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Research

Tackling surprises when co-designing by playing role-playing games: application of the *Sumak Kawsay* game for understanding socio-ecosystem transitions in the Bolivian Altiplano

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ABSTRACT. We propose a methodology for the co-design of role-playing games based on analyzing surprises. Surprises are understood by researcher-designers as unexpected and significant occurrences during game sessions, often resulting from players appropriating or circumventing the rules. Our objective is to understand to what extent the analysis of surprises in a role-playing game session reveals key mechanisms of the socio-ecosystem under study that are sometimes difficult for researcher-designers to tackle. We assume that analyzing surprises during game sessions enables us to reconsider our hypotheses, gain a better understanding of the socio-ecosystem studied, and support the co-design process. Based on the literature, interviews concerning the social-ecological context and participatory observations, we pre-designed an initial version of a game, which was then co-designed in participatory workshops with two communities in the central Altiplano of Bolivia. We distinguished three types of surprises: (1) misunderstanding or disagreement with a rule or game mechanism, (2) circumvention of the rules, and (3) improvisation and appropriation of the rules. We also identified different facilitator behaviors in response to these surprises. Addressing the first two types of surprises is essential in both the game's co-design process and its underlying conceptual model, as it favors the integration of different kinds of knowledge about the socio-ecosystem. The third type of surprise revealed a paradoxical attachment to the community, between family economic strategies of diversification and migration and those of community obligations, participation, and investment. This complex relationship between the individual and the collective revealed a lack of community cohesion that could have been difficult to understand through individual interviews alone. Finally, based on our analysis of surprises in game sessions, we discuss the capacity of role-playing games to surprise productively. We advocate for player freedom as the main condition for the emergence of surprises and argue for the relevance of this approach in integrating diverse knowledge in the co-design process.

Key Words: *Role-playing game, co-design, surprise, socio-ecosystem transition, Bolivian Altiplano, knowledge integration*

INTRODUCTION

In science as in everyday life, the term "surprise" is highly polysemous. Surprise is studied in a wide range of disciplines, yet there is still no consensus on how to define it (Modirshanechi et al. 2022). In organizational and management sciences, surprise stems from a lack of knowledge and is indicative of errors that better planning could prevent (Yourstone and Smith 2002, Weick and Sutcliffe 2007). In the study of complex systems and socio-ecosystems (SES), surprise is often synonymous with unexpected events to which systems must adapt in order to develop resilience (Holling 1996, Longstaff and Yang 2008). Surprise then stems from the nature of systems and constitutes an opportunity to learn and adapt (McDaniel et al. 2003, Goldstein 2009). The ability of surprise to foster learning is also the subject of studies in educational science (Adler 2008) as well as in psychology and cognitive science (Foster and Keane 2019, Munnich et al. 2019). Cognitive scientists consider surprise to be an emotion, and have set out to measure it in order to better understand what causes it and the effects it can have on the brain and on human behavior (Munnich et al. 2019).

In this study, we examine the value of surprise in the research and knowledge production process. We draw on work in philosophy of science, particularly that inspired by Morgan (2003, 2005). Morgan investigates the surprise produced by experiments and models. Her work has been followed up and discussed by numerous authors (Boumans 2012, Parke 2014, Currie 2018), but the debate is generally confined to these two epistemics mediators. French and Murphy (2023) remain an exception: they endeavor to broaden the debate by including thought experiments and theoretical derivations. However, to date, little work has focused on the capacity of participatory approaches, particularly participatory modeling, to study surprise in a productive way as an epistemic mediator at the intersection of experiments and models.

Participatory modeling includes a diversity of approaches that use modeling with stakeholders to support decision-making processes and adaptive co-management of SESs (Voinov and Bousquet 2010, Edwards et al. 2019) and encompasses several trends and different types of modeling, including companion modeling, to which this work belongs (hereafter referred to as ComMod; Bousquet et al. 2005, Daré et al. 2009, Étienne 2014). Role-playing games (RPGs) are particularly appropriate models for non-scientific stakeholders and participatory processes because of their playful nature (Grimm et al. 2005, Bommel 2009). RPGs have also long been identified as relevant tools for studying governance of SESs (Mermet 1992, Piveteau 1994). Supervised by a game master, an RPG is a simulation in which players embody characters in a fictional environment composed of tangible elements and governed by a set of rules (Mucchielli 1983, Abrami and Becu 2021). The phrase "serious game" is also used. Serious

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games are defined as "games that do not have entertainment, enjoyment or fun as their primary purpose" (Michael and Chen 2005:21).

Research on participatory modeling has demonstrated that involving stakeholders in the design or implementation of models as a joint activity with researchers (also known as model co-design, co-construction, or co-building) facilitates the exchange of information and viewpoints, enhances understanding of the complexity of the SES, generates shared knowledge, and empowers stakeholders (Barreteau et al. 2013, Étienne 2014, van Bruggen et al. 2019). The co-design process is challenging to implement because the complex interactions between knowledge and power have to be taken into consideration. When participants have different knowledge, customs, and experiences, they may struggle to understand each other (Raymond et al. 2010). In research for development, integrating traditional and scientific knowledge raises issues of power asymmetries and knowledge hierarchies (Mohan 2001, Barnaud and Van Paassen 2013, Jordan et al. 2018). A participatory modeling approach should facilitate mutual recognition and the integration of stakeholders' representations, including those of researchers, without prioritizing any particular point of view.

Despite their heuristic potential (Daré and Barreteau 2003), surprises from the researcher-designers' point of view that can occur in game sessions are rarely studied. We differentiate between these surprises and surprises or events intentionally introduced by the facilitators of a game session to foster the players' learning process (van der Spek et al. 2013, Wouters et al. 2017, Zhonggen 2019), which have been the subject of more studies. The originality of the present study lies in its set-up. Our approach was to propose an uncompleted but realistic game that was playable from the start, based on essential contextual information, and to analyze the surprises that occurred during the game session to support the co-design process. The game and the underlying conceptual model were thus co-constructed during the participatory sessions.

Here, we propose a methodology for co-designing RPGs based on the analysis of surprises. Our objective is to understand to what extent the analysis of surprises in an RPG session reveals key mechanisms of the system studied that are sometimes difficult for researcher-designers to tackle. To achieve this goal, we use specific examples of the surprises that occurred during the game sessions.

This study is part of the Wasaca project, funded by Agropolis International Fondation, the aim of which is to better identify issues encountered in the Bolivian Altiplano by imagining development paths in partnership with local actors. The game was co-developed as a participatory diagnostic tool.

THEORETICAL FRAMEWORK OF THE METHODOLOGY

A companion modeling approach to participatory diagnosis

We chose to implement a ComMod approach (Bousquet et al. 2005, Daré et al. 2009, Étienne 2014), developed in the 2000s, which focuses on the recognition of multiple stakeholder viewpoints. ComMod practitioners have defined ethical principles in a deontological charter (Barreteau et al. 2003a). These principles are: (1) to challenge the assumptions underlying the model through fieldwork, (2) to make all hypotheses explicit for more transparency, (3) to consider the impact of the research process on the field, and (4) to pay particular attention to the validation of the research approach. ComMod uses co-designed simulation tools as mediating objects to produce knowledge on SES, in order to discuss, to share views, and to help decision-making (Barreteau et al. 2003b, Le Page 2017).

The choice of a ComMod approach situates this work within a constructivist epistemological framework (Étienne 2014). The complexity of the context and the diversity of problems encountered by farmers and breeders on the Altiplano justify the implementation of an inductive and exploratory grounded theory methodology (Reiter 2013, Sandu 2018). Grounded theory (Glaser and Strauss 1967) is an approach to empirical theorizing that is based on a back-and-forth between field data and conceptualization. Empirical data serve as the starting point for theorizing and also enable it to be verified, leading to an explanatory model of a contextualized social phenomenon.

To this end, we sought to involve stakeholders from the very beginning of the project so as to define the issues to be addressed in a participatory way. We co-designed an RPG called *Sumak Kawsay* ("Living Well" in Quechua), in order to (1) support a participatory diagnosis of the Poopó Lake area and understand the main problems experienced by farmers and breeders of the Altiplano, (2) refocus our research accordingly, validate its relevance, and build its legitimacy with local populations, and (3) imagine viable development scenarios with them. As explained above, our co-design process is based on the analysis of surprises.

Defining surprise in a serious game co-design session

In this paper we examine the value of surprises in the research and knowledge production process, as applied to a serious game co-design workshop. Morgan investigates the surprise produced by epistemic mediators, defined as "tools of investigation to help find out about either the world or theories" (Morgan 2005:318). She addresses two forms of epistemic mediators, "mathematical model experiments" (models or simulations) and "laboratory experiments" (experiments). Her main argument for differentiating these tools is that the former simply produces "surprise," whereas the latter can also "confound," without dwelling on the definition of these terms. Several authors define surprise by drawing on Morgan's work, such as Currie, who defines it as "an occurrence which is unexpected given a particular epistemic or doxastic state" (Currie 2018:7). In contrast, a confounding result may be surprising, but beyond that is "unexplainable within the given realm of theory" (Morgan 2005:324). Surprise and confoundment are therefore both positive with respect to knowledge production. Whereas these authors speak of surprising "results," "experiments," or "simulations," we speak more of surprising "observations" or "events," because they take place during the course of a process: the game session. A game session can be described as both an experiment and a (non-mathematical) simulation, and it is an epistemic mediator, as we argue in the Discussion section. The definition of surprise we use is in line with the above-mentioned work, but we thought it would be interesting to consider work in the cognitive sciences to better characterize it.

Defining surprise is far from easy. A first important distinction must be made between the emotion of surprise (internal feeling or phenomenal surprise), and the event at the origin of this emotion (surprising event; Miller 2015, Currie 2018). Regarding the second point, Baras and Na'aman (2022) introduce another distinction between descriptive events (those which cause the emotion of surprise) and normative events (those which justify the emotion of surprise). When we talk about surprise, we are talking about events that justify a reaction of surprise for researcher-designers, regardless of what they actually felt. This raises two questions: what kinds of events count as surprises, and why are they considered surprising? In our study, the surprises are actions (or inactions) by players that reveal a discrepancy between players' mental models (Piaget and Inhelder 1967, Daré et al. 2010) and the game, the latter reflecting the researcher-designers' mental model of the SES at the start of the co-design process. This discrepancy can take many forms, which is why, in the Results section, we identify several types of surprises that are not equally capable of producing knowledge about the SES, an issue we explore further in the Discussion section.

These events can be described as "surprises" for researcher-designers because they are both unexpected and significant. Although many authors agree that unexpectedness is a key factor of surprise (McDaniel et al. 2003, Currie 2018, Munnich et al. 2019, Baras and Na'aman 2022), the predictability of some unexpected events in game sessions is debatable. Despite anticipating unforeseen events in co-design sessions, the exact nature and impact of these surprises remain uncertain, as they are not triggered, warranting their classification as surprises. However, unexpectedness alone is not enough to justify surprise; the event itself must also be significant (Baras and Na'aman 2022). Baras and Na'aman identify four types of significance in events that cause surprise: personal, moral, aesthetic quality, and epistemic significance. We focus exclusively on the last, which corresponds to the epistemic relevance of an unexpected event to something of importance to the researcher. Thus, an unexpected observation can justify the researcher's surprise "because it challenges previously held theories and prompts a new theory that changes what we believe about the world" (Baras and Na'aman 2022:206). This distinguishes true surprises from mere errors or malfunctions in game design. Additionally, these surprises often sparked discussions among participants, highlighting the different perspectives between players and the importance of a constructivist epistemic framework. Not all surprises led to changes in or improvements of the game.

A "surprise" in an RPG session must be understood from the researcher-designers' point of view as (1) an unexpected event that occurs during the course of the game and is often linked to the appropriation or circumvention of rules by the players; (2) because of its significance, this unexpected event arouses the curiosity of researcher-designers who, in this case, have preconceived a game by formulating a series of hypotheses based on their knowledge of the SES; and (3) the observation of the event and the ensuing exchanges may reveal elements of reality that are only poorly taken into consideration in the game or even disregarded (Daré et al. 2020). We assume that the analysis of surprises during the game session will enable us to reconsider our hypotheses, gain a better understanding of the socio-ecosystem under study, and support the co-construction process.

CONTEXT OF THE STUDY AND FIELD IMPLEMENTATION

The central Altiplano: extreme conditions for farming and livestock breeding

The Bolivian Altiplano, a large arid plain in the Andes at an average altitude of 3800 m a.s.l., has undergone significant changes in recent decades. In the Poopó Lake region, agriculture intensified with the quinoa boom in the south (Vieira Pak 2012) and livestock breeding increased in the north (Hervé and Rojas 1994).

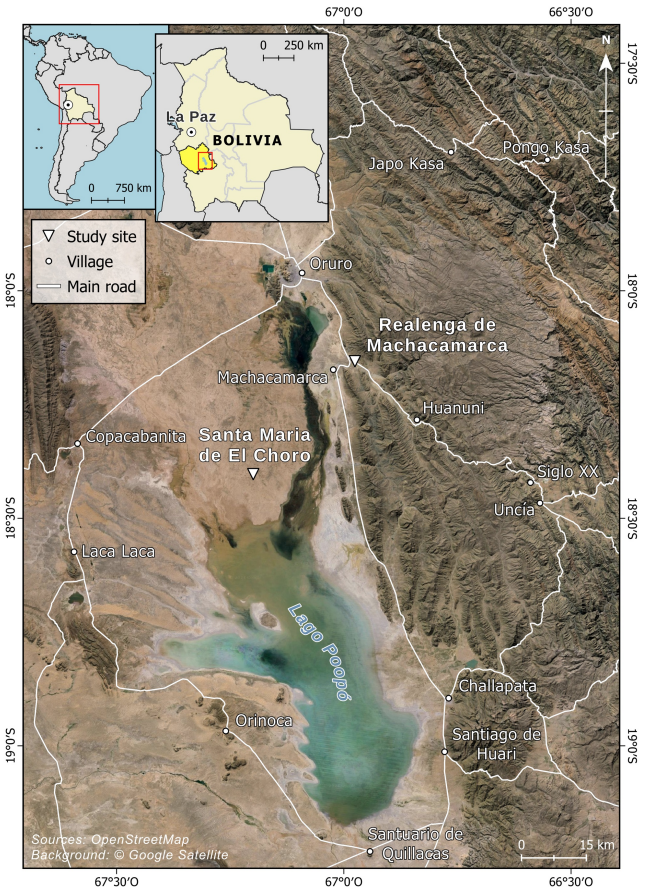
The drying-up of Lake Poopó in 2016 continues to impact the local incomes of rural communities. This disaster is symptomatic of the desertification of the Altiplano, driven by climate change, which disrupts seasons and increases temperatures and evapotranspiration (Lima-Quispe et al. 2021). Additionally, El Niño and La Niña events cause droughts and floods around the lake (Canedo-Rosso et al. 2021). Although the level of the lake has experienced large inter- and intra-annual fluctuations and has already dried up in the past (Pillco Zolá and Bengtsson 2006), its current drying up is additionally due to anthropogenic actions: Peru's rerouting of the Mauri River (the main tributary of Desaguadero River, itself the main tributary of Lake Poopó; Calizaya 2009, Whitt 2022), increasing irrigation in the upper lands, urban growth, and mining (Perreault 2020) have all altered the hydrology of the region.

The drying-up of the lake is compounded by high water salinity originating from geological dynamics of this endorheic watershed (Torres-Batlló et al. 2020) and from contamination by mining and typical urban activities (French et al. 2017). This water contributes to soil contamination and salinization via irrigation (Garrido et al. 2017). These combined issues drive many families to migrate, at least temporarily, and abandon their rural communities to go and live or work in cities (Canedo and Tassi 2021).

Study area: two neighboring but contrasted communities

The present study was carried out in two rural communities: Santa Maria, municipality of El Choro, and Realenga, municipality of Machacamarca (Fig. 1) located near the city of Oruro and Lake Poopó. According to the 2009 constitution, they are classified as Indigenous, native, and peasant communities. They were selected in collaboration with the project partners on both sides of Lake Uru Uru and Lake Poopó. Selection criteria included involvement in agriculture and irrigation, having faced problems of contamination, and accessibility from Oruro. The vernacular language is Quechua (field data), while Spanish is widely used, particularly for assemblies. A "community" consists of families who share a collectively-defined territory and infrastructure and services. All families have to do collective tasks, mainly building and maintaining the infrastructure and services, such as carrying out the duties of the communal authorities or taking part in meetings. When necessary, the community makes collective decisions on how to manage both internal affairs and relations with the outside world, facilitated by the communal authorities and according to their habits and customs (Albó 1985). A community can be defined as a unit of governance of the common pool resources located within its territory (Ostrom 1990, Le Gouill and Poupeau 2019).

Fig. 1. Map of the zone showing the location of the study sites and Oruro, the main town. Created by combining a satellite image and a base map (source: Pottier 2024).



Although geographically close, these two communities are contrasting cases. Santa Maria, with 70 families, is located north of Lake Poopó on flat land. It faces flooding, salinization, and mining contamination, particularly because of irrigation using the Desaguadero River. Realenga, with 67 families, is located on the edge of the Altiplano, on hilly land. It is directly affected by mining contamination by the Huanuni River, another tributary of Lake Poopó that is contaminated by a tin mine located upstream. By road, Santa Maria is over two hours from Oruro whereas Realenga is only thirty minutes away, making it well connected.

Organization of field work

The president of the water users' board of the Desaguadero-Mauri watershed, our first local contact and partner non-governmental organization (NGO) collaborator, introduced us to the communities. Meetings for project presentations were arranged during community assemblies in order to address the project's potential value for the communities, gauge their interest in participating, and to apply for permission to collaborate with them. The project was well received, and the researchers were welcomed to collect the necessary field data with local people to first design and assess the game.

An initial version of the game was designed by researchers on the basis of knowledge gathered from participatory observations, study reports, and advice from experts. *Sumak Kawsay* is a board game that represents a small community in which players make decisions concerning their agricultural and livestock activities. The game was tested with members of the NGO *Agua Sustentable* and students from the Technical University of Oruro. An observer took notes on any problems that arose during the trial games, and feedback was collected from players during the debriefing period after game sessions. Testers rated the game as realistic, interesting, and fun. The main improvements requested were simplifying the game and improving calibration of the degree of difficulty.

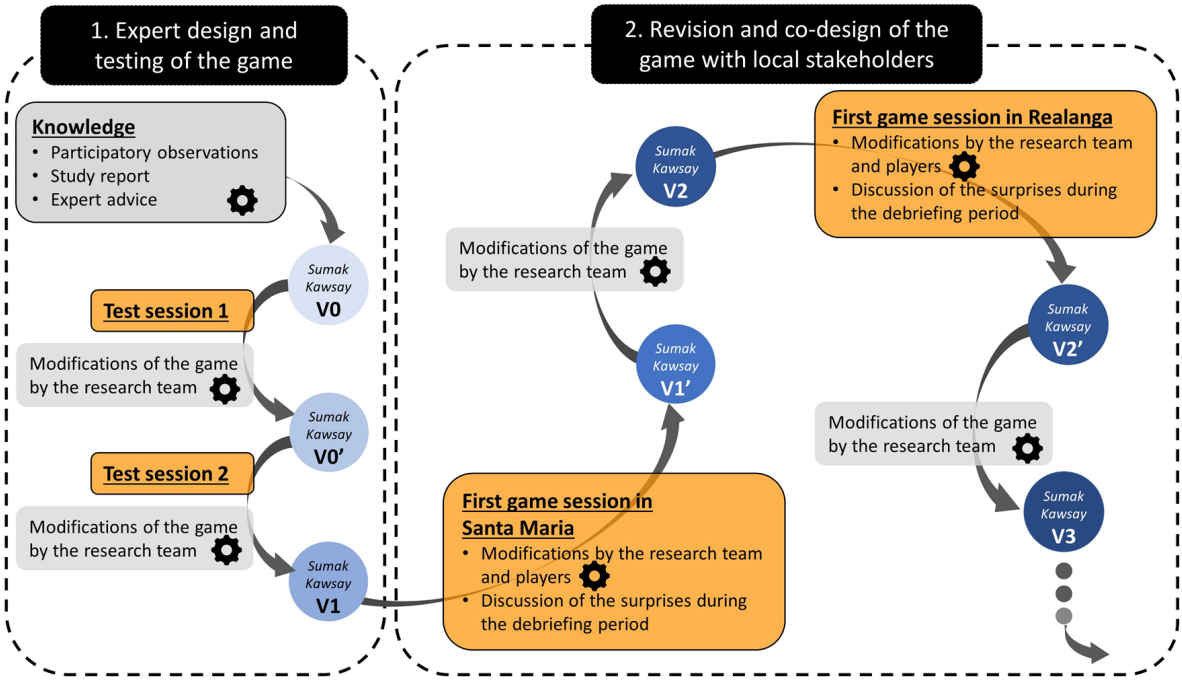
The revised version was then presented to the two communities to initiate the co-design process. We introduced the already playable version to workshop participants as a game that we wanted to improve thanks to the feedback they would give us both while playing the game and afterward during debriefing. In addition to the two workshops held to test the game, we organized four game-playing workshops, two in each community that involved 24 players in all. The following section summarizes the co-design process.

The four workshops brought together members of the committees of the irrigators' associations, local authorities, and less notable members of the communities, mainly livestock breeders and farmers. The participants were originally selected by our first local contact. The second sessions were organized by the presidents of the committees of the irrigators' associations, on their own initiative. They took place in the meeting room of each community (Fig. 2.).

A total of nine game evaluation interviews were conducted a few days later with volunteer participants. All game sessions and interviews were video recorded when electricity was available and audio recorded when it was not. In addition to the agreement given at the assembly to carry out this work, the informed consent of each participant was sought at the beginning of each participatory workshop and interview.

Fig. 2. Photo of the first game workshop held in Santa Maria on 2 February 2022.

Fig. 3. From experts' to local stakeholders' design of the *Sumak Kawsay* game.



RPG co-design process with local actors

Game sessions were facilitated by two to four members of the research team. One person was always in charge of observing the session, inspired by the Serious Games Observation Guide (Daré et al. 2020). A game session lasts about 3 hours: 30 minutes were needed to set up the game and to introduce and explain the rules. The game itself lasted an hour and a half, and was followed by an hour-long debriefing period. Surprises that occurred during the game were discussed directly whenever possible, and the game was immediately modified accordingly. When the proposed changes were too complex to be considered during the game session, or were only discussed during the debriefing period, modifications were made by the research team in preparation for the following session. The co-design process is summarized in Figure 3 and detailed in the Appendix.

Description of the *Sumak Kawsay* game

Sumak Kawsay consists of a board on which the land and farms of six farming families are shown. One round represents one year and four rounds are planned for one game. The objective of the players is to feed their family during each round and to increase their level of satisfaction. Each family starts with nine plots and an endowment. Each round is divided into five steps. In the first step, the players must build up or renew their herd and invest, for example, in irrigation, building a barn, or purchasing seed. In the second step, the board is updated according to plant growth dynamics that depend on rainfall and irrigation. In the third step, thanks to the yields of their fodder crops, the families are able to feed their herd. In the fourth step, the animals reproduce, thereby producing income. At the end of the round, each family checks if it has been able to meet its needs in the year concerned. The organization of a round and the components of the game are shown in Figure 4.

Events planned by the facilitators can be both individual and collective, social or natural, and can disrupt the game. The players can then reinvest any remaining money in preparation for the next round, for example, by purchasing animals, or by investing in non-farm activities such as their children's education, purchasing a house in town or a truck, based on the multi-activity dynamics and dual residences typical of these communities. To reflect the Bolivian context, exchanges between families are encouraged by events (drought, floods) that require mutual aid or joining forces.

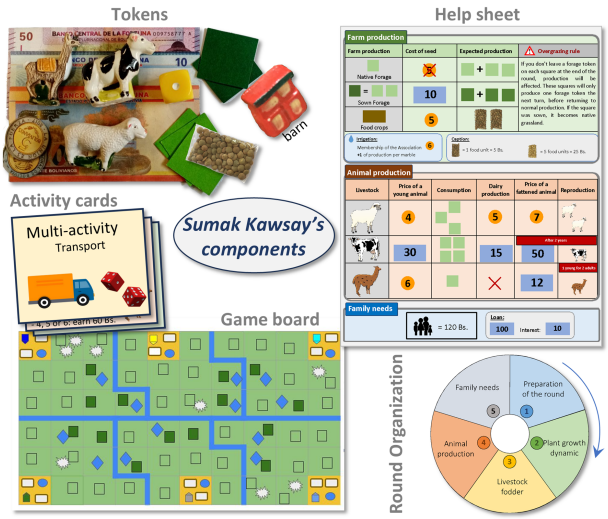
In addition to time spent on improving the game, the debriefing periods enable exchanges concerning the difficulties encountered by the participants, the collective dynamics of the community, and, at the family level, strategies for subsistence and for improving livelihood conditions.

RESULTS

Here we present our classification of epistemic surprises that occurred during the game, illustrated by concrete examples, after which we describe the facilitator's reactions to these surprises.

Surprises that occur are discussed during the course of the game if the opportunity and the need arise. However, if the negotiations and changing the rule would take too long, they are postponed until the debriefing period. The debriefing period after the game session gave players the opportunity to tell us what they did not understand, what in the game was not realistic, and how the game could be improved.

Fig. 4. The structure of *Sumak Kawsay*. The red dotted lines underline points of surprise developed later.



We classified the surprises that occurred during the course of the game into three types, supported by concrete examples; see Table 1 for a summary. Concrete examples of the first and second types of surprise are selected because they are particularly significant. The concrete examples of the third type of surprise were the only ones we were able to observe.

Surprises that provide a better co-design process

First type: misunderstanding or disagreement with a rule or a game mechanism

When the players have difficulty understanding the rules of a game, this often means that a game mechanism is too far from reality. Disagreement can reveal a mis-simplification of the game. This type of surprise must be taken into consideration for a better understanding of the system as perceived by the stakeholders. However, there is a risk of being drawn into a game that is increasingly complex and close to reality. The more complex the game, the greater the risk of making it long and boring, with a loss of its essential playfulness. This question of simplification or realism is recurrent in modeling (Edmonds and Moss 2005). It is particularly important to address it when the participation of stakeholders is sought.

To give a concrete example, when the game rules were being explained during a session in Santa Maria, the players disagreed with the help sheet, which stated that llamas consume three forage units whereas sheep consume only two. When we wrote the help sheet, we referred to two studies on sheep and cattle feed (Dulphy et al. 1990, Aquino and Yùgar 2008). Having found almost no information concerning the amount of forage consumed by llamas on the Altiplano, we assumed that since llamas are slightly bigger than sheep, they would consume more. One player, followed by the others, argued that the opposite was true. A llama eats little and has a very efficient metabolism, whereas sheep are gluttons and eat three times as much as llamas. Together, we changed the rules and the model of the game that now states a sheep's dietary need is three forage units, whereas a llama's is one forage unit.

Second type: circumvention of the rules by one or more players

In this example, the rule is understood, but unlike the disagreement, the player does not oppose it openly. Rather, he or she bypasses it. This circumvention in the game does not always reflect reality, but more the taking advantage of a loophole in the rules to gain an advantage in the game. When the game rules really did contain a major flaw, the players did not hesitate to use it in the different game workshops. It is consequently important to question the participants about the actions they take in the game to find out if they are simply taking advantage or if their actions are realistic. It may be necessary to change the rule to make sure the game runs smoothly.

Again, to give a concrete example: in the game, building a barn is expensive, but it allows a player to store fodder for several years. During one game session, two players started talking about buying a barn together and sharing its costs. The collective dynamic was interesting, and there was no rule preventing a joint purchase, nor limiting the storage capacity of the barn. The other players then also wanted to join in the purchase of the barn and to share it. We asked the players if, in reality, barns are shared by several families, and were told they are not. After negotiating, we all agreed on a new rule: a barn can only have a maximum of two joint owners.

Surprises that provide a better understanding of SES transitions

Third type: appropriation of the rules by a player and improvisation

Beyond misunderstanding, disagreeing with, or circumventing the rules, this third type of surprise reveals that a player is simply ignoring the rules. He or she no longer really plays by the rules of the game but invents his or her own story and improvises. These surprises stem from the unconventional behavior of certain players. This only occurred twice, in two different sessions. Each time, the actions carried out were openly discussed by the other players during the game and again during the debriefing. Because these surprises tended to be exceptional, they did not result in any rules being changed.

Concrete example 1: During the first session in Realenga, at the end of the game, a woman decided to sell all of her animals except her llamas, to go and work in town, and to become a businesswoman:

> *I want to sell all my cows, and go and live in the city … I already have a house in the country, now I want a truck to sell cattle, sheep and llamas. That's going to be my job now. I'm going to be a businesswoman.*

The city is not represented on the game board. There is a card that represents off-farm activities and activities unconnected with livestock rearing, but these are more like part-time jobs that do not themselves provide enough income for a livelihood. In this case, the action goes beyond the idea of "multi-activity" to complete the income required to be able to continue living in the community. Instead, it reflected her desire to leave the community and move to the city in pursuit of new opportunities, fortune, and social advancement. This action illustrates the rural exodus that

Table 1. Classification of surprises and facilitator's reactions to their occurrence (examples in bold are discussed in the article body).

Type of surprise	Facilitator's reactions to the surprise	Examples
Misunderstanding or disagreement with a rule or a game mechanism	Helping the players	Feeding the animals
	Recalibration	**Animals' dietary needs**
	Removing elements responsible for the misunderstanding	Removal of a multi-activity card
	Changing the rules after discussion and negotiation	Reproduction dynamics of animals
Circumvention of the rules	Allowing it to happen	Obligatory contribution (in cash or in kind)
	Refusing to allow it to happen and tightening of the rule	-
	Changing the rule after collective discussion and negotiation	**Purchase of a barn by several players: maximum 2 co-owners permitted**
Appropriation of the rules and improvisation	Reminding the players of the rules of the game	-
	Leave room for player to express his/her opinion, then discuss and negotiate the decision and act concerning the game's dynamics if needed	**A player sells her animals at the end of the game to buy a truck, leave the rural community and become a businesswoman**
		A player buys a truck and asks for a work contract to diversify his activity

communities of the Altiplano are experiencing. However, she chose to keep some llamas, reflecting her attachment to the community, as do the *residentes* (Spanish expression), who work and live mainly in the city, while maintaining a link with their community of origin.

Concrete example 2: In the first session in Santa Maria, a player purchased a truck and asked for a contract to transport forage:

> *Now I should be able to have a contract, now I have the truck ... I want a transport contract.*

He refused to play the multi-activity card and insisted on having this contract. After negotiating the salary so as not to distort the calibration of the game, the player drew up his own work contract, which was signed by one of the facilitators (Fig. 5). This example illustrates a similar pattern to the previous one. Investing in a truck would allow the player to go into business, earn more money, increase his standard of living, and advance socially.

In both sessions, these surprises made the other players laugh. However, during the game or during the following debriefing period, these behaviors were criticized. In the first example involving the woman, the president of one irrigators' association explained that, in his opinion, this was not a good strategy and that it is necessary to invest in the country, in livestock, to create activity in the community. In the second example, several participants pointed out that there is very limited transport where they live and the inhabitants earn their living mainly from raising livestock. These two examples are quite revealing of the tensions between the individual and the collective we observed in the field: on the one hand, economic strategies are conceived at the family scale, and opportunities outside the community are often more attractive; on the other hand, it is necessary to invest in community lands in order to maintain them and participate in decisions concerning their future. In reality *residentes* (those who live in the city) contribute little to the community. The third type of surprises are the most remarkable: they reflect exceptional and unforeseeable situations that play a fundamental role in understanding the dynamics of the socio-ecosystems, and are thus particularly significant.

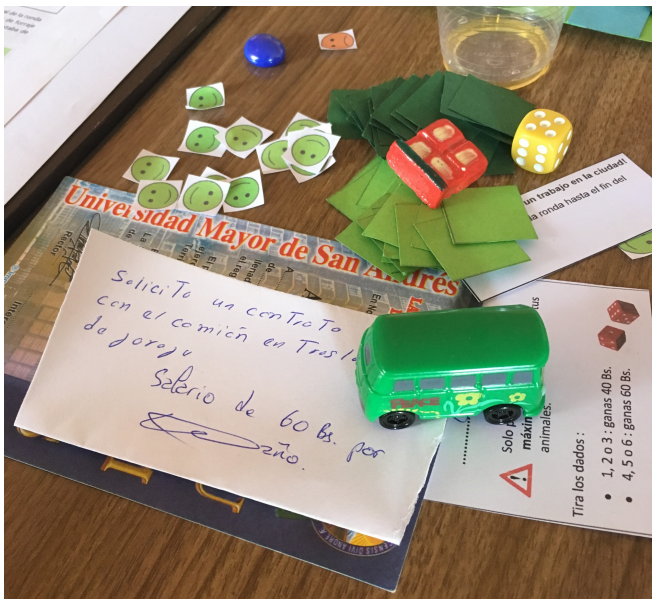
The facilitator's reactions to surprises

Surprises cannot be considered separately from the facilitator's reaction. As we mentioned when defining surprises, in addition to the occurrence of a surprising event during a session, this event must also arouse the curiosity of the researcher-designers, who engage with the players to understand it. However, it is not possible to start a discussion every time there is a divergence from the rules because it would be too time-consuming and would risk interrupting the flow of the game. Thus, faced with these surprises, we, as facilitators, had different reactions, also summarized in Table 1, which reveal different postures. We classified the reactions in four categories based on the gradient of participation and recognition of the players' discourse.

1. Not allowing or refusing surprise, for example by reminding players of the rules. This posture was rarely expressed because our objective was to co-design and improve the game through trial and error by incorporating as much input as possible from participants.
2. Offering help. Although assistance is essential to support players while they are experiencing the game and to find a balance between differences in the ways players understand them, we do not really consider offering help as a posture of openness to surprise. By helping a player, we may inadvertently encourage them to adopt our model and our point of view, without fully considering theirs or the source of their misunderstanding. Conversely, when a player helps another player to understand the rules, it proves that the proposed model is at least understandable to some of the players.
3. Removing the element that caused the surprise, which is often a misunderstanding or disagreement. In this case, there is no real discussion of the element in question with the aim of making it understandable to everyone and integrating it in the game in another way. This happens because of a lack of time or because the element in question is too complex to change while the game is underway.
4. Changing the rule after discussion and negotiation. These exchanges take place between the facilitators and the players, but more particularly between players, who discuss their different views of the system.

Validation of a new rule is therefore the result of negotiation between the players. This posture ensures real co-design of the game and its underlying model. This is the ideal we aimed for, even if the discussion of type three surprises did not lead to any modification of the game rules.

Fig. 5. Photo of the signed work contract and the truck.



DISCUSSION AND PERSPECTIVES

Our objective was to understand to what extent an analysis of surprises in an RPG reveals key mechanisms of the system under study that are sometimes difficult for researcher-designers to tackle. We identified three types of surprises that occur in a game session: (1) misunderstanding or disagreement with a rule or a game mechanism, (2) circumvention of the rules, and (3) improvisation and appropriation of the rules. Accounting for the first two types of surprises is essential in both the co-design process of a game and its underlying conceptual model. This facilitates the integration of different kinds of knowledge about the SES involved. In this study, type 3 surprises (improvisations that went beyond the rules but were possible because of the flexibility of the game) helped us acquire a deeper understanding of the socioeconomic transitions underway in the Altiplano. These insights revealed the importance of considering the diversification of activities by stakeholders rather than focusing only on agricultural income, the dynamics of the aging population, and the decline of rural communities. While this highlights the role of serious games in learning about a SES (Daré and Barreteau 2003), it is worth following up on all of the leads revealed during the game sessions.

To ensure rigor, we triangulated this information with a review of the literature presented in the first subsection. Additionally, in the second subsection, we discuss how game sessions act as epistemic mediators, capable of generating meaningful surprises. We must acknowledge several limitations of our method. Firstly, as with any participatory approach, the representativeness of participants is a key constraint (Carr et al. 2012, Barreteau et al. 2013). Thus, the social-ecological dynamics revealed through observed surprises depend on who is present in the workshops, meaning some dynamics may go unnoticed. Secondly, although our aim was to present a very simple first version of the game to encourage open critique and adaptation that facilitate emergence of surprises, creating an uncomplex first version proved challenging. Furthermore, rule discussions and modifications during the session can be time-consuming and risk disrupting the flow of the game or disengaging participants. Changes made mid-game can also introduce bias or perceived unfairness between players. Finally, the analysis of surprises relies on participants feeling free to express themselves, voice criticism, and suggest changes—something that cannot always be taken for granted. The third subsection suggests ways to address some of these limitations and emphasize the importance of freedom as a condition for the emergence of surprises. Finally, the fourth subsection examines the potential of surprise analysis in addressing the challenge of integrating knowledge in participatory processes and suggests directions for analyzing surprises in game sessions.

Stay or leave? Surprises revealed a paradoxical attachment to the community

The improvisation surprise (type 3) revealed the ideal of finding work outside the community and achieving social advancement. The fact that these events provoked discussion and criticism during the debriefing period is evidence of people's attachment to the community and the desire to live there together. This paradox between family economic strategies of diversification and migration and community attachment revealed by the game is also reported in the literature.

In addition to the difficulties faced by farmers and breeders because of extreme conditions, a phenomenon of fragmentation of agricultural land has been underway since the 1953 Agrarian Reform (Albarracin 2021). This reform has led to very small farms that are no longer big enough to support an entire family. Additionally, rural Andean populations face a shortage of agricultural land because the possibility of purchasing land remains very limited (McDowell and Hess 2012). In response, households are diversifying their sources of income. Some members move abroad, whereas others find work in the city or in mines. In the communities themselves, work opportunities are limited to the processing and sale of food, working as an agricultural laborer, or doing other small jobs, especially if one's own farm does not have sufficient means of production.

Migration can be pendular, temporary, or permanent. Many people have multi-activities and several residences, in town and in the country. Often, the money earned through mobility and multi-activity is not reinvested in the countryside, but rather in children's education or is used to purchase land in the city. "Leaving the village is the ideal sought by the majority of the people who are experiencing upward mobility" (Zoomers 2012). Migration mainly concerns young people, who leave to study and to look for job opportunities (Mazurek 2010, Brandt et al. 2016). This change in lifestyle means migrants often do not return to the communities, switching from being temporary to permanent migrants (Brandt et al. 2016). Rural communities are thus experiencing a slow but certain decline.

However, for many, it is essential to hold onto land in the countryside as a form of security. Sometimes family members who remain in the community fulfill community obligations and look after the migrants' land and livestock. Zoomers (2012:127) summarizes this contradiction very well: "It is striking that the

majority stress that they hope their children will be able to build a life outside the community, but also emphasize the importance of maintaining contact with the community."

The productivity of surprises that emerge during RPG sessions

RPG session: an epistemic mediator at the intersection of experiment and simulation

It is relevant to look at the ability of RPGs to induce productive surprises, as they lie at the intersection of experiments and simulations, which have been at the center of discussions on the value of surprise in science (Morgan 2005, Boumans 2012, Parke 2014, Currie 2018, French and Murphy 2023). Morgan justifies the difference in capacity to surprise between models and experiments by their difference in ontology, which affects the strength of inference from the epistemic mediator to the real world. Models "create an artificial world" whereas experiments "re-create part of the real world in an artificial environment" (Morgan 2005:321). There is a strong parallelism between agent-based models and RPGs. RPGs are a type of agent-based model where agents are real players, a time step is a game turn, the spatial grid is the game board, and a simulation corresponds to a game session (Barreteau 2003). The game session creates an artificial world in which real actors of the SES participate. We consider an RPG session to be a participatory simulation, and hence a hybrid epistemic mediator between simulation and experiment. The debriefing at the end of the game session often draws a parallel between the game and reality (Daré et al. 2020). However, as a result of this hybridity, reality also shines through in game play (Daré 2005). This reality, when it is at odds with the game model (and consequently with that of the researcher-designers) is a source of surprises, and this is why analyzing surprises in a game session is essential for capturing it. However, the different types of surprises identified do not have the same capacity to produce knowledge about the SES.

Productivity of surprises induced by epistemic mediators

Morgan (2005) distinguishes between "surprising results," understood as unexpected, and "confounding results," which are inexplicable results that generate new phenomena and open up new avenues of research. From this perspective, RPGs cannot produce confoundment: surprises do not remain inexplicable because they are discussed with the players. However, Morgan's distinction between surprise and confoundment is questioned. Currie (2018) proposes to focus on "productive surprise," echoed by French and Murphy (2023), who speak of "disruptive surprise." Currie draws on the work of Winsberg (2009) and Parke (2014) to differentiate between the object of study with which researchers interact directly (in our case, the game and the players) and the epistemic aim, the target of the research (here, the SES). Object and target have explanatory resources, which include a set of models, theories, or narratives attached to them. Currie distinguishes two types of surprise apart from phenomenal surprise. An epistemic surprise, when the object's behavior challenges its explanatory resources, and a productive surprise (which goes beyond epistemic surprise) when the explanatory resources needed to explain the object's behavior also explain the target's behavior. In the latter case, researchers feel the need to integrate the surprising result into existing knowledge, which motivates scientific work. In this way, a productive surprise has the capacity to stimulate further research on the target.

In our research, surprises of types one and two are clearly epistemic surprises because they led us to revise the model's assumptions, to modify and correct it. They have the potential to be a productive surprise as they favor the integration of different kinds of knowledge about the SES, thus enabling a better understanding of it. The third type of surprise, on the other hand, can be considered truly productive. In addition to giving us a better understanding of the transitions of the SES, they stimulated further research, in particular bibliographical research to better understand paradoxical attachment to the community. They can lead to a reorientation of the project or motivate future research. Because the analysis of the three types of surprise can produce knowledge about the SES studied, an RPG session can thus surprise in a productive way. However, in order to be interested in surprises and to study them, the surprises must first occur. The following paragraphs address the question of freedom as the main condition for their emergence.

Freedom: the main condition for the emergence of surprises

We advocate for player freedom as the main condition for the emergence of surprises. This freedom is enabled by the design of the game and the facilitator's openness to surprises.

Consideration must be given to the freedom allowed by the game and the flexibility of its rules system that must be easy to modify during game sessions. Lynam et al. (2007) emphasize the importance of having a flexible tool. In order to bring out knowledge about implicit reality and to represent it, the game needs to give players freedom (D'Aquino et al. 2002). Many games are built on actions and objectives to be accomplished, thus limiting playful behaviors and experiences motivated by curiosity and exploration (Hamari and Keronen 2017). We have tried to move away from this type of game by drawing on the self-design modeling approach (D'Aquino et al. 2003, Dolinska 2017). These RPGs are designed to give participants maximum freedom, with no predefined rules or objectives. However, such games can be difficult to play and to facilitate. We therefore sought a balance between control and freedom. In the end, although the first version of *Sumak Kawsay* was less "simple" than we had hoped, the players had no trouble understanding its rules, which they found very close to their reality. Daré and Barreteau (2003) show that players' acceptance of the model as a representation of their reality is necessary for them to bring reality into the game. This suggests that more than the design, it is the acceptance of the game by players as a model of their SES, and the resulting immersion, that encourages the occurrence of surprises.

In addition to the freedom of game design, freedom of speech and the posture of the facilitators also influence the occurrence of surprises. As many authors have pointed out, speech is not free during collective and participatory workshops and events, but constrained by a multitude of micro-expressions of power (Becu et al. 2008, Barnaud and Van Paassen 2013, Wesselow and Stoll-Kleemann 2018). The facilitator can help create a playful space and an atmosphere of trust that is indispensable to free up speech to a certain extent. Furthermore, the facilitator's posture toward surprises requires a balance between openness and adaptation to the unexpected, time management, and respect for the rules of the game.

Morgan comes to the same conclusion regarding the epistemic tools she studies. Her second argument to justify the difference in the ability to surprise between experiment and simulation is the

freedom allowed by the former. Experimental subjects have the freedom to behave in a way that is unexpected by the experimenter. "This is an important consideration in the design of experiments: experiments need to be set up with a certain degree of freedom on the part of participants so that their behavior in the experiment is not totally determined by the theory involved, nor by the rules of the experiment" (Morgan 2005:324). If everything is determined, surprise cannot emerge. A balance between control and freedom is essential to produce productive surprises and thus to the success of an experiment (Currie 2018).

An approach based on the analysis of surprises to meet the challenge of knowledge integration

A central question in the co-design of participatory modeling tools and games is how, during the process, the knowledge and viewpoints of the different participants are considered, discussed, and integrated into the game and into the underlying model. How can the game designer be sure that some knowledge is not implicitly disregarded?

The process of integrating scientific and local knowledge is a challenge for the governance of SES. It offers participants the opportunity to learn from each other, whatever the type of knowledge involved, through dialogue and deliberation (Raymond et al. 2010). These authors raise the questions: Who controls the process of examining the validity and reliability of knowledge? Who is in a position to say which knowledge is valid and which is not? Even when approaching a constructivist epistemological posture, involving heterogeneous participants in a balanced co-design process is a challenge (Le Page and Perrotton 2017). If the game is the expression of the researcher's point of view (Daré and Barreteau 2003), how can participants' point of view be taken into account in the co-design process without risking a hierarchy of knowledge? We argue that identifying surprises and analyzing them systematically can help counter such hierarchy of knowledge.

D'Aquino et al. (2002) distinguish two facets of reality: explicit and implicit reality. Explicit reality encompasses everything that is perceptible, such as stated rules and recognized incentives. Implicit reality, on the other hand, encompasses intangible, sometimes subconscious elements that can also be implicit rules or power struggles. "In this layout, links with reality are into what happens around and outside the rules of the game: in other words, the 'inner game'" (D'Aquino et al. 2002:279). So, if explicit reality constitutes the perceptible and the tangible, both must be represented in the game if they are in line with its objective. Implicit reality remains to be discovered through the study of the unknown, the unexpected, and the overlooked. Lynam et al. (2007) invite us to study and clarify surprising or contradictory results in knowledge integration and stakeholder involvement approaches. This can identify errors in assumptions or provide valuable new information: "We often learn most from investigating surprises" (Lynam et al. 2007:13).

This raises a major challenge: how can we systematically observe surprises? Although our observation protocol for the game sessions included an observer and video or audio recordings, not all player actions and reactions were captured, and some surprises likely went unnoticed. One concrete suggestion for improvement would be to develop an observation protocol specifically tailored to identifying and analyzing surprises, while remaining cost-effective. Such a protocol would enable a deeper exploration of the subjective nature of surprise by examining what is perceived as surprising and by whom. It would also support a cross-perspective approach, incorporating players' own views on the surprises triggered by others' actions: perspectives that could be further explored during the debriefing period. This proposition invites us not only to listen to those who speak loudest, but to those who are out of step. It suggests looking for the gap, the unexpected, the differences in mental models, recognizing them and taking the time to discuss them. We need to use the reality introduced in the game to renegotiate the rules together and improve the model. Improving the model is also a way to improve mutual understanding of the SES under study.

This approach presents a second major challenge: it requires researchers to remain open to unexpected directions, which may fall outside their area of expertise or the original scope of the project, and this involves a certain degree of risk. For instance, although our project initially focused on agriculture and livestock breeding, the analysis of surprises led us to explore themes such as migration and community attachment, topics rooted more in sociology than agronomy.

CONCLUSION

Our objective was to understand to what extent the analysis of surprises in an RPG session reveals key mechanisms of the SES under study, which is sometimes difficult for researcher-designers themselves to tackle. We demonstrated that the analysis of surprises can produce knowledge about the SES studied, and that an RPG session can thus surprise in a productive way. But the three types of surprise we identified do not have the same capacity to produce knowledge. Whereas the first two types of surprises are epistemic surprises and must be taken into consideration in order to co-design the game and improve the underlying model, the improvisation surprises (type three) are truly productive, revealing a paradoxical attachment by the players to their community, between family economic strategies of diversification and migration, and community obligations, participation, and investment. This complex relationship between the individual and the collective reveals a lack of community cohesion that would have been difficult to understand through individual interviews. Faced with such surprises, modification of the rules after discussion and negotiation with and among the players themselves are necessary for real co-construction of the game and for fostering knowledge integration. The main condition for the appearance of surprises is the freedom allowed to players by the game design and the facilitation. Even if analysis of surprises in the RPG session provides valuable knowledge, it is necessary to triangulate data and cross-check information from the game session with real-world surveys and literature. Finally, the analysis of surprises in an RPG session is fully in line with our inductive posture of knowledge production, constructivist epistemology, and grounded theory approach.

This study underlines the need for a game to envision the territory's future and address rural exodus, aiming to create a shared community vision. The co-design method will continue mobilizing the game to explore the future of the commons in the Indigenous Andean peasant community. Previous sessions indicated the significance of commons, prompting further investigation to aid local actors in future territorial planning.

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Data Availability:

The data and code that support the findings of this study are available on request from the corresponding author, LN. None of the data and code are publicly available because they contain information that could compromise the privacy of research participants.

LITERATURE CITED

Abrami, G., and N. Becu. 2021. Concevoir et utiliser des jeux de rôle pour la gestion de l'eau et des territoires. Sciences Eaux & Territoires 35(1):46-53. https://doi.org/10.3917/set.035.0046

Adler, J. E. 2008. Surprise. Educational Theory 58(2):149-173. https://doi.org/10.1111/j.1741-5446.2008.00282.x

Albarracin, J. 2021. Las políticas públicas y la agricultura: análisis histórico de sus efectos en la estructura del sistema alimentario de Bolivia. Pages 215-240 in J.-F. Le Coq, C. Grisa, S. Guéneau, and P. Niederle, editors. Políticas Públicas y Sistemas Alimentarios en América Latina. Editora E-papers, Rio de Janeiro, Brasil.

Albó, X. 1985. La paradoja aymara o Desafios de la solidaridad aymara. Centro de Investigación y Promoción de Campesinado, La Paz, Bolivia.

Aquino, L. Q., and J. B. Yùgar. 2008. Educación Técnica Agropecuaria de Jóvenes y Adultos : Producción pecuaria - Aera técnica y technológica - Nivel Técnico Medio. Comisión Episcopal de educación y Red FERIA, Oruro, Bolivia. http://www.redferia.org.bo/w/wp-content/uploads/2019/04/OruroPecuaria.pdf

Baras, D., and O. Na'aman. 2022. What makes something surprising? Philosophy and Phenomenological Research 105 (1):195-215. https://doi.org/10.1111/phpr.12820

Barnaud, C., and A. Van Paassen. 2013. Equity, power games, and legitimacy: dilemmas of participatory natural resource management. Ecology and Society 18(2):21. https://doi.org/10.5751/ES-05459-180221

Barreteau, O., M. Antona, P. D'Aquino, S. Aubert, S. Boissau, F. Bousquet, W. Daré, M. Etienne, C. Le Page, R. Mathevet, G. Trebuil, and J. Weber. 2003a. Our companion modelling approach. Journal of Artificial Societies and Social Simulation 6 (2):1. https://jasss.soc.surrey.ac.uk/6/2/1.html

Barreteau, O. 2003. The joint use of role-playing games and models regarding negotiation processes: characterization of associations. Journal of Artificial Societies and Social Simulation 6(2):3. https://www.jasss.org/6/2/3.html

Barreteau, O., P. Bots, K. Daniell, M. Etienne, P. Perez, C. Barnaud, D. Bazile, N. Becu, J. -C. Castella, W. Daré, and G. Trebuil. 2013. Participatory approaches. Pages 197-234 in B. Edmonds and R. Meyer, editors. Simulating social complexity: a handbook. Springer, Berlin, Germany. https://doi.org/10.1007/978-3-540-93813-2_10

Barreteau, O., C. Le Page, and P. D'Aquino. 2003b. Role-playing games, models and negotiation processes. Journal of Artificial Societies and Social Simulation 6(2):10. http://jasss.soc.surrey.ac.uk/6/2/10.html

Becu, N., A. Neef, P. Schreinemachers, and C. Sangkapitux. 2008. Participatory computer simulation to support collective decision-making: potential and limits of stakeholder involvement. Land Use Policy 25(4):498-509. https://doi.org/10.1016/j.landusepol.2007.11.002

Bommel, P. 2009. Définition d'un cadre méthodologique pour la conception de modèles multi-agents adaptée à la gestion des ressources renouvelables. Dissertation. Université Montepellier II, France. https://theses.hal.science/tel-00396803v3

Boumans, M. 2012. Mathematics as quasi-matter to build models as instruments. Pages 307-318 in D. Dieks, W. Gonzalez, S. Hartmann, M. Stöltzner, M. Weber, editors. Probabilities, laws, and structures. Springer, Dordrecht, Netherlands. https://doi.org/10.1007/978-94-007-3030-4_22

Bousquet, F., G. Trebuil, and B. Hardy. 2005. Companion modeling and multi-agent systems for integrated natural resource management in Asia. International Rice Research Institute, Los Baños, Philippines.

Brandt, R., R. Kaenzig, and S. Lachmuth. 2016. Migration as a risk management strategy in the context of climate change: evidence from the Bolivian Andes. Pages 43-61 in A. Milan, B. Schraven, K. Warner, N. Cascone, R. Brandt, R. Kaenzig, S. Lachmuth, editors. Migration, risk management and climate change: evidence and policy responses. Springer, Cham, Switzerland. https://doi.org/10.1007/978-3-319-42922-9_3

van Bruggen, A., I. Nikolic, and J. Kwakkel. 2019. Modeling with stakeholders for transformative change. Sustainability 11(3):825. https://doi.org/10.3390/su11030825

Calizaya, A. T. 2009. Water resources management efforts for best water allocation in the Lake Poopó Basin, Bolivia. Dissertation. Department of Water Resources Engineering, Lund University, Sweden.

Canedo, M. E., and N. Tassi. 2021. "Una pata en la chacra y una en el mercado". La reconfiguración de la economía campesina en La Paz. Cahiers des Amériques latines (96):105-127. https://doi.org/10.4000/cal.12685

Canedo-Rosso, C., S. Hochrainer-Stigler, G. Pflug, B. Condori, and R. Berndtsson. 2021. Drought impact in the Bolivian Altiplano agriculture associated with the El Niño-Southern Oscillation using satellite imagery data. Natural Hazards and Earth System Sciences 21(3):995-1010. https://doi.org/10.5194/nhess-21-995-2021

Carr, G., G. Blöschl, and D. P. Loucks. 2012. Evaluating participation in water resource management: a review. Water Resources Research 48:W11401. https://doi.org/10.1029/2011WR011662

Currie, A. 2018. The argument from surprise. Canadian Journal of Philosophy 48(5):639-661. https://doi.org/10.1080/00455091.-2017.1368860

D'Aquino, P., O. Barreteau, M. Etienne, S. Boissau, and S. Aubert. 2002. The role playing games in an ABM participatory modeling process: outcomes from five different experiments carried out in the last five years. Pages 275-280 in A. E. Rizzoli, and A. J. Jakeman, editors. Proceedings of the International Environmental Modelling and Software Society Conference, 24-27 June 2002, Lugano, Switzerland.

D'Aquino, P., C. Le Page, F. Bousquet, A. Bah. 2003. Using self-designed role-playing games and a multi-agent system to empower a local decision-making process for land use management: the SelfCormas experiment in Senegal. Journal of Artificial Societies and Social Simulation 6(3):5. https://jasss.soc.surrey.ac.uk/6/3/5.html

Daré, W. 2005. Stakeholders' behaviors in play and reality : independence or correspondence ? Sociological analysis of the use of role-playing game to support negotiation process. Dissertation. École nationale du génie rural, des eaux et des forêts (ENGREF)- AgroParisTech, Paris, France. https://pastel.archives-ouvertes.fr/tel-00452429

Daré, W., R. Ducrot, A. Botta, M. Etienne. 2009. Repères méthodologiques pour la mise en oeuvre d'une démarche de modélisation d'accompagnement. Cardère éditeur, Avignon, France. http://agritrop.cirad.fr/572498/

Daré, W., A. Van Paassen, R. Ducrot, R. Mathevet, J. Queste, G., Trébuil, C. Barnaud, and E. Lagabrielle. 2010. Learning about interdependencies and dynamics. Pages 233-262 in M. Étienne, editor. Companion modelling: a participatory approach to support sustainable development. Springer, Dordrecht, Netherlands. https://doi.org/10.1007/978-94-017-8557-0_10

Daré, W., and O. Barreteau. 2003. A role-playing game in irrigated system negotiation: between play and reality. Journal of Artificial Societies and Social Simulation 6(3):6. https://jasss.soc.surrey.ac.uk/6/3/6.html

Daré, W., E. Hassenforder, and A. Dray. 2020. Observation manual for collective serious games. CIRAD-ComMod Association, Montpellier, France. https://agritrop.cirad.fr/597391/

Dolinska, A. 2017. Bringing farmers into the game. Strengthening farmers' role in the innovation process through a simulation game, a case from Tunisia. Agricultural Systems 157:129-139. https://doi.org/10.1016/j.agsy.2017.07.002

Dulphy, J., B. Carle, C. Demarquilly, L. L'Hôtelier, G. Moins, A. Ollier. 1990. Quantités ingérées et activités alimentaires comparées des ovins, bovins et caprins recevant des fourrages conservés avec ou sans aliment concentré. I. Etude descriptive. Annales de Zootechnie 39(2):95-111. https://doi.org/10.1051/animres:19900202

Edmonds, B. and S. Moss. 2005. From KISS to KIDS-an 'anti-simplistic' modelling approach. Pages 130-144 in P. Davidsson, B. Logan, K. Takadama, editors. Multi-agent and multi-agent-based simulation. Joint Workshop MABS 2004, New York, New York, USA. Lecture Notes in Computer Science 3415. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-32243-6_11

Edwards, P., L. Sharma-Wallace, A. Wreford, L. Holt, N. A. Cradock-Henry, S. Flood, and S. J. Velarde. 2019. Tools for adaptive governance for complex social-ecological systems: a review of role-playing-games as serious games at the community-policy interface. Environmental Research Letters 14(11). https://doi.org/10.1088/1748-9326/ab4036

Étienne, M. 2014. Companion modelling: a participatory approach to support sustainable development. Springer, Dordrecht, Netherlands. https://doi.org/10.1007/978-94-017-8557-0

Foster, M. I., and M. T. Keane. 2019. The role of surprise in learning: different surprising outcomes affect memorability differentially. Topics in Cognitive Science 11(1)75-87. https://doi.org/10.1111/tops.12392

French, M., N. Alem, S. J. Edwards, E. Blanco Coariti, H. Cauthin, K. A. Hudson-Edwards, K. Luyckx, J. Quintanilla, and O. Sánchez Miranda. 2017. Community exposure and vulnerability to water quality and availability: a case study in the mining-affected Pazña Municipality, Lake Poopó Basin, Bolivian Altiplano. Environmental Management 60(4):555-573. https://doi.org/10.1007/s00267-017-0893-5

French, S., and A. Murphy. 2023. The value of surprise in science. Erkenntnis 88(4):1447-1466. https://doi.org/10.1007/s10670-021-00410-z

Garrido, A. E., and W. H. J. Strosnider, R. T. Wilson, J. Condori, and R. W. Nairn. 2017. Metal-contaminated potato crops and potential human health risk in Bolivian mining highlands. Environmental Geochemistry and Health 39(3):681-700. https://doi.org/10.1007/s10653-017-9943-4

Glaser, B. G. and A. L. Strauss. 1967. The discovery of grounded theory: strategies for qualitative research. Aldine Transaction, New Jersey, USA. https://doi.org/10.4324/9780203793206

Goldstein, B. 2009. Resilience to surprises through communicative planning. Ecology and Society 14(2):33. https://doi.org/10.5751/ES-03074-140233

Grimm, V., E. Revilla, U. Berger, F. Jeltsch, W. M. Mooij, S. F. Railsback, H.-H. Thulke, J. Weiner, T. Wiegand, and D. L. DeAngeliset. 2005. Pattern-oriented modeling of agent-based complex systems: lessons from ecology. Science 310 (5750):987-991. https://doi.org/10.1126/science.1116681

Hamari, J., and L. Keronen. 2017. Why do people play games? A meta-analysis. International Journal of Information Management 37(3):125-141. https://doi.org/10.1016/j.ijinfomgt.2017.01.006

Hervé, D., and A. Rojas. 1994. Vias de intensificacion de la ganaderia bovina en el Altiplano Boliviano. Instituto Francés de Investigacion Cientifica para el Desarrollo en Cooperación, La Paz, Bolivia.

Holling, C. S. 1996. Surprise for science, resilience for ecosystems, and incentives for people. Ecological Applications 6(3):733-735. https://doi.org/10.2307/2269475

Jordan, R., S. Fray, M. Zellner, P. D. Glynn, A. Voinov, B. Hedelin, E. J. Hedelin, K. Leong, L. S. Olabisi, K. Hubacek, et al. 2018. Twelve questions for the participatory modeling community. Earth's Future 6(8):1046-1057. https://doi.org/10.1029/2018EF000841

Le Gouill, C., and F. Poupeau. 2019. IX. Le commun à l'épreuve des communautés andines. Éléments pour une analysedes formes d'auto-organisation communautaires. Pages 139-150 in C. Laval, P. Sauvêtre, and F. Taylan, editors. L'alternative du commun. Hermann, Paris, France. https://doi.org/10.3917/herm.laval.2019.01.0141

Le Page, C. 2017. Simulation multi-agent interactive: engager des populations locales dans la modélisation des socio-écosystèmes pour stimuler l'apprentissage social. Habilitation à diriger des recherches. Sorbonne Université, Paris, France.

Le Page, C., and A. Perrotton. 2017. KILT: a modelling approach based on participatory agent-based simulation of stylized socio-ecosystems to stimulate social learning with local stakeholders. Pages 156-169 in G. Sukthankar, and J. Rodriguez-Aguilar, editors. Autonomous Agents and Multiagent Systems. International Workshop on Multi-Agent Systems and Agent-Based Simulation 2017, São Paulo, Brasil. Lecture Notes in Computer Science 10643. Springer, Cham, Switzerland. https://doi.org/10.1007/978-3-319-71679-4_3

Lima-Quispe, N., M. Escobar, A. J. Wickel, M. von Kaenel, D. Purkey. 2021. Untangling the effects of climate variability and irrigation management on water levels in Lakes Titicaca and Poopó. Journal of Hydrology: Regional Studies 37:100927. https://doi.org/10.1016/j.ejrh.2021.100927

Longstaff, P., and S.-U. Yang. 2008. Communication management and trust: their role in building resilience to "surprises" such as natural disasters, pandemic flu, and terrorism. Ecology and Society 13(1):3. https://doi.org/10.5751/ES-02232-130103

Lynam, T., W. de Jong, D. Sheil, T. Kusumanto, and K. Evans. 2007. A review of tools for incorporating community knowledge, preferences, and values into decision making in natural resources management. Ecology and Society 12(1):5. https://doi.org/10.5751/ES-01987-120105

Mazurek, H. 2010. L'impact territorial du vieillissement en Bolivie : un problème structurel. Autrepart 53(1):35-56. https://doi.org/10.3917/autr.053.0035

McDaniel, R. R. J., M. E. Jordan, and B. F. Fleeman. 2003. Surprise, surprise, surprise! A complexity science view of the unexpected. Health Care Management Review 28(3):266-278. https://doi.org/10.1097/00004010-200307000-00008

McDowell, J. Z., and J. J. Hess. 2012. Accessing adaptation: multiple stressors on livelihoods in the Bolivian highlands under a changing climate. Global Environmental Change 22(2):342-352. https://doi.org/10.1016/j.gloenvcha.2011.11.002

Mermet, L. 1992. Stratégies pour la gestion de l'environnement: la nature comme jeu de société?. L'Harmattan, Paris, France.

Michael, D., and S. Chen. 2005. Serious games: games that educate, train and inform. Thomson Course Technology PTR, Boston, Massachusetts, USA.

Miller, C. R. 2015. Surprise: the poetics of the unexpected from Milton to Austen. Cornell University Press, Ithaca, New York, USA. https://doi.org/10.7591/9780801455780

Modirshanechi, A., J. Brea, and W. Gerstner. 2022. A taxonomy of surprise definitions. Journal of Mathematical Psychology 110:102712. https://doi.org/10.1016/j.jmp.2022.102712

Mohan, G. 2001. Beyond participation: strategies for deeper empowerment. Pages 153-167 in B. Cooke and U. Kothari, editors. Participation: the new tyranny? Zed Books, London, UK.

Morgan, M. S. 2003. Experiments without material intervention: model experiments, virtual experiments, and virtually experiments. Pages 216-235 in H. Radder, editor. The philosophy of scientific experimentation. University of Pittsburgh Press, Pittsburgh, Pennsylvania, USA. https://doi.org/10.2307/j.ctt5hjsnf.15

Morgan, M. S. 2005. Experiments versus models: new phenomena, inference and surprise. Journal of Economic Methodology 12(2):317-329. https://doi.org/10.1080/13501780500086313

Mucchielli, A. 1983. Les jeux de rôles. Presses Universitaires de France, Paris, France.

Munnich, E. L., M. I. Foster, and M. T. Keane. 2019. Editors' introduction and review: an appraisal of surprise: tracing the threads that stitch it together. Topics in Cognitive Science 11:37-49. https://doi.org/10.1111/TOPS.12402

Ostrom, E. 1990. Governing the commons: the evolution of institutions for collective action. Cambridge University Press, Cambridge, UK. https://doi.org/10.1017/CBO9780511807763

Parke, E. C. 2014. Experiments, simulations, and epistemic privilege. Philosophy of Science 81(4):516-536. https://doi.org/10.1086/677956

Perreault, T. 2020. Climate change and climate politics: parsing the causes and effects of the drying of Lake Poopó, Bolivia. Journal of Latin American Geography 19(3):26-46. https://doi.org/10.1353/lag.2020.0070

Piaget, J., and B. Inhelder. 1967. La psychologie de l'enfant. Presses Universitaires de France, Paris, France.

Pillco Zolá, R., and L. Bengtsson. 2006. Long-term and extreme water level variations of the shallow Lake Poopó, Bolivia. Hydrological Sciences Journal 51(1):98-114. https://doi.org/10.1623/hysj.51.1.98

Piveteau, V. 1994. L'avenir à long terme des zones rurales fragiles apport des jeux de prospective à la réflexion stratégique. Économie rurale 222:46. https://doi.org/10.3406/ecoru.1994.4958

Raymond, C. M., I. Fazey, M. S. Reed, L. C. Stringer, G. M. Robinson, and A. Evely. 2010. Integrating local and scientific knowledge for environmental management. Journal of Environmental Management 91(8):1766-1777. https://doi.org/10.1016/j.jenvman.2010.03.023

Reiter, B. 2013. The epistemology and methodology of exploratory social science research: crossing Popper with Marcuse. Government and International Affairs Faculty Publications (99). https://digitalcommons.usf.edu/gia_facpub/99

Sandu, A. 2018. Constructionist grounded theory - GT. Conceptual and methodological clarifications. Revista Romaneasca pentru Educatie Multidimensionala 10(1):183-209. https://doi.org/10.18662/rrem/28

Torres-Batlló, J., B. Martí-Cardona, and R. Pillco-Zolá. 2020. Mapping evapotranspiration, vegetation and precipitation trends in the catchment of the shrinking Lake Poopó. Remote Sensing 12(1):73. https://doi.org/10.3390/rs12010073

van der Spek, E. D., H. van Oostendorp, and J.-J. C. Meyer. 2013. Introducing surprising events can stimulate deep learning in a serious game. British Journal of Educational Technology 44 (1):156-169. https://doi.org/10.1111/j.1467-8535.2011.01282.x

Vieira Pak, M. 2012. Le boom de la quinoa dans l'Altiplano sud de la Bolivie : bouleversement du système agraire, discours et tensions socio-environnementale. Dissertation. AgroParisTech - Science agronomique et de l'environnement, Paris, France. https://pastel.archives-ouvertes.fr/tel-01077876

Voinov, A., and F. Bousquet. 2010. Modelling with stakeholders. Environmental Modelling & Software 25(11):1268-1281. https://doi.org/10.1016/j.envsoft.2010.03.007

Weick, K., and K. Sutcliffe. 2007. Managing the unexpected resilient performance in an age of uncertainty. Wiley & Sons, San Francisco, California, USA.

Wesselow, M., and S. Stoll-Kleemann. 2018. Role-playing games in natural resource management and research: lessons learned from theory and practice. Geographical Journal 184(3):298-309. https://doi.org/10.1111/geoj.12248

Whitt, C. 2022. From flooded fields to a vanished lake: the politics of broken water cycles in the Bolivian Altiplano. Geoforum 181:243-251. https://doi.org/10.1016/j.geoforum.2018.03.009

Winsberg, E. 2009. A tale of two methods. Synthese 169 (3):575-592. https://doi.org/10.1007/s11229-008-9437-0

Wouters, P., H. van Oostendorp, J. ter Vrugte, S. vanderCruysse, T. de Jong, and J. Elen. 2017. The effect of surprising events in a serious game on learning mathematics. British Journal of Educational Technology 48(3):860-877. https://doi.org/10.1111/bjet.12458

Yourstone, S. A., and H. L. Smith. 2002. Managing system errors and failures in health care organizations: suggestions for practice and research. Health Care Management Review 27(1):50-61. https://doi.org/10.1097/00004010-200201000-00005

Zhonggen, Y. 2019. A meta-analysis of use of serious games in education over a decade. International Journal of Computer Games Technology 2019:4797032. https://doi.org/10.1155/2019/4797032

Zoomers, A. 2012. Migration as a failure to adapt? How Andean people cope with environmental restrictions and climate variability. Global Environment 5(9):104-129. https://doi.org/10.3197/ge.2012.050905

CO-DESIGN PROCESS OF *SUMAK KAWSAY*

When talking about co-design in participatory modeling, it is often the conceptual model that is co-constructed (Barreteau et al. 2003, Becu 2020, Le Page et al. 2014), but not the operational one - for example a role-playing game (RPG) (Souchère et al. 2010) or an agent-based model (ABM) (Zellner 2008). Etienne et al. (2011) proposed the ARDI method, so named because it involves defining the actors (A), resources (R), dynamics (D) and interactions (I) that make up the system in a given context around a question that is chosen collectively. The ARDI method is widely used in the co-design of ABMs and RPGs in the ComMod community. The conceptual model of the system, built collectively and shared, serves as a basis for the researchers to implement the operational model. A few other co-design methods are described in the literature. Daré et al. (2018) designed an RPG and an ABM based on participatory mapping workshops with a variety of watershed stakeholders. Becu (2006) used individual interviews with farmers, each of which is formalized in an object-oriented diagram, then validated with the respondent through a "playable stories" workshop during which the respondent reconstructs his or her model. These diagrams are then used to code the behavior of the agents in the ABM, while taking the stakeholders' different representations into account. Bommel et al. (2014) co-designed an ABM directly with cattle farmers using executable UML diagrams. However, the literature mainly discusses the importance of early co-design of the simulation model (Le Page and Perrotton 2017) and of the iterative co-conception process between field, conceptualization and implementation – local actors and stakehoslders rarely being included in the last step (Barreteau et al. 2014, D'Aquino et al. 2002). In the ComMod community, but also more broadly in participatory modeling and serious gaming, few works detail the co-design and co-construction process of the operational model in a participatory workshop (Gugerell and Zuidema 2017, Halbe 2019).

This is why we propose the first version of a game directly to local stakeholders (V1) as a draft to initiate the co-design process. The final version of the game was thus designed in two stages: the design of a playable draft by the researchers, and co-design proper, where the game is proposed to local stakeholders and modified with them during participatory workshops and by the research team only between two workshops, as detailed in the following figure (3).

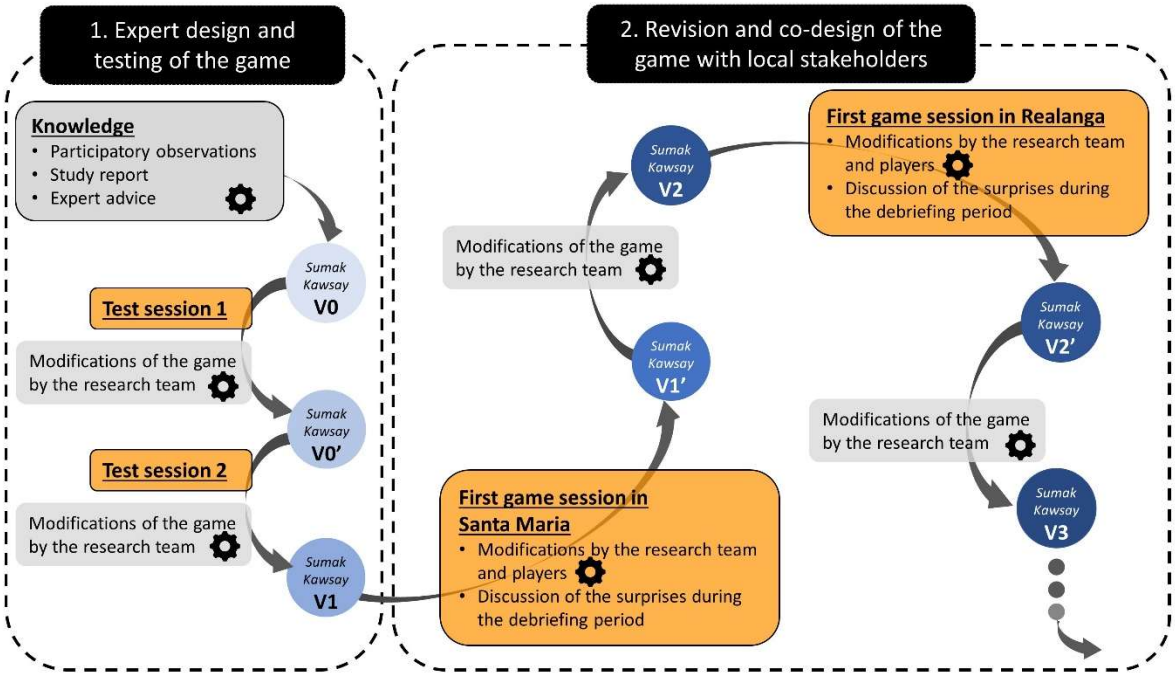

Fig. 3. From experts' to local stakeholders' design of the *Sumak Kawsay* game

In the first step, the initial version of the game (V0) was designed by researchers based on knowledge gathered during participatory observations, from study reports and advice from experts. V0 was tested during a game session with the partner NGO, and improved based on their feedback, (for example, we added a bank loan mechanism and the possibility to buy a barn to store fodder from one year to the next, and removed the indicator tracking sheet that players had to fill in) which resulted in version V0'. V0' was tested with the Technical University of Oruro, and improved based on their feedback, this resulted in V1 (mainly aimed at recalibrating the game's difficulty). In the second step, the real co-design process started using V1. During each game session, surprises that occurred during the game were discussed directly whenever possible, and the game was immediately modified accordingly. V1 thus evolved into V1' as the game changed, for example, by adding a rule specifying that a barn can be purchased by a maximum of two player co-owners. Table 1 lists some examples of the surprises that occurred during the game sessions. When the changes proposed were too complex to be considered during the game itself, or were only discussed during the debriefing period, modifications were made by the research team in preparation for the following game session, turning V1' into V2, and so on, over the remaining three sessions.

LITERATURE CITED

Barreteau, O., M. Antona, P. D'Aquino, S. Aubert, S. Boissau, F. Bousquet, W. Daré, M. Etienne, C. Le Page, R. Mathevet, G. Trebuil, and J. Weber. 2003. Our companion modelling

approach. Journal of Artificial Societies and Social Simulation 6(2):1. https://jasss.soc.surrey.ac.uk/6/2/1.html

Barreteau, O., F. Bousquet, M. Étienne, V. Souchère, and P. d'Aquino. 2014. Companion Modelling: A Method of Adaptive and Participatory Research. Pages 13–40 in M. Étienne, editor. Companion Modelling: A Participatory Approach to Support Sustainable Development. Springer, Dordrecht, Netherlands. https://doi.org/10.1007/978-94-017-8557-0_2

Becu, N. 2020. Les courants d'influence et la pratique de la simulation participative : contours, design et contributions aux changements sociétaux et organisationnels dans les territoires. Habilitation à diriger des recherches. La Rochelle Université, La Rochelle. https://hal.science/tel-02515352

Becu, N. 2006. Identification et modélisation des représentations des acteurs locaux pour la gestion des bassins versants. PhD Thesis. Sciences de l'environnement. Université Montpellier II, Montpellier, France. https://hal.inrae.fr/tel-02587869

Bommel, P., F. Dieguez, D. Bartaburu, E. Duarte, E. Montes, M. Pereira Machin, J. Corral, J. Pereira de Lucena, and H. Morales Grosskopf. 2014. A Further Step Towards Participatory Modelling. Fostering Stakeholder Involvement in Designing Models by Using Executable UML. Journal of Artificial Societies and Social Simulation 17(1):6. https://www.jasss.org/17/1/6.html

D'Aquino, P., O. Barreteau, M. Etienne, S. Boissau, and S. Aubert. 2002. The Role Playing Games in an ABM Participatory Modeling Process: Outcomes from Five Different Experiments Carried out in the Last Five Years. Pages 275-280 in A. E. Rizzoli, and A. J. Jakeman, editors. Proceedings of the International Environmental Modelling and Software Society Conference, 24-27 June 2002, Lugano, Switzerland.

Daré, W., J. -P. Venot, C. Le Page, and A. Aduna. 2018. Problemshed or Watershed? Participatory Modeling towards IWRM in North Ghana. Water 10(6):721. https://doi.org/10.3390/w10060721

Étienne, M., D. Du Toit, and S. Pollard. 2011. ARDI: A Co-construction Method for Participatory Modeling in Natural Resources Management. Ecology and Society 16(1):44. https://doi.org/10.5751/ES-03748-160144

Gugerell, K., and C. Zuidema. 2017. Gaming for the energy transition. Experimenting and learning in co-designing a serious game prototype. Journal of Cleaner Production, Experimentation for climate change solutions 169:105-116. https://doi.org/10.1016/j.jclepro.2017.04.142

Halbe, J. 2019. Participatory modelling in sustainability transitions research. Pages 182-206 in E. A. Moallemi, and F. J. de Haan. Modelling Transitions. Routledge, London, UK.
Le Page, C., G. Abrami, O. Barreteau, N. Becu, P. Bommel, A. Botta, A. Dray, C. Monteil, and V. Souchère. 2014. Models for Sharing Representations. Pages 69-101 in M. Étienne, editor. Our Companion : A Participatory Approach to Support Sustainable Development. Springer, Dordrecht, Netherlands. https://doi.org/10.1007/978-94-017-8557-0_4

Le Page, C. and A. Perrotton. 2017. KILT: a modelling approach based on participatory agent-based simulation of stylized socio-ecosystems to stimulate social learning with local stakeholders. Pages 156-169 in G. Sukthankar, and J. Rodriguez-Aguilar, editors. Autonomous Agents and Multiagent Systems. International Workshop on Multi-Agent Systems and Agent-Based Simulation 2017, São Paulo, Brasil. Lecture Notes in Computer Science 10643. Springer, Cham, Switzerland. https://doi.org/10.1007/978-3-319-71679-4_3

Souchère, V., L. Millair, J. Echeverria, F. Bousquet, C. Le Page, and M. Etienne, M., 2010. Co-constructing with stakeholders a role-playing game to initiate collective management of erosive runoff risks at the watershed scale. Environmental Modelling & Software 25(11):1359–1370. https://doi.org/10.1016/j.envsoft.2009.03.002

Zellner, M. L. 2008. Embracing Complexity and Uncertainty: The Potential of Agent-Based Modeling for Environmental Planning and Policy. Planning Theory & Practice 9(4):437–457. https://doi.org/10.1080/14649350802481470