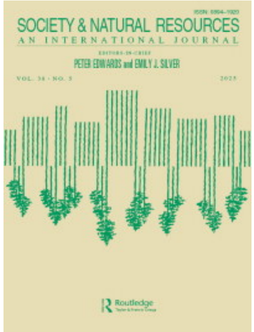

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A Practical Approach to Developing and Using Online Games for Transdisciplinary Research into Complex Social-Ecological Systems

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ABSTRACT
Research games provide a promising avenue for studying social-ecological systems because they can capture complexity and reflect multiple stakeholders' perspectives. However, there are few methodological studies on the design, validation and implementation of research games. This paper focuses on the development and implementation of an online multi-player game representing the social-ecological system underlying farmers' decision-making. We detail three key aspects of spatially explicit game development: design, validation and game sessions. Our approach provides new integration of social science ecology and practice knowledge using informed-design elements, and demonstrates mediated fieldwork with community mobilizers and personal smartphones. We also provide practical suggestions for scaling-up games to increase the number and diversity of participants and the spatial scale of social-ecological research.

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Co-design; game methods; research games; land management; pest resistance

Introduction

Today's most pressing socio-ecological challenges (e.g. adaptation to climate change, biodiversity crisis) are complex, multi-faceted and involve many different actors with varying interests and needs, at multiple levels of society. They are embedded in complex social-ecological systems (SES), in which contexts are dynamic and people are interdependent (Holland 1992; Preiser et al. 2018). To better understand these challenges and the possibilities for intervention, we need social research that assesses dynamic social interactions within changing contexts and across scales. Multiplayer online games have been pointed out as an approach to address this (e.g. Duthie et al. 2021; Long et al. 2023; Preiser et al. 2018).

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Games are competitive or goal-oriented activities that model a strategic scenario where the participants' results depend on the actions of other participants according to a defined model and sets of rules. This interdependence of participants' actions makes games particularly well suited for studying the complexity of SES (Redpath et al. 2018), and in particular "patterns of dynamic interaction between system elements as well as between the elements and their wider environment" (Preiser et al. 2018, 5).

Games can be characterized depending on many different features: type of artifact (e.g. digital games), number of players (e.g. single players, multiplayer), type of world-representations at play (e.g. simulations, role play). Games can also be characterized by their objectives beyond the play itself (e.g. educational games), a feature that is relevant when speaking about research. Among the different types of games used in research, there are two types that have received much attention: serious games and research games.

Serious games – a term coined by Abt (1970) – aim to represent real-world issues and capture complex interactions, while being entertaining (Powell et al. 2021; Flood et al. 2018; Aubert, Bauer, and Lienert 2018). Serious games are largely used in in-person settings, mostly to build knowledge about values and morals, usually have educational purposes, and to address conflicts (Redpath et al. 2018; Ampatzidou et al. 2018). The development of serious games tends to build on co-design, involving a range of actors with relevant expertise on the topic of the game (Gugerell 2023).

Research games are artifacts designed with the primary purpose of data collection (Grogan and Meijer 2017) and have a long history of being used in social research. For example, research games have been used in economics, psychology and political science to collect data about people's behavior (also called "behavioural games") in controlled and reproducible environments since the 1950s (e.g. Deutsch 1958). Traditionally, such games emulate lab experiments and use economic incentives to study the decisions of participants (e.g. Webster and Sell 2014). Outside the lab settings, research games have been used in field settings in combination with questionnaires and debriefing interviews to study decision-making regarding land management, in natural resource-use, and in biodiversity conservation (e.g. Rakotonarivo et al. 2021a, 2021b; Bell et al. 2016).

Multiplayer research games can be used to explore interactions and decision making in complex scenarios. This is particularly relevant for studying SES because of their potential to capture (1) the complexity of stakeholders' perspectives beyond traditional disciplinary domains (Powell et al. 2021), (2) the divergent interests involved in natural resource dilemmas (Rakotonarivo et al. 2021c) and (3) the difficulty of resolving conflicts (Redpath et al. 2018). A game representing a social-ecological system simulates real-life decision-making scenarios that players can understand, assess, and act upon (Bogost 2008). Therefore, the game can provide both a critical enquiry into land management decisions and a critical lens that reflects socio-cultural issues around land management (Coulton and Hook 2017).

The use of games in research has so far faced two limitations for collecting quantitative data on interdependent decision-making: (1) most serious games incorporating social-ecological dynamics and complexity are played as physical and thus limited by a low number of players (few players in every game with a limited number of opportunities for the game being played (Barreteau et al. 2021)); and (2) most large scale online research games until now have been developed as single player games and thus not able to incorporate the complex interactions between players (e.g. Long et al. 2023;

Lieberoth et al. 2014; Pedersen et al. 2017). Online multiplayer games address both limitations if optimized for data collection (Duthie et al. 2021; Long et al. 2023), but there is still a lack of methodological reflection on how digital games used in research are designed and implemented (Roungas et al. 2021). Our research has explored how to incorporate design elements of serious games into digital research games in order to harness the potential to collect data on participants' interaction at a large scale, in a systematic way and remotely. In this paper we reflect on the lessons learnt in the process and provide insights for advancing the use of these methods. In particular, our paper showcases the design of an online digital research game that integrates stakeholder engagement and digital technologies to collect data on a large scale and across multiple locations. We focus on the development and implementation of an interactive online game exploring a specific social-ecological system: agricultural pesticide-resistance management.

In "Literature insights on design and development of research games" section, we summarize the state of the art regarding the design and development of research games. In "Case study: A game for studying farmers' land management decisions in Brazil" section, we present our case study, with background on the issue the game explores, which is agricultural pesticide-resistance management ("Background: Agricultural land management in the context of pesticide resistance evolution" section), the methods we used in the design and development of the game ("Methods" section), a description of the game ("The ENDORSE game" section), a detailed account of its design and validation ("Design and validation of the research game" section), and information on game sessions and data collected ("Fine-tuning the game storytelling" section). Discussion of lessons learnt and critical considerations are in "Discussion" section and conclusions and in "Implications and concluding remarks" section.

Literature Insights on Design and Development of Research Games

Insights into the design of research games are scattered in the literature due to the variety of disciplines and approaches involved, including research on simulation and gaming and on games methods (Lukosch et al. 2018). In this paper we focus on aspects that are relevant for games collecting data on the interaction of multiple players, and so we draw on the simulation literature regarding online games, and the methods literature relating to serious games. In this section, we look in detail at four key aspects identified in the study of gaming simulations, that are of interest for designing online multi-player research games-design, validation, game sessions and knowledge management (Roungas et al. 2021).

Game design in research games corresponds to representing the social and ecological interactions through the creation of models, rules, and specific possibilities for play (Bogost 2008). While there are multiple approaches for the design of games (Lukosch et al. (2018) provide a detail review for simulation games, for example), most approaches include a series of sequenced steps (e.g. Duke 1980) and account for the need of balancing play possibilities with the representation of reality and meaning (Harteveld 2011).

A critical element of the design to achieve the balance of play, representation of reality and meaning is storytelling. Games tell stories through procedural rhetoric (rule-based representations and interactions that configure the game system) and indexical elements (the signs that an action leaves in the game for the players to interpret) (Fernandez-Vara 2011; Bogost 2008). Procedural rhetoric and indexical elements together give context and form to the content (i.e. background and scenario) using characters (e.g. roles played by players) and plot elements (i.e. challenges and opportunities that arise during the game) (Mukherjee 2016). Additionally, in research games, this storytelling must adhere to scientific criteria, facts and knowledge that provide validity to the experiment and the collected data (Grogan and Meijer 2017).

Validation consists of determining if the game serves the intended objectives and can be implemented through pilot testing the game with stakeholders (Roungas et al. 2021). Traditionally, game design contains an iterative stage of pilot testing consisting of going back and forth between users and the development team to test the changes until a satisfactory version is reached (e.g. Duke 1980). Modern game design approaches also include additional validation mechanisms such as debriefing phases (e.g. Roungas et al. 2021). For research, piloting and validation are crucial for meeting the research objectives within the available time and resources (Grogan and Meijer 2017).

Game-playing sessions are “the instantiation of a game” (Roungas et al. 2021, 186). In the context of research, game sessions require considerable planning and support activities, including coordinating participants, scheduling sessions, delivering supporting information and gaining informed consent (Grogan and Meijer 2017). The effectiveness of game sessions (i.e. that are successful in engaging the players and the game unfolds as planned, without unexpected situations unaccounted for at the design stage) is critical to collect consistent and complete data to minimize generalization and reproducibility issues (Roungas et al. 2021; Long et al. 2023).

Knowledge management in research games refers to the collection of data generated in the game, data which will allow observations and to develop and test hypotheses (Grogan and Meijer 2017). Game sessions also produce additional knowledge in the form of the experience gained by players (Grogan and Meijer 2017). The players’ experience and lessons learned during the game can be accessed and measured through the complementary use of surveys and debriefing sessions (e.g. Rakotonarivo et al. 2021b).

While knowledge management depends on the specific research topic and hypothesis, the design, validation and game sessions can be approached as transferable methodological considerations. Avenues identified by the literature to advance research games’ data collection methods include involving stakeholders in the design and prototyping of the games (Powell et al. 2021) and extending the outreach of the research through the spread of online connections and smart technology (Duthie et al. 2021; Long et al. 2023). However, there is very limited information published on how to conduct the design, validation and game sessions for digital games used in research (Roungas et al. 2021). In this paper, we address this knowledge gap, describing and reflecting on the process followed in a study using a multiplayer online game, to provide practical recommendations.

Case Study: A Game for Studying Farmers’ Land Management Decisions in Brazil

This section details the specifics of a game developed to study farmer decision-making for pest management in the context of pesticide resistance. In the first part we present a brief introduction of the specific social-ecological system that was the focus of our research and the context of the research game. The second part details the methods we used in the development of the game, and the third part describes in detail the game and the design, validation and game sessions process.

Background: Agricultural Land Management in the Context of Pesticide Resistance Evolution

Approximately 40% of crops are lost to pests and diseases (FAO 2017), with large-scale monoculture farming being particularly susceptible to pest outbreaks (Andow 1991; Stenberg 2017). Agricultural intensification relies on widespread application of chemical insecticides, which provide economic benefits from improved crop quality and yield (Aktar, Sengupta, and Chowdhury 2009; Rasmussen et al. 2018). However, pests develop resistance to pest control methods over time, eventually reaching a point when frequently-used pest control methods are no longer effective (pest resistance). In particular, the mismanagement and overuse of chemical pesticides can cause undesirable changes in insect pest populations and lead to insecticide resistance.

Conventional agriculture usually addresses pest outbreaks with higher pesticide use, which can initiate a vicious cycle that is often referred to as a pesticide or technological "treadmill" – the constant development of technological innovations (like new crops or control methods) that are to be purchased by the farmers (IPES-Food 2016; Altieri and Nicholls 2020). This treadmill increases production costs and does not address the persistent evolution of pest resistance (IPES-Food 2016; Oliveira and Hecht 2016).

Biopesticides and integrated pest management (IPM) have recently gained considerable momentum as alternative approaches to pest outbreaks and crop protection. IPM consists of a combination of complementary methods of pest control based on agronomic and biological techniques that increase the biodiversity of agroecosystems (Pretty 2018), providing an opportunity for less consistent evolutionary selection, and the development of crops that are less vulnerable to resistant pest outbreaks (Hatt et al. 2018; Hufnagel, Reckling, and Ewert 2020). Among the tools that IPM uses, biopesticides are pest control products based on living organisms or derived molecules (Mangan et al. 2023). Still, conventional cropping systems often deliver higher yields, hindering the wider adoption of alternative conservation and organic agricultural practices (Pittelkow et al. 2015; Wittwer et al. 2021). Consequently, there is an ongoing need to enhance our understanding of farmers' land management decisions (Dessart, Barreiro-Hurlé, and Van Bavel 2019; Skrimizea et al. 2020).

There is extensive research on factors influencing farmers' decision-making, including their willingness to adopt innovative approaches into their agricultural practices (e.g. Dessart, Barreiro-Hurlé, and Van Bavel 2019; Sutherland et al. 2012; Skrimizea et al. 2020). Farmer decision-making is driven by many factors including sociodemographic features, moral values, knowledge, perceptions of efficacy, previous experiences, socio-cultural aspects related to access to information and social interactions, and contextual, economic and institutional factors (Carlisle 2016; Prager and Posthumus 2010; Grover and Gruver 2017; Dessart, Barreiro-Hurlé, and Van Bavel 2019; Defrancesco et al. 2008; Constantine et al. 2020; Sutherland et al. 2012; Siebert, Toogood, and Knierim 2006; Taylor and Van Grieken 2015). Scholars have also identified the paramount role that decisions by neighboring farmers or other farmers in their community can play (Grover and Gruver 2017; Sutherland et al. 2012; Hatt et al. 2018; Dessart, Barreiro-Hurlé, and Van Bavel 2019; Siebert, Toogood, and Knierim 2006; Carlisle 2016). In particular, farmers' adoption of biopesticides and IPM systems is highly influenced by the participation in training and contact with agricultural extension officers (Kabir, Rainis, and Azad 2017) and having a positive disposition toward experimentation done by their neighbors (Sutherland et al. 2012; Hatt et al. 2018). Usually farming decisions are made in isolation; farmers decide on plants and agricultural inputs without knowing the choices of all the other farmers (Höhler and Müller 2021). However, engendering sustainable pest control (and other aspects of ecological sustainability) could profit tremendously from coordination among neighbors to ensure that selection is not consistent across farms (Pretty 2018).

Methods

We explored the feasibility of co-designing online research games to collect data on farmer's decision making, in terms of strategies and behavior, regarding innovative approaches to managing pest treatment in a context of resistance to pesticides. Our study, which was set in Brazil, encompassed two phases: (1) design and validation of the research game and (2) roll-out of the game sessions.

The research team was organized in two hubs: a scientific hub, located in the UK, and an engagement hub, located in Brazil. The scientific hub, which included one researcher each with expertise from evolutionary biology, conservation science, social science, and computational biology, led the overall research process and the scientific design of the online game. The engagement hub, which included experts in plant protection and the Brazilian agricultural context and stakeholders, led the validation process and recruitment of local collaborators ("champions" as detailed later in "Game sessions and data collected" section) and participants.

We obtained approval from the dedicated University ethics committee for both the participatory design process and the roll-out of the game. Informed consent was collected from all the participants in the workshops, in the deliberative trials, and in the game through a dedicated questionnaire embedded in the registration form.

We followed an informant design approach of co-design, in which different stakeholders are involved in the design process in different phases to optimize their contributions in terms of knowledge and time invested (De Jans et al. 2017). This process, which is detailed in "Design and validation of the research game" section, was documented in research memos that described and reflected pilot-test debriefing sessions and consultation workshops. A total of 7 farmers, 8 agricultural experts and 6 agronomy students participated along the co-design process. The participants, who were identified and selected by the engagement hub among their network of stakeholders, were selected to represent a diversity of knowledge regarding pest treatment in Brazil (expert and practical knowledge) and familiarity with the use of online games and mobile devices (younger and older generations).

The roll-out of the game, detailed in "Fine-tuning the game storytelling" section, was documented in a logbook, stored on a secure University server, which included the participants' responses to the questionnaires and a record of the game data. A total of 75 farmers participated in completed games.

There were no economic rewards to participants for participating in the co-design process or the game sessions.

The ENDORSE Game

The resulting interactive research tool (the game) was a WordPress website that integrated with R code (R Core Team 2021) and was optimized for smartphones. It consisted of three parts: *(i) a registration questionnaire to collect information about the farmers' attitudes toward land diversification and the adoption of biopesticides; (ii) the interactive game to collect information about farmers' choices in a context of uncertainty, and (iii) a short exit questionnaire to collect reflections on the game experience. In this paper, we focus on the development of the interactive game.

The game consisted of the management of a looped farming landscape (i.e. that has no boundaries, as if it was a cylinder surface), managed by two or more players (N) under the pressure of multiple waves of pest outbreaks during successive cropping seasons (game rounds). The players' objective was to maximize both the productivity of their farms while trying to keep the productivity of the overall farming landscape as high as possible. The game actions (as detailed in the following paragraphs) were triggered by pests attacking the crops and forcing players to choose whether and how to protect their yield from pests. Then, the game was sustained by the evolution of pesticide resistance as the game progressed, forcing the farmers to review their control strategies to protect their yield. While pest outbreaks and the level of crop losses were explicit during the game, the impact of pesticide resistance was realistically less explicit. Instead, players simply observed a reduction in the effectiveness of pest control and reacted without perfect knowledge of the cause. One possible winning strategy involved creating heterogeneity in the landscape (a high level of crop diversification) while using biopesticides. The complexity of biological pest control created more context specific selection for pesticide resistance than occurred for chemical pesticides (Mangan et al. 2023). The highest levels of landscape-wide diversification required some coordination with neighboring farmers.

Each participant managed an equal share of the landscape: a 3 by 3 grid of fields, totaling 9 cells. Each farm was neighbored by another to the left and right, creating a continuous landscape. The sequence of actions in the game was restrictively scripted (Figure 1). For each cell, participants were prompted to choose what crop to plant at the beginning of each season (step 1), and then twice a season were asked to choose a form of pest control (steps 2 and 3). There were three available choices for crops (yellow, green, and blue crops) which are equally compatible with one another and, similarly vulnerable to pests and have equal value. Similarly, there were three available choices for pest control (doing nothing, using bio-pesticides or using synthetic pesticides). At the end of each season (step 4), participants saw the productivity of all fields (including those of neighbors) in the form of points (0 to 10), and the productivity of their farm and the whole landscape in the form of percentages (0–100%). In steps 2, 3 and 4, participants were able to scroll the landscape left and right to see the situation in the other farms, but there was not a functionality that allow them to speak with each other or to know what the decisions of the other players looked like before deciding their choices. The game automatically recorded data on the choices made by the participants and the context of those choices.

Figure 1. Step-by-step diagram illustrating the progression of a cropping season in the ENDORSE game. The starting scenario and the outcome screen show the players land (*"seu terreno")* divided in 9 fields (*"parcelas"*) and the number of choices made and remaining (*"escolhas feitas"*). The decision-making in step 1 asks the player which crop do they want to plant (*"Que cultura/s voce vai plantar?"*) and available choices are green crop (*"cultura verde"*), yellow crop (*"cultura amarela"*) or blue crop (*"cultura azul"*). The bottom question asks if the player wants to apply the same choice for all fields (*"Aplicar a mesma escohla a todos as 9 parcelas?"*) with choices being Yes (*"Sim"*) or No (*"Nao"*). The decision-making in steps 2 and 3 asks the player what do they want to spray (*"O que voce vai pulverizar?"*) and available choices are synthetic pesticides (*"Agrotoxico"*), biopesticies (*"Defensivo biologico"*) or nothing (*"nada"*). As in step 1, the bottom question asks if the player wants to apply the same choice for all fields (*"Aplicar a mesma escohla a todos as 9 parcelas?"*) with choices being Yes (*"Sim"*) or No (*"Nao"*). The end of season screen shows the harvest results "Your harvest" (*"Sua colheita"*), with a number (from 0 to 10) representing the quantity of harvest collected in each field. Total points are added at the bottom as "Harvest points" (*"Pontos de colheita"*) over the total of available points 90 for each player. Total yield for player (*"Seu rendimento"*) and total yield for the group of players (*"Rendimiento da comunidade"*) also appears as percentage at the bottom of the results screen.

The storyline unfold as the game progresses represented fundamental scientific concepts concerning the evolution of pesticide resistance, agricultural productivity and diversification, and farmers' decision-making. The storytelling was the result of the assemblage of texts describing the context and rules of the game, and visual elements that signpost the storyline progression relying on environmental, indexical and procedural elements (Figure 2). The environmental storytelling was articulated through:

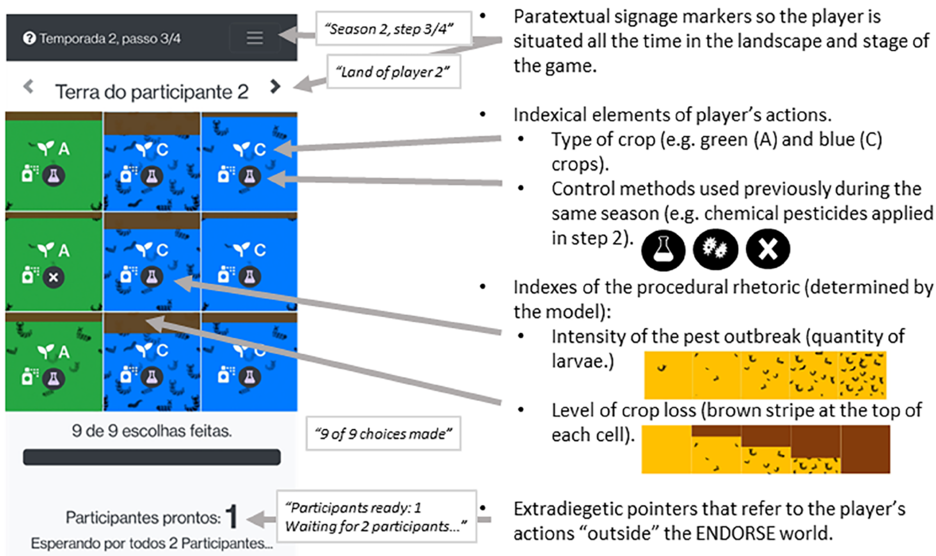

Figure 2. Indexes and paratextual elements used in the game. See "Methods" section for a more detailed explanation of the storytelling elements and their relationships to social and ecological concepts.

(i) the evocation of the agricultural landscape as a clear and delimited simple boardgame, similar to others that the players might have played, and (ii) micro-narratives that pop-up during the first season explaining what is happening in the landscape and asking players to act. The pop-up windows included information needed to interpret the events in the game and instructions for the player to interact with the game (e.g. tapping on the screen to make the choices). The game indexical storytelling consisted of visual elements representing the spread of the pests, the choices made, and the yield scored at the end of each season, allowing players to gain information about the effectiveness of their choices and those of fellow players.

The procedural elements representing agricultural land management processes included a model of pest outbreaks running in the background, the choices among forms of pest control available and the configuration of the landscape and representations of crops, crop damage, and pests. Through these elements, the game made implicit claims about farming practices (e.g. that untreated pest outbreaks will worsen over time, that consistent synthetic pesticide use will lead to resistance among pests, and the use of biopesticides and higher levels of landscape diversity slow down biopesticide resistance evolution). Moreover, the game elements also presented the procedural rhetoric of the game that helped characterize the stakes and quality of outcomes (e.g. the animosity of the caterpillar cartoon as the enemy and the brown coloring that accumulated with crop losses as something undesirable).

Design and Validation of the Research Game

The design process was shaped by the need to develop the game remotely in the context of the covid-19 pandemic: the game had to become a self-contained and self-explanatory research tool that allowed participants' interaction. The success of the research depended on the capacity to engage stakeholders in playing the game, thus getting stakeholders views became a key aspect of the design.

The design process was iterative and user-centred (focusing on considering the knowledge and expertise of the Brazilian farmers) and consisted of 4 stages: (1) preliminary design; (2) deliberative participatory workshops; (3) prototyping; and (4) iterative and discursive pilot trials (Figure 3).

Stages 1 and 3 consisted of work in the scientific hub. Stages 2 and 4 were participatory and were developed jointly by the scientific and engagement hubs with active involvement of farmers and other stakeholders.

In stage 1, the scientific knowledge that framed the research (see "Background: Agricultural land management in the context of pesticide resistance evolution" section) was translated into different elements of the game (e.g. a model simulating pest outbreaks) and players' profile questionnaires to explore the factors influencing their decision-making (e.g. sociodemographic features, knowledge and experience, perceived efficacy, networks).

Stage 2 consisted of two online workshops in which the preliminary design concept was presented to a group of 4 Brazilian farmers and 8 agricultural experts, followed by a facilitated discussion guided by a set of pre-defined questions. The input was analyzed and incorporated into the later phases of design.

Stages 3 and 4 configured an iterative process. In stage 3, the outcomes of the workshops and the pilot trials informed the game prototype and changes in the questionnaires to enhance their uptake. Stage 4 consisted of iterative rounds of piloting with 4 experts, 3 farmers and 6 agronomy students, followed by facilitated discussion to refine the different elements and characteristics of the game and questionnaires. This stage consisted of five sessions between January and March 2021 until the entire team agreed on a final version, considering the balance of resources used (e.g. staff

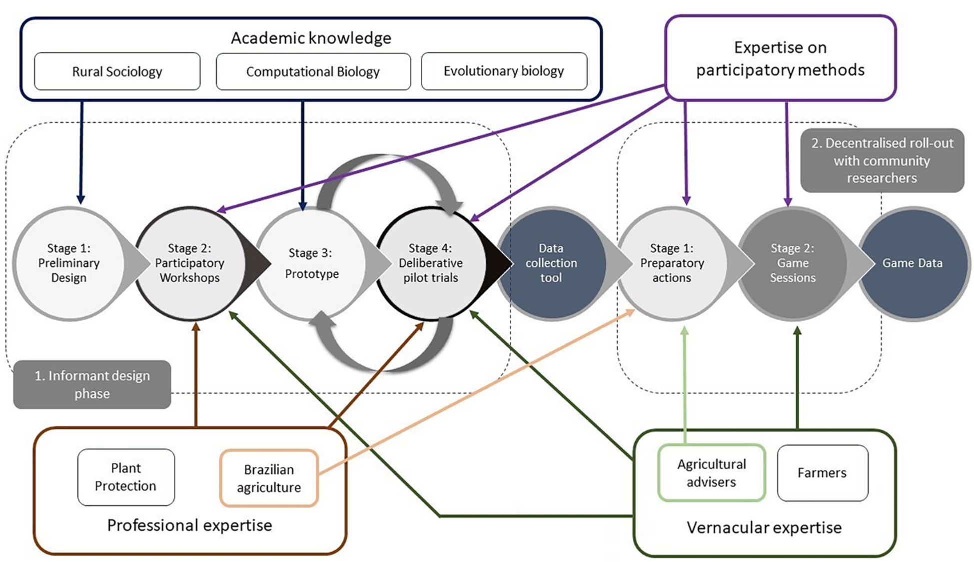

Figure 3. Knowledge inputs in the different stages followed in the informant design process and roll-out of the game.

time and financial resources for the game components) and the level of engagement achieved. We considered we had reached such balance once we got a version of the game that met the following three conditions: (1) the stakeholders involved in stage 4 considered the game acceptable (in terms of the game being playable and providing a satisfactory representation of the farming problem of pesticide resistance); (2) the research team considered that the data points collected through the game were sufficient to explore farmer's decision-making regarding management of pesticide resistance to check hypotheses within the conceptual and analytical framework of reference; and (3) none of the remaining desirable additions to the game that had been identified (e.g. including a chat function that allows participants to communicate) were achievable within the project budget and timelines.

To avoid confirmation bias in the game design and output, we split the team between the design of the game (led by DV, NB, RMcK) and analyses of the game data collected (led by LB). We checked that data was collected during the pilot game play and that we created an efficient data collection tool.

Fine-Tuning the Game Storytelling

The iterative consultation process highlighted four important weaknesses in the original storytelling configuration that were hindering the farmers' uptake of the game, and so the overall research process.

First, the model determining the intensity of the pest outbreaks presented the evolution of resistance too slowly to evoke a player action. Resistance evolution typically takes time, and even if the model was initially faster than real-world time scales, it was necessary to accelerate it, so that pests developed resistance to pesticides sooner than would be realistic in a natural scenario.

Second, the preliminary design and first versions included points representing costs of pest treatment and revenue of the yield: using pesticides had a small cost in terms of points that was deducted from the overall yield. However, the deliberative trials showed that these elements were hindering the uptake of the game in two ways: (i) the points were not sufficiently realistic to represent the costs and advantages of pest control methods; and (ii) it was a distracting element that interrupted the game storyline and tended to be overlooked by the players. Therefore, we dropped the cost component from the game and limited the narrative on productivity to yield and production terms rather than monetary profits.

Third, in the first trials we struggled to keep the game moving forward at a reasonable pace. Debriefing discussions with the stakeholders suggested that the main barrier to rapid decision-making was the complexity of real-farming conditions represented in the game. The game was not portraying diverse Brazilian agriculture in sufficient detail, in terms of types of crops or pests' impacts. As such, the farmers struggled to relate to the role they were playing, raising questions about the types of crops, pests, and pest control methods before making any decision. Attempts to generalize to "Brazilian agriculture" and setting the game in abstract terms (crops A, B, C) were both problematic for players. In response, we discussed and reshaped narrative elements of the farming particularities during iterative rounds of discussions according to stakeholders' inputs (Table 1). The agreed solution was to set the game in a context

Table 1. Configuration of the narrative elements in the game.

Type of input	Narrative element	Summary	Design element
Scientific-led	Objective: Maximizing Productivity	The objective of the farmers is to maximize income from crops. Pest outbreaks compromise the farm productivity, so a farmer wants to use pest control. There are different options available that can pose different benefits in the short and long-term depending on the land management decisions adopted.	Scoring system depending on yield collected
	Challenge: Pest resistance	Pests develop resistance to pest control methods over time, eventually reaching a point when frequently-used pest control methods are no longer effective. Increased diversity in the fields helps to slow down and reduce the development of resistance, especially for biological control methods.	Model running in the background of the game representing the pest outbreaks. The evolving resistance of pests adds a degree of uncertainty to the outcome of the player's action and triggers continuing action against the pest outbreaks for the duration of the game.
	Solution: Diversification of landscapes	Homogeneous landscapes provoke resistance, so coordinating with other farmers to produce landscape-wide diversity is beneficial for crop yield. The achievement of highly diverse landscapes depends on the farmer's cooperation.	Possibility and encouragement to observe and respond to what other players are doing. Requires an effort without an immediate observable reward.
Practice-led	Context: Particularities of farming	Farming is place-bounded. Type of crops, types of pest outbreaks and type of pest control methods available are diverse and depend on geography.	Identification of game elements (crops and context). Visual identity of game elements (crop damages, pests).

that was equally unrelatable for all participants by building on the storytelling elements of the game. The game became contextualized in a fantasy world called "Planet ENDORSE" (acronym of the research grant funding the work) and the crops were given generic names referring to their colors (Yellow, Green, Blue). The pest attacking the crops was given the form of a larvae instead of simply dots that indicated their prevalence, and the quantity of crop loss was represented by a dark brown strip in each field resembling real-life crop damages. The introduction of these visual elements supporting the storytelling meant a radical change in the farmers' acceptance of the game. Also, avoiding reference to Brazilian agriculture opened the potential to roll-out the game in other countries without introducing major design changes, making the game generalizable and insights comparable to other case studies.

The new storytelling was introduced orally, when the game was explained to participants (during recruitment and before the game session) and through detailed pop-up explanatory boxes that appeared at every step during the first season of the game.

The fourth weakness flagged through the iterative design was the need to provide players with a take-home message. A common question after every test game was "what was the optimal strategy?" Because the game is a tool to investigate player decision-making and strategies, and we did not want to influence potential players with inside knowledge of the model, it was impossible to provide detailed information about game mechanisms in advance or during game sessions. Our solution was to include a short explanation in an automated thank you message that the players received from the game website after submitting the post-game questionnaire (supplemental material).

Identifying and addressing these four weaknesses in the original storytelling improved the pace at which farmers made sense of the game and understand the rules, and so had a critical impact on making possible the game sessions and the data collection process.

Game Sessions and Data Collected

Roll-out of the game was online (through a dedicated interactive website developed to host the game and questionnaires), decentralized, and simultaneous in six Brazilian States. The decentralization of the fieldwork was facilitated through the involvement of community mobilizers labeled as "champions", who were well-connected farmers or agronomists embedded in farmer communities or networks in the Brazilian States where the research took place. Champions were recruited by the engagement hub through their network of agronomists, demonstrators, researchers, and farmers. The champions recruited farmers to participate in games, introduced farmers to the research and platform, questionnaires, and game, and assisted them in registration, arranged game sessions and in resolving technical issues. Champions were coordinated by researchers in the engagement hub and social scientists in the scientific hub, who organized and hosted game sessions. Each champion got a contract for service providers for a value of R$3500 for finishing game sessions with at least 12 farmers.

The champions had a specific training session to introduce them to the research project, and played the game following the same steps that participants would follow (registration, initial questionnaire, gaming session and post-game questionnaire), experiencing first-hand the same challenges of the game process and connectivity that the farmers might encounter. In each session, the champion and coordinators were connected by videoconference, while the champion connected with farmers by different means depending on what was most suitable for them (e.g. via messaging app, videoconference, or in-person). As all data were collected within the game application, the difference in setting did not impact data consistency. However, we acknowledged that different settings provided different possibilities for the participants to potentially interact with each other. To minimize bias, all players were encouraged to interact with the other participants only through the in-game options (e.g. seeing their neighbors' land).

Once all participant farmers were logged into the game and indicated that they were ready to start, the host (a member of the research team) started the game. Games usually had between 2 and 4 participants (plus the host) and lasted 3 seasons. On occasions when there were crashes due to connectivity failures, shorter games (2 seasons) were played. Crashes usually traced back to the loss of connection of one or more participants. In a small number of cases, the cause of crashes could be linked to the participants' multi-tasking digital behaviors (e.g. responding to social media notifications, refreshing the page when it took time to load). The briefing and debriefing of the game sessions were facilitated by the champions and structured by the registration and post-game questionnaires embedded in the game website.

The debriefing of the game sessions was limited to answer questions about the game or the research or to discuss any point that the participants might rise in after playing the game. The topics and main points in the individual debriefing sessions were discussed in the engagement hub and served to identify limitations of the game, in particular the frustration of games crashes and the desirability of a functionality that allow players to

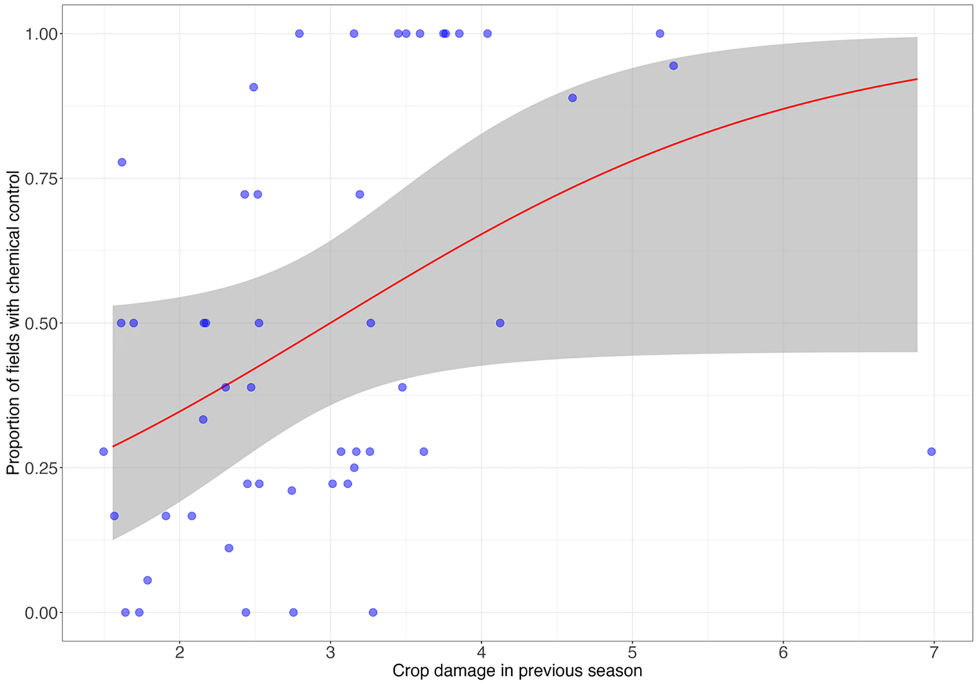

Figure 4. Observed changes in the probability that a player will use chemical pest control as a function of pest damage in the previous year.

communicate among them during the game. Thirty-one sessions were completed during six weeks in July and August 2021, involving a total of 75 farmers in completed games, and generating a dataset on over 11,000 individual land management decisions.

Data collected illustrate how in-game events prompt changes in player behavior that will allow us to assess factors promoting cooperation. As an example, Figure 4 illustrates observed changes in the probability that a player will use chemical pest control as a function of pest damage in the previous year (pest populations and the damage they cause are affected by both player decisions and stochastic elements during gameplay). Each point represents the proportion of fields on which a player (N = 69) elected to use chemical control in the last game round. To facilitate visualizing overlapping points, observations have been adjusted with small random horizontal jitter and are represented with transparency. The red line represents the fitted binomial logistic regression for the unjittered points, and the shaded ribbon represents the 95% confidence interval for this regression; this regression illustrates the predicted effect of heightened pest densities on the use of more aggressive pest control methods.

The feedback from the sessions gathered through the exit questionnaires was in general very positive. Just under 80% of participants (79.4%) considered the game very or extremely useful for instigating discussions about farming decisions among farmers. In addition, 87.8% of players suggested that if the game were based on specific crops and pests relevant to their farming, it would also be very or extremely useful tool in decision-making about crops and pest control methods, although this was beyond the objectives of our game.

Discussion

The ENDORSE game joined a tradition of spatially explicit games that involve the synchronous interaction of several participants, such as NonCropShare (Bell, Zhang, and Nou 2016), Goosebumps (Rakotonarivo et al. 2021a), and Elephants and Crops (Rakotonarivo et al. 2021b). These studies had already highlighted the potential for games to collect data and evaluate farmers' decision making, their willingness to coordinate actions and different aspects of land management dilemmas.

The game collects detailed data in addition to the player actions, such as, but not limited to, time spent in taking decisions and if the neighboring farm was examined before taking decisions. Furthermore, the digital game captures data on the exact game conditions in which a decision is made by each player (e.g. records of pest infestation levels in each cell at any given time). This detailed data collection allows one to assess how decisions are made, to identify patterns of individual and group behavior regarding the management of resources (in this case agricultural land and pest) and optimize management (e.g. what characterized games where better results were achieved). Also, the data can be linked to player profiles via a registration questionnaire, which can help explore questions on how sociodemographic characteristics, player knowledge, and values and experience might influence game decisions and results.

The novelty of our game includes the integration of informed-design elements and community mobilizers, for an online multiplayer experience, with significant implications for fieldwork and roll-out.

Co-Design

The iterative consultation process aligned with informant design approaches of co-design (De Jans et al. 2017). This allowed for improved farmer uptake and participation. In line with suggestions by Powell et al. (2021), our work illustrates how introducing co-designed elements in research games helps prioritize the participant's experience and incorporates stakeholders' views. This is particularly important when exploring social-ecological systems, since this requires a diversity of knowledge approaches to inform integrated management decisions (Cuppen 2012; Dewulf et al. 2005; González-Chang et al. 2020).

The co-design highlighted the framing of the problem as a crucial component of the storytelling, in this case the adoption of biopesticides and diversification of agricultural landscapes. In particular, three of the four weaknesses unpacked in "Fine-tuning the game storytelling" section refer to the need to simplify the representation of some elements in order to gain playability (intensity of the pest outbreaks, acknowledgement of costs and yield, types of crops and pests). To solve all these weaknesses – and also the fourth one on providing a clear take-home message – the critical and reflective iteration during design allowed us to consider alternatives and challenge assumptions about what worked and what did not, and helped researchers to adopt a critical approach, avoiding bias and dogmas (Coulton and Hook 2017).

In line with Roungas et al. (2021), the validation process and the effectiveness of our game proved to have a virtuous link: the iterative rounds promoted generalization and increased the effectiveness and credibility of the sessions. Effectiveness was measured as completion of games and rounds played, and credibility as acceptance and uptake of the game among farmers that had not been part of the game development what is particularly relevant in contexts where confidence in agricultural experts is declining (Rust et al. 2022; Stoate et al. 2019).

The co-design in our game followed an informant design approach that maximized the participation of stakeholders in a context of time and resource constraints. Future research building on this type of game should allocate time and resources to wider cooperative inquiry design experiences (De Jans et al. 2017). For example, the inclusion of participants in the design of the model and procedural rhetoric (e.g. participatory modeling techniques) in a collaboration on an equal footing to the researchers.

Balance of Quality, Playability and Feasibility

It is important to navigate expectations and possibilities of the game development within the scope of the project in terms of boundaries and resources. Establishing clearly and early what the necessary and sufficient criteria are for considering the game prototype acceptable for game sessions is advised. These criteria could include factors such as the game's technical performance (e.g. that the application does not crash), the representation of the SES that the game provides, and its playability (e.g. that the possibilities for players' action are engaging). In this vein, the benchmarks for prototyping serious games refer to balancing standards on quality (being fit for purpose, meeting the initial specification), playability, and feasibility (on the technical side and regarding time and resources) (Khaled and Vasalou 2014; Gugerell and Zuidema 2017; Ampatzidou and Gugerell 2019). However, we have not found a clear definition of criteria to measure such balance (i.e. a set of indicators), as the standards might be specific to each game.

In our case, the standards presented in "Design and validation of the research game" section also fall under the domains of quality, playability, and feasibility. Playability and feasibility are similar to the standards established in other cases: that participants were engaged in the play through the game and wanted to try again, and that modifications are possible within the technology and resources available. However, regarding quality, we understand that research games need to reach not only the player's satisfaction with the representation of the social-ecological system and the issue explored in the game (in our case, the representation of the pesticide resistance problem), but also the researchers' satisfaction with the data points offered by the game and the conditions of data collection. So, benchmarking in the codesign of research games also needs to balance data quality and validity requirements, which will depend on the specific hypotheses and analytical framework of each study.

Implications of Being an Online Game

Our game showcases the potential of online roll-outs for interactive research tools. The online mediated approach, despite its constraints, allowed us to effectively collaborate between UK and Brazil hubs, mobilizing local expertise critical for the game co-design (Howlett 2022) and tuning the qualitative aspects of the game design to match the expectations of both the research team and the stakeholders (Roungas, Bekius, and Meijer 2019).

The study also capitalized on the increased usage of smartphones to engage with participants that otherwise would have been hard-to-reach (Bell et al. 2016; Duthie et al. 2021), who were able to participate in the game sessions from their homes or workplaces. This avoided travel and gatherings, reducing the environmental footprint (Reñosa et al. 2021) and improving the safety of participants and researchers during the pandemic (Kara and Khoo 2020). The videoconferencing used for the co-construction design phase aligns with moves toward online qualitative research during the pandemic (Howlett 2022). It also provided a comfortable context for participants to join the game, avoiding feelings of being observed, and giving them more autonomy and an active role in the research.

However, the use of smartphones also presented challenges. The functionality of the game depended on the stability of the connection of all participants in any given session, evidencing the requirement for researchers and participants to have compatible software and reliable internet (Howlett 2022). Other researchers have also noted the challenge of network interruptions when working remotely (e.g. Reñosa et al. 2021; Reinoso Chavez, Castro-Reyes, and Echeverry 2020). Participation required a certain level of techno-competence as players' decision-making relies on tapping on a smartphone screen. Limited techno-competence of some participants, particularly within older cohorts, made the game difficult in some sessions particularly when rolled out in combination with videoconferencing. All these issues illustrate the complexity of the digital divide (Kara and Khoo 2020). In addition, the use of personal smartphones, being multi-purpose tools, made it easy for participants to get distracted by notifications or other actions that took the focus away from the ongoing activity. Thus, clear guidance should be provided to participants on how to use the smartphone during game sessions.

The future of this research methodology involves developing tools that allow games to continue despite connection interruptions, which would provide smoother experiences for participants and limit frustration. It should be possible to develop research apps that make use of in-built operating system functionalities like "focus mode" to control actions external to the game more tightly. Although not explored in our study, using smartphones provides the potential to capitalize on the rise of digital communities of practice among farmers, with farming influencers getting a crucial role in disseminating agricultural information and spreading innovations (Rust et al. 2022).

Decentralized Fieldwork

As Grogan and Meijer (2017) pointed out, the roll-out of a research game requires significant planning and supporting infrastructure that includes recruitment and coordination of participants, scheduling and organizing the game sessions, delivering briefing materials and gathering informed consent. The pandemic context in which our research was developed required online fieldwork, with mobility restrictions and uncertainty making participant recruitment challenging. A collaborative decentralized plan via the engagement hub and through the involvement of community mobilizers (the 'champions') allowed the roll-out. These champions acted as local ambassadors of the research, reaching a higher number of farmers than members of the research team could have managed on their own. This outcome is consistent with results of other decentralized studies (Creaney et al. 2022), particularly during the Covid pandemic (e.g. Nchafack and Ikhile 2020).

In our research, the champions were also critical in assuring the quality of the data gathered, as they helped communicate to the farmers the aim, context, storyline and rules of the game. Their critical role was only possible thanks to the initial training that explained the research, and the opportunity to experience the game first hand. The involvement of community mobilizers has a great potential to enhance transdisciplinary research, an aspect that has not been completely realized by our project. More active involvement of the champions in the game sessions and the debriefing would open new avenues for their further involvement as true community researchers in the sense of Creaney et al. (2022) and including them in the co-design and analysis stages could better optimize efficiency and consistency.

Critical Considerations

Despite demonstrating the feasibility of co-produced online multi-player games, our approach had several shortcomings that future projects aiming to codesign research games could address. Our resources and research process were impacted by the global pandemic, having to adapt the research plan to rely fully on online-settings.

A shortfall of our game was its dependence on technology beyond our control, which our game sessions showed was critical to the enjoyment of participants and success of the data collection. Our digital artifact was vulnerable to software changes and incompatibilities, and internet connection breaks. Investing time and resources in the development of more robust digital artifacts (including options for offline operation) would streamline game roll-outs and data collection. Close cooperation between professional gaming companies and researchers is still rare (e.g. Spiers, Coutrot, and Hornberger 2023) but would go a long way toward solving technical issues.

The possibilities that the synchronous multiplayer experience provide were not fully harnessed in our game. Players missed having the possibility of communicating with the other players within the game. Adding a chat functionality could provide such opportunities for the players, as well as qualitative data about the coordination of decisions. A chat would also provide possibilities for the research team to communicate directly with the players during the game introducing details or twists in the storytelling through narrative elements if needed (e.g. to test specific hypothesis that are relevant for the characteristics of each group of players or the results of the first rounds of play). In any case, it is important to consider that adding a chat function could slow down the pace of the game and make the game sessions last longer, increasing the risk for connection breaks during the game. Another possibility to overcome some of the obstacles that we found for online multiplay could be enabling the possibility for single player games with the action of neighbors being simulated by agent-based-models refined based on the data from real multiplayer games and communication with AI-operated chat-bots.

The analysis of the data gathered is beyond the scope of this article, which has focused on assessing the feasibility of coproducing the design, validation and fieldwork (game sessions) of the research game. Thus, it does not illustrate the full potential of involving people in the management of the knowledge generated in the game. From the co-production perspective, future research might look to incorporate champions and participants in the interpretation of the results and their integration in the game underlaying model and the hypothesis design of future research.

Implications and Concluding Remarks

This article provides insights and practical information on designing and implementing research games. We believe this will benefit those interested in game methods, transdisciplinary research and co-production of research tools, including developers of apps for users outside their own communities. Specific information concerning the challenge of representing farming practices, including managing pesticide resistance, might be of interest for researchers interested in land management decisions and engagement concerning biocontrol and integrated pest management.

Our experience provides evidence on the relevance of co-designed games for studying social-ecological systems and introducing transdisciplinary knowledge-exchange in adapting game storytelling. Aligning the storytelling in our game to the stakeholders' expectations was critical for engaging farmers and securing the success of the data collection. As a result, the games provided data on farmer decision-making concerning landscape diversity and pest control, that is relevant for research from a scientific perspective (structured data on choices in scenarios of pest outbreaks parametrized by the research team that, that is comparable and susceptible of standardized analysis in order to provide insights on decision making). Moreover, engaging farmers in the development of the game helped build rapport between researchers and farmers, while enhancing the validity of any resulting advice that could eventually arise from the research.

In addition, our work provides evidence that games adapted to smartphones are useful for engaging farmers in internet-mediated research; they help assure safety during times of restricted social interactions, allow participants to choose the context for joining the research (e.g. the place from where they join, including lighting and comfort conditions, etc.), and can link with digital communities of practice among farmers. However, when designing the software, particularly in multi-player settings, the complexities of the digital divide must be taken into account, including uneven geographies of signal and broadband availability across spaces, quality and stability of connections, and existing inequalities regarding individuals' access to devices and digital competence. It is important to provide participants clear guidance on how to use the devices to minimize participants' frustration and the risk of session failures.

Our study also provides insights on developing collaborative decentralized fieldwork, particularly across different countries. First, integrating the engagement experts in the research team allowed us to contextualize and frame the action from the beginning, and paved the way for the success of the participatory stages of the design. Second, the involvement of community mobilizers in the roll-out was critical for successfully recruiting participants, as the champions could efficiently and rapidly reach high numbers of farmers through their networks. To secure comparable data among participants across a wide area, it is crucial that champions obtain the same initial training and adhere to the same protocols.

Recruiting champions would require recruiting professionals that know about the topic of the game and that understand and have experience of farming life. It is critical that they know the region and farmers so can explain the aim of the game and research, who are the experts behind the sessions (who sometimes speak other language) in order to provide the farmers security and trust for accepting the invitation. Using professional networks contacts is a recommended path.

In summary, the transdisciplinary and participatory process we followed for the game design and roll-out provides important lessons for co-producing research on social-ecological systems in general, and on agricultural transformation in particular. Useful tips for any future research using games and collaborative research are: (i) to consider allocating time and resources to participatory co-design when planning the research projects, (ii) to develop interactive tools that solve issues of connectivity loss and allow games to continue if the connection breaks, (iii) to include community mobilizers in further stages of the research (e.g. analysis) and include them in the teams as community researchers in citizen science approaches.

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