdisciplinarity.

Our observations suggest that the game co-creation exercises effectively served as a boundary object to enable communication and mutual learning, since it allowed both academic and practitioner participants from different disciplines to contribute their expertise and personal experiences, and resulted in tangible outcomes that bridge disciplines and backgrounds. The preliminary results of the Q-method assessment confirm this finding by highlighting a convergence of perspectives on transdisciplinary

505   processes in climate change action among the participants after participating in the school. The content of the lectures given during the school contributed to shaping the game prototypes, demonstrating that the group exercise also provided space for participants to collectively process teaching content and enhance peer learning. All these elements affirm the value of games as a tool in complex learning environments (Arnab et al., 2019; Flood et al., 2018). Notably, game co-creation translated complex and abstract lecture topics into experiential learning, making these topics more accessible and actionable. As stated

510   by Morini and colleagues (2022), playfulness and imagination are powerful ways to connect educational activities to reality. This aligns with the growing recognition of creativity as a crucial skill in addressing complex societal challenges such as climate adaptation (Edgell & Lee, 2023). Overall, the transformative potential of game-based education bridges gaps between knowledge systems and promotes mutual understanding in transdisciplinary contexts (Lundgren, 2020; van Bruggen et al., 2019).

515   However, the transfer of power dynamics in the group settings and the observed language barriers call for further work on strategies to foster equal participation in the future schools.

Furthermore, we found the Q-method assessment method effective in demonstrating positive outcomes of the learning process instigated within the CATER school. This highlights the significant potential of using Q-method to evaluate transdisciplinary collaborations. However, some adjustments to the methodology are needed to stimulate higher participation rates in future

520   assessment surveys. For example, attempts could be made to reduce the cognitive load by simplifying the data collection procedures and to further tailor the statements to the participants' cultural diversity. Future research should extend our approach beyond the school format, for example by applying to governmental or community settings. This would also stimulate

connecting the game co-creation process with contextually relevant and socially legitimate settings (Costa et al., 2022; Bremer & Meisch, 2017).

525 In conclusion, our initial experiences demonstrate the potential of combining game co-creation with Q-methodology as a powerful strategy for cultivating transdisciplinary capacities and critically assessing their development. Looking ahead, forthcoming CATER schools will not only provide opportunities to refine and validate this approach but also serve as catalysts for broader, sustained science–society collaborations. By fostering environments where transdisciplinarity, creativity, mutual learning and inclusivity are at the core, we intend to continue to build a cohort of academics and practitioners who will be able

530 to shape adaptive and relevant responses to complex climate-related challenges.
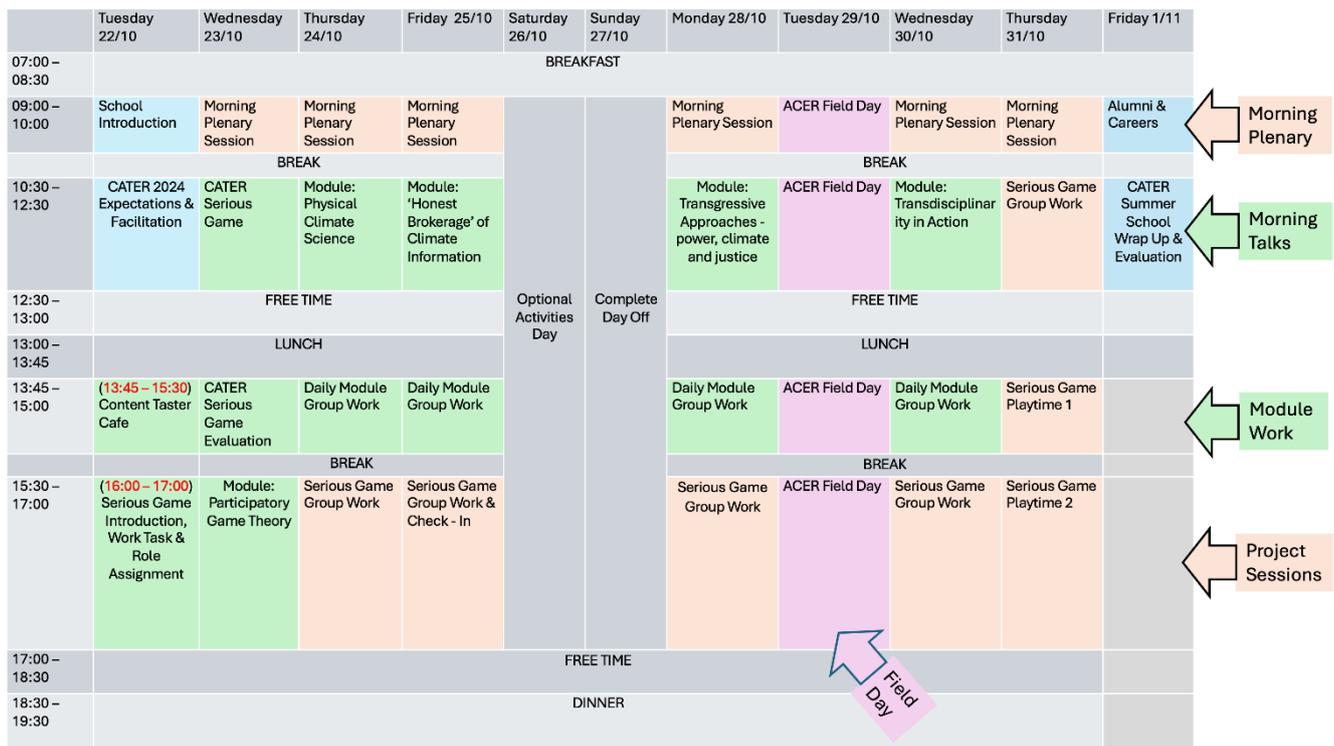
Appendix A

Figure A1: Daily schedule for the 2024 CATER school in Tanzania.

535 **Appendix B**

Table B1. Self-reported demographic characteristics of the TD-assess respondents.

Demographics		World regions lived, worked, or with strong connection	
Gender		**Africa**	
Female	8	Northern	1
Male	9	Western	3
No response	1	Middle	1
Age		Eastern	9
26 years old or younger	1	Southern	7
Between 27-32 years old	8	**Europe**	
Between 33-39 years old	6	Northern	8
Between 40-49 years old	3	Western	6
Discipline		Southern	2
Natural Sciences	7	**Other regions**	
Social Sciences	4	North America	6
Interdisciplinary	7	South America	1
Career Experience		South Asia	2
10 years or less	15	East Asia	3
Between 11-25 years	3	Australia/Oceania	2

Table B2. Statements with the largest ranking changes after attending CATER school, where one or more individuals reversed the sign of their ranking (i.e., difference is ±4 or more), as indicated in bold. Negative shifts (2 or more) are in yellow, and positive shifts in blue. Note that the numbers in the table show ranking differences (0 to ±6), and are not the same as the Q-sort rankings.

#	Statement	P16	P15	P12	P10	P05	P02	P01
12	In transdisciplinary research, societal relevance is a better indicator of 'quality' than scientific robustness.	**-4**	0	**-5**	0	+1	-3	-2
7	Co-production processes take too much time, effort, and logistics to be widely feasible.	+3	**-4**	+3	+2	-1	0	-1
23	Understanding the physics of the climate system is necessary to take action on reducing climate impacts.	-2	**-4**	**-4**	+1	-1	-1	0
1	A successful adaptation process involves bringing together different actors to understand the interactions within the entire system.	0	**+4**	-2	+2	-1	-1	+3
20	Transdisciplinary approaches for climate adaptation help break down silos which helps avoid maladaptation.	**+5**	+1	+1	+1	+1	-2	-1
2	Any scientist producing climate services needs to be open to constructive criticism and alternative forms of knowledge and expertise.	0	-1	+2	-1	+2	-1	**+4**
21	Transparent communication of scientific uncertainties is key to building trust between climate information providers and end users.	**+5**	+1	-1	-1	0	+2	-1
13	It is impossible to scale up local transdisciplinary projects because they need to be context-driven.	-2	**+4**	0	0	-1	-1	-2
4	Because climate change has cross-cutting impacts, it should be prioritized over other societal challenges.	-2	**-4**	+1	-1	0	0	-1

Table B3. Factors loadings with flagged Q-sort correlations shown in bold (P < 0.05 and a majority of common variance). One Q-sort corresponding to a CATER school staff is indicated with an asterisk (*).

Participant	Timing	Repeat?	Factor 1	Factor 2a	Factor 2b	Factor 3
P09	Before		**0.8835**	0.0094	-0.0094	0.0541
P12	After	Yes	**0.8178**	-0.2019	0.2019	-0.0841
P01	After	Yes	**0.8047**	0.1103	-0.1103	0.1659
P05	Before	Yes	**0.7944**	0.0091	-0.0091	0.0689
P05	After	Yes	**0.7377**	0.0353	-0.0353	0.2296
P10	Before	Yes	**0.7284**	-0.3144	0.3144	0.2769
P14*	Before		**0.7101**	-0.1042	0.1042	-0.1027
P06	Before		**0.7041**	-0.2627	0.2627	0.3417
P08	Before		**0.6683**	0.0935	-0.0935	0.2894
P02	After	Yes	**0.6662**	0.3669	-0.3669	-0.0049
P10	After	Yes	**0.6585**	-0.0145	0.0145	0.2485
P12	Before	Yes	**0.5748**	0.2522	-0.2522	0.1307
P02	Before	Yes	0.1593	**0.6954**	-0.6954	0.2591
P04	Before		0.2536	**0.6362**	-0.6362	0.0169
P15	Before	Yes	-0.1852	**0.5205**	-0.5205	-0.0558
P11	Before		0.1113	-0.5705	**0.5705**	0.4042
P15	After	Yes	0.02	0.2656	-0.2656	**0.7716**
P17	After		0.1245	0.013	-0.013	**0.6652**
P16	After	Yes	0.0509	-0.1038	0.1038	**0.6304**
P18	After		0.5126	-0.1722	0.1722	**0.5723**
P07	Before		0.5672	-0.4153	0.4153	0.496
P03	Before		0.4059	0.1337	-0.1337	0.2789
P01	Before	Yes	0.373	-0.0281	0.0281	0.0799
P13	Before		0.2537	0.3104	-0.3104	0.4081

| P16 | Before | Yes | -0.4174 | 0.5186 | -0.5186 | 0.326 |
| percent explained variance | | | 31 | 10 | 10 | 12 |

Table B4. Statements used in Q-sort exercise ordered by highest statistical consensus between factors to lowest. Rankings reflect the composite Q-sort valued, weighted based on the respondent correlation to the factor.

#	Statement	Factor 1	Factor 2a	Factor 2b	Factor 3
22	Understanding on-the-ground climate vulnerabilities is key to putting climate information into practical use.	1	1	2	3
21	Transparent communication of scientific uncertainties is key to building trust between climate information providers and end users.	3	0	1	1
9	Effectively bridging science and society requires trained intermediaries to support scientists and local officials to engage with each other.	0	2	1	0
17	Stakeholders should decide on the levels of uncertainty in climate information they are comfortable with.	0	-3	0	-2
20	Transdisciplinary approaches for climate adaptation help break down silos which helps avoid maladaptation.	1	1	0	2
7	Co-production processes take too much time, effort, and logistics to be widely feasible.	-1	-1	1	0
13	It is impossible to scale up local transdisciplinary projects because they need to be context-driven.	-2	-3	-2	0
14	Local knowledge should be mobilized where it exists and is relevant, rather than following trends of "integrating local knowledge."	0	2	0	-1
6	Climate information products need to be co-designed with end-users to ensure they are usable and useful.	3	0	2	1
16	Science is the basis of climate adaptation; without science, there is nothing.	-3	0	-1	-3
23	Understanding the physics of the climate system is necessary to take action on reducing climate impacts.	-1	0	-3	-2
18	Traditional knowledge and indigenous spiritual systems must be at the base of climate adaptation because they are rooted in centuries of respect for the land.	0	3	-1	1

10	Empowering users with ownership of a product is the most important outcome in co-production.	-1	-1	2	2
4	Because climate change has cross-cutting impacts, it should be prioritized over other societal challenges.	-2	-2	0	-3
8	Creating an environment where everyone feels safe and comfortable to share their viewpoints is essential for successful transdisciplinary research.	1	-1	-2	-1
12	In transdisciplinary research, societal relevance is a better indicator of 'quality' than scientific robustness.	-1	1	-2	0
2	Any scientist producing climate services needs to be open to constructive criticism and alternative forms of knowledge and expertise.	1	2	-1	-2
19	Transdisciplinary approaches are key to rebalancing power dynamics through equal consideration of different perspectives and priorities.	2	-1	0	-1
3	Bad decisions or maladaptive practices are often caused by oversimplification of climate information.	-2	1	1	2
1	A successful adaptation process involves bringing together different actors to understand the interactions within the entire system.	2	0	-1	3
15	Locally-based people should lead internationally-funded projects because they have the best understanding of their climate issues.	0	3	-3	0
11	Ensuring everyone understands the reasons behind the need for climate adaptation actions is crucial for effective engagement.	2	-2	3	-1
5	Climate inaction stems more from a lack of understanding of policy mechanisms and institutional settings than a lack of understanding of climate information.	-3	-2	3	1

Data availability

550 Aggregated data related to the Q-method assessment are available in the Appendix of the manuscript. More information can be provided by the authors upon reasonable request.

Author contributions

All authors contributed to the conceptualization of the work and to the writing of the manuscript. IV, AA and IR performed the investigation during the CATER schools. AA designed the Q-method with contribution from all co-authors and carried out the Q-method formal analysis.

Competing interests

The authors declare that they have no conflict of interest.

Ethical statement

Any personal data collected through observation and feedback was anonymised. Participation in debriefing sessions was voluntary, prioritising participants' educational goal and safety. The Q-method component of this research was formally registered with the INRAE data-protection authority to ensure compliance with all ethical and legal requirements governing the processing of personal data in France and the European Union. It was confirmed to adhere to the General Data Protection Regulation (GDPR), and all data were anonymized prior to analysis so that no personally identifiable information was retained or processed.

Disclaimer

Copernicus Publications remains neutral with regard to jurisdictional claims made in the text, published maps, institutional affiliations, or any other geographical representation in this paper. While Copernicus Publications makes every effort to include appropriate place names, the final responsibility lies with the authors. Views expressed in the text are those of the authors and do not necessarily reflect the views of the publisher.

28

Review statement

References

Akhtar-Danesh, N.: An Overview of the Statistical Techniques in Q-Methodology: Is There a Better Way of Doing Q Analysis.
580 Operant Subjectivity 38 (3/4): 29–36, https://doi.org/10.15133/j.os.2016.007, 2016.

Amano, T., Ramírez-Castañeda, V., Berdejo-Espinola, V., Borokini, I., Chowdhury, S., Golivets, M., González-Trujillo, J.D., Montaño-Centellas, F., Paudel, K., White, R.L., Veríssimo, D.: The manifold costs of being a non-native English speaker in science. PLoS Biology 21(7):e3002184, https://doi.org/10.1371/journal.pbio.3002184, 2023.

Arnab, S., Clarke, S., Morini, L.: Co-creativity through play and game design thinking. Electronic Journal of E-Learning
585 17(3):184-98, https://doi.org/10.34190/JEL.17.3.002, 2019.

Banasick, S.: EQ Web Sort, https://doi.org/10.5281/zenodo.8339819, 2023.

Banasick, S.: Ken-Q Analysis (Version 2.0.1) [Computer software], https://doi.org/10.5281/zenodo.8310377, 2023

Banholzer, S., Kossin, J., Donner, S.: The Impact of Climate Change on Natural Disasters. In: Zommers Z, Singh A (eds) Reducing Disaster: Early Warning Systems for Climate Change. Springer Science+Business Media, Dordrecht, pp 21–49,
590 2014

Berrang-Ford, L., Biesbroek, R., Ford, J.D., et al: Tracking global climate change adaptation among governments. Nat. Clim. Chang. 9: 440–449, https://doi.org/10.1038/s41558-019-0490-0, 2019.

Bremer, S., Meisch, S.: Co-production in climate change research: reviewing different perspectives. WIREs Clim. Change 8: e482, https://doi.org/10.1002/wcc.482, 2017.

595 Brown, S.R.: A Primer on Q Methodology. Operant Subjectivity 16, no. 3/4 : 91–138, 1993.

Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jäger, J., Mitchell, R.B.: Knowledge systems for sustainable development. Proceedings of the National Academy of Sciences, 100(14), 8086-8091, https://doi.org/10.1073/pnas.1231332100, 2003.

Costa, M.M., Oen, A., Nesset, T., Celliers, L., Suhari, M., Huang-Lachmann, J.T., ... & Schuck-Zöller, S.: Co-production of
600 Climate Services: A diversity of approaches and good practice from the ERA4CS projects (2017–2021). Linkoping University Electronic Press, https://doi.org/10.3384/9789179291990, 2022.

Davies, B.B., Hodge, I.D.: Shifting Environmental Perspectives in Agriculture: Repeated Q Analysis and the Stability of Preference Structures. Ecological Economics 83: 51–57. https://doi.org/10.1016/j.ecolecon.2012.08.013, 2012.

Den Haan, R.J., Van der Voort, M.C.: On evaluating social learning outcomes of serious games to collaboratively address
605 sustainability problems: A literature review. Sustainability 10(12): 4529. https://doi.org/10.3390/su10124529, 2018.

Dishon, G., Kafai, Y.B.: Making more of games: Cultivating perspective-taking through game design. Computers & Education. Apr 1;148:103810. https://doi.org/10.1016/j.compedu.2020.103810, 2020.

Eden, S., Donaldson, A., Walker, G.: Structuring subjectivities? Using Q methodology in human geography. Area 37(4): 413-422, https://doi.org/10.1111/j.1475-4762.2005.00641.x, 2005.

610 Edgell, R.A. and Lee, D.: Theorizing creative challenges: Why are social creativity and reimagined universities necessary for tackling society's problems?. Journal of Creativity 33.2: 100051, https://doi.org/10.1016/j.yjoc.2023.100051, 2023.

Flood, S., Cradock-Henry, N.A., Blackett, P., Edwards, P.: Adaptive and interactive climate futures: systematic review of 'serious games' for engagement and decision-making. Environmental Research Letters 13(6):063005, https://doi.org/10.1088/1748-9326/aac1c6, 2018

615 Freie, J.F.: The Effects of Campaign Participation on Political Attitudes. Political Behavior 19, no. 2: 133–56, https://doi.org/10.1023/A:1024858108803, 1997.

Fritz, L., Binder, C. R.: Whose knowledge, whose values? An empirical analysis of power in transdisciplinary sustainability research. *European Journal of Futures Research*, *8*(1), 3, https://doi.org/10.1186/s40309-020-0161-4, 2020.

Galesic, M., Barkoczi, D., Berdahl, A.M., Biro, D., Carbone, G., Giannoccaro, I., Goldstone, R.L., Gonzalez, C., Kandler, A., 620 Kao, A.B., Kendal, R.: Beyond collective intelligence: Collective adaptation. Journal of the Royal Society interface 20(200):20220736, https://doi.org/10.1098/rsif.2022.0736, 2023.

Harteveld, C.: Triadic game design: Balancing reality, meaning and play. Springer, London Dordrecht Heidelberg New York, https://doi.org/10.1007/978-1-84996-157-8, 2011.

Hilger, A., Rose, M., Keil, A.: Beyond practitioner and researcher: 15 roles adopted by actors in transdisciplinary and 625 transformative research processes. Sustain Sci 16: 2049–2068, https://doi.org/10.1007/s11625-021-01028-4, 2021.

Hoppe, T., van den Berg, M.M., Coenen, F.H.J.M.: Reflections on the uptake of climate change policies by local governments: Facing the challenges of mitigation and adaptation. Energy Sustain Soc 4: 1–16, https://doi.org/10.1186/2192-0567-4-8, 2014.

Kriz, W.C.: Creating effective learning environments and learning organizations through gaming simulation design. Simulation & Gaming, 34(4), 495-511, https://doi.org/10.1177/1046878103258201, 2003

630 Lankford, B.A., Craven, J.: Rapid Games Designing; Constructing a Dynamic Metaphor to Explore Complex Systems and Abstract Concepts. Sustainability, 12(17), 7200, https://doi.org/10.3390/su12177200, 2020.

Lundberg, A., de Leeuw, R., Aliani, R.: Using Q Methodology: Sorting out Subjectivity in Educational Research. Educational Research Review 31: 100361, https://doi.org/10.1016/j.edurev.2020.100361, 2020.

Lundgren, J.: The grand concepts of environmental studies boundary objects between disciplines and policymakers. Journal 635 of Environmental Studies and sciences 11(1): 93-100, https://doi.org/10.1007/s13412-020-00585-x, 2021.

Madani, K., Pierce, T.W., Mirchi, A.: Serious Games on Environmental Management. Sustain. Cities Soc., 29, 1–11, https://doi:10.1016/j.scs.2016.11.007, 2017

Mayer, I., Bekebrede, G., Harteveld, C., Warmelink, H., Zhou, Q., Van Ruijven, T., ... & Wenzler, I.: The research and evaluation of serious games: Toward a comprehensive methodology. British journal of educational technology, 45(3): 502-640 527, https://doi.org/10.1111/bjet.12067, 2014.

McClure, A., Ziervogel, G., Patel, Z.: Expansive learning of climate scientists towards transdisciplinarity. Climate Risk Management 45:100642, https://doi.org/10.1016/j.crm.2024.100642, 2024.

Moser, D.J., and Baulcomb, C.: Social Perspectives on Climate Change Adaptation, Sustainable Development, and Artificial Snow Production: A Swiss Case Study Using Q Methodology, Environmental Science & Policy, 104 (February 2020): 98–

645   106, https://doi.org/10.1016/j.envsci.2019.10.001, 2020.

Morini, L., Chen, Y.F., Adefila, A., Mahon, D., Dawson, M., Mohamad, F., Minoi, J.L., Schwartz, G.: Playful participatory mapping: co-creating games to foster systems thinking. In European Conference on Games Based Learning, https://doi.org/10.34190/ecgbl.16.1.591, 2022.

Pedercini, P.: SimCities and SimCrises–International City Gaming Conference Keynote, 2017.

650   Rodela, R., Ligtenberg, A., Bosma, R.: Conceptualizing Serious Games as a Learning-Based Intervention in the Context of Natural Resources and Environmental Governance, Water, 11, 245, https://doi.org/10.3390/w11020245, 2019.

Ruankaew, N., Le Page, C., Dumrongrojwattana, P., Barnaud, C., Gajaseni, N., van Paassen, A., Trébuil, G.: Companion Modelling for Integrated Renewable Resource Management: A New Collaborative Approach to Create Common Values for Sustainable Development. Int. J. Sustain. Dev. World Ecol. 2010, 17, 15–23, https://doi.org/10.1080/13504500903481474,

655   2010.

Simon, W., and Stenner, P.: Doing Q Methodology: Theory, Method and Interpretation. Qualitative Research in Psychology 2, no. 1: 67–91, https://doi.org/10.1191/1478088705qp022oa, 2005.

Sneegas, G., Beckner, S., Brannstrom, C., Jepson, W., Lee, K., Seghezzo, L.: Using Q-Methodology in Environmental Sustainability Research: A Bibliometric Analysis and Systematic Review. Ecological Economics 180: 106864,

660   https://doi.org/10.1016/j.ecolecon.2020.106864, 2021.

Speelman, E.N., van Noordwijk, M., Garcia, C.: Gaming to Better Manage Complex Natural Resource Landscapes. Co-investment in ecosystem services: global lessons from payment and incentive schemes, World Agroforestry Centre, 2018.

Tafel, L., Ott, E., Brillinger, M., Schulze, C., Schröter, B.: Attitudes of Administrative Decision-Makers towards Nature-Based Solutions for Flood Risk Management in Germany. Sustainability Science 17, no. 1: 135–49, https://doi.org/10.1007/s11625-

665   021-01072-0, 2022.

Terti, G., Ruin, I., Kalas, M., Láng, I., Cangròs i Alonso, A., Sabbatini, T., Lorini, V.: ANYCaRE: a role-playing game to investigate crisis decision-making and communication challenges in weather-related hazards. Natural Hazards and Earth System Sciences, 19(3), 507-533, https://doi.org/10.5194/nhess-19-507-2019, 2019.

van Bruggen, A., Nikolic, I., Kwakkel, J.: Modeling with stakeholders for transformative change. Sustainability 11(3):825,

670   https://doi.org/10.3390/su11030825, 2019.

Vigna, I., Jeuring, J., Sivle, A.: Melkeværet. A serious game to bridge climate service providers and agricultural users. METreport, Norwegian Meteorological Institute, 2024.

Walton, M.L.: A Case Study Investigating the Influence of Deliberative Discussion on Environmental Preferences. Society and Natural Resources 26, no. 3: 303–24, https://doi.org/10.1080/08941920.2012.689932, 2013.

675 Wesselow, M., Stoll-Kleemann, S.: Role-Playing Games in Natural Resource Management and Research: Lessons Learned from Theory and Practice. Geogr. J., 184, https://doi.org/10.1111/geoj.12248, 2018.

Zabala, A., Sandbrook, C., Mukherjee, N.: When and how to use Q methodology to understand perspectives in conservation research. Conservation Biology 32(5): 1185-94 https://doi.org/10.1111/cobi.13123, 2018.

Zhou, Q., & Mayer, I.S.: Models, simulations and games for water management: A comparative q-method study in The

680 Netherlands and China. Water 10(1): 10, https://doi.org/10.3390/w10010010, 2017.