Simulation games as a catalyst for social learning: The case of the water-food-energy nexus game

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Abstract

Role-playing simulations have gained in popularity in recent years as a novel method of engaging researchers and stakeholders in a variety of social and environmental issues. While academic interest has grown on this topic, knowledge remains sparse on the underlying theories that may guide the design of such games. This article provides a game design framework built on the concepts of social learning and procedural rhetoric. We describe and discuss the conceptual basis for our framework, giving a detailed account of its application through the recently developed the Water–Food–Energy Nexus Game (Nexus Game) as an example. We illustrate the process involved in designing the Nexus Game through initial scoping, prototyping, and design decisions, and how game structure and debriefing have been crafted to foster social learning focused on the understanding of the underlying social-ecological system as well as fostering collaboration between stakeholders. We also provide preliminary discussion of qualitative data collected during recent gaming sessions across three continents to evaluate the Nexus Game's potential learning effects.

Keywords: Role-playing simulation (RPS), social learning, procedural rhetoric, water–energy–food nexus, Nexus Game

1. Introduction

The recent years has seen a shift toward greater research engagement with stakeholders for the study of global change and new modes of research such as citizen science (Weichselgartner and Kasperson 2010; Mauser et al. 2013; Cornell et al. 2013; Fazey et al. 2014; Coleman et al. 2017; Fazey et al. 2018) and knowledge co-production (Norström et al. 2020). Within this greater trend, role-playing simulations (also referred to as "serious games" or "policy exercises") have regained popularity in recent years as a way of involving citizens in active research (Stefanska et al. 2011; Schenk and Susskind 2014; Rumore et al. 2016; Mochizuki et al. 2018) and to motivate social learning, Reed at al. (2010) define social learning as "a change in understanding that goes beyond the individual to become situated within wider social units or communities of practice through social interactions between actors within social networks". Social learning is increasingly seen as crucial to achieving sustainability in the context of global change characterized by high levels of uncertainty and ambiguity (Berkhout 2002; Wals and Rodela 2014; Tschakert et al. 2016; Coleman 2017; Rodela and Swartling 2019).

Various forms of interactive games have been used for decades to address complex global environmental problems (Abt 1970; Parson 1996 a,b,c; Olsson 2001; van Asselt Marjolein and Rijkens-Klomp 2002; Costanza et al. 2014; Stanitsas et al. 2019), the focus of our article is its subset, namely "simulation role-playing games" which facilitate social learning. As the term "role play" signifies, such games expose players to rich contexts within which social and environmental issues arise. (Kimmich et al. 2019). The term "simulation" signifies the simulation of real-world situations, in which players learn of the consequences of their individual or collective decisions. Such simulations, in contrast to the mainstream entertainment games, more often forfeit the "winning rule" to make place for individual reflection and self-assessment. The use of games for social learning further signifies that such reflection and learning are intended to be shared widely through networks of actors across diverse communities of practice (Reed et al. 2010; Kristjanson 2013). Simulation games are used for stakeholder engagement in wide-ranging topics such as climate change mitigation, adaptation, disaster risk reduction, sustainable forest management, and tourism, to name just a few (Castella et al. 2005; Krolikowska et al. 2007; Stefanska et al. 2011; de Suarez et al. 2012; Susskind and Rumore 2013; Jones et al. 2014; Hassenforder et al. 2015; Schenk and Susskind 2014; Rumore et al. 2016; Salvini 2016; Villamor and Badmos 2016; Magnuszewski et al. 2018; Mochizuki et al. 2018) and this trend will likely continue in the foreseeable future.

While the interest of academics and practitioners on the use of such games has grown significantly, existing theories and frameworks for game development give limited insights on how one may design them. For example, existing game design frameworks give guidance on designing systems that players can interact with, and, in turn, experience a particular emotional response intended by the designer (see e.g. Hunicke et al. 2004). Yet, they give little guidance on how one could effectively represent the complex environmental and social feedbacks or how one may design effective facilitation and feedback processes to bring about the most effective social learning experience. In essence, they give little guidance on how one could stay focused on the ultimate goal of social learning amid a plethora of design options that emerge through brainstorming and prototyping sessions.

This study hence proposes a new CompleCSus (Complexity-Collaboration-Sustainability) simulation game design framework for social learning on complex sustainability challenges, and explains how we applied it to our recent design experience of the Water–Food–Energy Nexus Game (hereafter, Nexus Game)." This article clarifies guiding concepts that define the role a game may play in facilitating social learning for complex socio-ecological problems and detailed design principles and constraints that allow us to carefully plan and implement gaming mechanics and application (including introduction, gameplay, and debriefing sessions), which has then been tested and evaluated through the recent game plays implemented over 14 countries.

The Nexus Game was chosen as an example because of its embedded linkages across and within different social and natural systems that are common to many sustainability issues that our generation faces. The game was initially developed at the request of Sustainable Energy for All (SE4ALL) (http://www.se4all.org/) and the UNDP-CAPNET initiative (http://www.cap-net.org/) and later adapted to various contexts for a number of diverse organizations and groups.
At the heart of the Nexus Game are two interrelated issues: (1) how the complexity of a highly interconnected socio-ecological system leads to uncertainty and management surprises, and (2) how issue framing and conflicting values and worldviews affect alternative individual and collective actions. It is precisely these multiple dimensions that pose significant design challenges for game design. Our framework offers guidance on how to overcome these challenges through the appreciation of social learning (Parson and Clark 1995) informed by the concept of procedural rhetoric (Bogost 2008). Together with the pragmatic understanding of design needs and constraints, it guides the choice of particular mechanisms and the mode of facilitation that nurtures collective reflection.

The ideas expressed in this study are by no means the only way to design simulation games. Clarifying why we make the design choices we make, and documenting the learning effects observed empirically however, allows us to contribute to the building of systematic knowledge on the use of simulation games as a method to foster social learning. We describe and discuss how our framework informed the particular choice of game format and mechanisms. We also provide first stage evaluation of social learning as self-reported by participants of several Nexus Game sessions.

The remainder of this article is organized as follows. Section 2 describes the CompleCSus design framework based on the concepts of social learning and procedural rhetoric with its associated practices. Section 3 then describes how this framework was adopted in the design of the Nexus Game. Section 4 provides an analysis of data collected during recent gameplays to highlight the potential learning effect of the Nexus Game. This is followed by Section 5 on discussions and conclusions.

2. Designing Role-Playing Simulation Games

2.1. State of the art of game design frameworks

A plethora of design frameworks are available for the development of simulation games (Braad et al. 2016). These frameworks may be broadly categorized to those clarifying distinct (and often iterative) phases of game development (Molenda 2003; Kirkley et al. 2005; de Suarez et al. 2012) and those guiding foundational conceptualization of various design-related concerns such as how one may understand the relationships among designer's (or researcher's) intent, game mechanisms and end-user interpretation (Hunicke et al. 2004; Gunter et al. 2006; Kiili 2005; Winn 2009; Aleven et al. 2010; Dillon 2013) and various trade-offs and tensions inherent in making design choices (Harteveld 2011; Rooney 2012). Of particular interest to this research is the latter body of literature, which we briefly summarise.

One of the common frameworks for the design of games are The Mechanics, Dynamics, Aesthetics (MDA) framework (Hunicke et al. 2004) which also serve as the basis of the development of serious games, including the Design, Play, and Experience (DPE) framework (Winn 2009) and other variants (Aleven et al. 2010; Dillon 2013). In these frameworks, design activities are conceptualized as those linking design- and user- ends of simulation games. Given games convey meanings only through active play and interpretation, MDA posits that designers have only limited control over what types of dynamics that may emerge and how players may interpret stimuli received. The MDA framework hence clarifies the types of mechanisms (e.g. rules, behavioral options) that are under designers' control so that they may achieve particular dynamics (e.g. time-pressure, competition, collaboration, etc.) which in turn lead to aesthetics (e.g. sensation and discovery) and these finally constitute elements of fun and learning in a game. In a similar vein still other frameworks such as Learning Mechanics-Game Mechanics (LM-GM) (Arnab et al. 2015) clarify the relationship between learning related actions (such as observation, questioning, experimentation and imitation) and game mechanics (such as role play, information, time pressure). While these frameworks define the relationship between designers and players, of additional concern for research on social learning are how such dichotomy may increasingly blur as dynamics and aesthetics not only affect the learning of players but also those of researchers observing and facilitating such sessions. Equally relevant are questions such as how in-game learning relates to real-word decisions, behaviors, and influences across wider communities of practice in which players belong.

Another common framework is the Triadic Game Design approach (Harteveld 2011) which distinguishes inherent trade-offs of serious game design among ‘Reality, Meaning, and Play’ and a similar variation by Rooney (2012) which situates design activities as balancing act of ‘Play, Pedagogy, and Fidelity’. Mitgutsch and Alvarado (2012) follow a similar approach in their Serious Game Design Assessment (SGDA) Framework that can be used to analyze “purpose-driven” games. Ahmad et al. (2016) also highlight the importance of a well-balanced interplay between these elements. The major contribution of these frameworks has been shedding light on crucial distinctions to be made between the design of entertainment- and learning-oriented games, highlighting the need to achieve the balance between play and the representation of real-world elements. As Harteveld (2011) writes, “if a game turns out to be unbalanced (...) it is unlikely that the game achieves for what it is designed for. It might be inappropriately linked to the real world, not create the value that goes beyond the context of playing the game or it might not be engaging and enjoyable enough for players to devote their time to (p. 35)”. While the core tensions highlighted in these frameworks are applicable to the design of serious games, detailed conceptual clarification regarding the situatedness of game reality, meaning-making, and play may benefit from further elaboration, as these aspects are essential for games serving social learning objectives.

In light of these concerns, more recent proposals such as the Transformational Framework proposed by Culyba (2018) goes a step further in emphasizing the situatedness of gameplay in real-world contexts, defining the transformation of a player in the real world as the ultimate goal of game design. Their practice-oriented framework guides the eight interconnected design steps and concerns including i) problem definition; ii) audience and context; iii) player transformation; iv) barriers to change; v) domain concepts (facts, processes, narratives, terms); vi) access to expert knowledge; vii) review of prior work; and viii) creation of an assessment plan. The framework includes guiding questions that help designers refine the meaningful purpose of their game intervention, understand the social context (what they term the ecosystem) in which a game will be played, giving ample empirical examples from a variety of educational disciplines. While their framework is useful in setting the broad scope for a new genre of ‘transformational’ game and outlining pragmatic design concerns, its theoretical underpinning is still unclear. We thus outline below our proposed framework which overcomes some of the limitations observed in the existing body of literature.

2.2. Designing games that foster social learning in complex systems - the CompleCSus framework

At the most fundamental level, the proposed game design framework is guided by the concepts (and associated literature) of social learning and procedural rhetoric. Social learning has emerged as a crucial part of sustainable development processes together with the transition from more expert-driven adaptive management (Holling 1978; Walters and Holling 1990) in the context of natural resource management to a broader stakeholder-driven adaptive co-management (Olsson et al. 2004) in the context of environmental governance (Folke et al. 2005; Cundill and Rodela 2012). This change reflected a deeper realization of the value of deliberation including different inputs from science, policy, and society to generate lasting and inclusive solutions (Verweij and Thompson 2006). An emphasis that we place on the social or relational aspects of game design distinguishes our approach from many single-player serious games (see Solińska et al. 2018; Gampell and Gaillard 2016).

Social learning despite its significance for environmental governance, is frequently defined only loosely, where conditions, processes, and outcomes are not fully separated (Reed et al 2010; Siebenhüner et al 2016). This poses challenges for operationalization and evaluation regarding its role and effects (Suškevičs et al. 2018). One promising approach is to distinguish three different dimensions of social learning: cognitive, relational, and normative (Baird et al. 2014), which has been the basis of a number of empirical studies (Huitema et al. 2010; Munaretto and Huitema 2012). This distinction is also consistent with the multi-party collaboration literature that distinguishes between problem-solving and relational activities at individuals, groups, organizations, and coalitions levels (Bouwen and Taillieu 2004). Thus, games that aspire to support sustainable development must take into account not only the technical, problem-solving aspects of the real-world problem situations but also their social, institutional, and relational dimensions (Rodela et al. 2019).

Social learning in the game world is relevant to the real world challenges faced by participants when the real world problem situation is represented adequately in the game space. This aspect of the game design is guided by the notion of procedural rhetoric - “authoring arguments through processes” (Bogost 2008, p. 125), with the goal of persuading others or presenting effectively particular concepts. Game creators design elements of the game structure that procedurally represent particular real-life systems or their elements. To *represent procedurally*, in this context, means to create a set of rules that when interacted with, generate specific representation for the person interacting (Murray 1997). This means that when players encounter the processes within this structure through the gameplay, they gain first-hand, active experiences of how the represented system works. The interactive nature of this experience makes the message more transparent and open for investigation, as the player makes decisions and almost immediately faces their consequences (Walsh et al. 2012).

Game Structure

Our guiding concepts (principles) shape other aspects of game design and application - we express these relationships in Figure 1. Game structure, produced in such a design process, carefully represents the important elements of the real-world problem situation from the perspective of game objectives. At the most basic level, a simulation game intended to convey sustainability challenges must clearly express the underlying interactions of social and ecological systems including resource and governance systems (Ostrom 2007; Ostrom 2009; McGinnis and Ostrom 2014) as well as different public discourses. Key design decisions here include the selection of *roles* (important actors to be included in the game), determination of *decisions* they can make within *action situations*, and linking these decisions with the *game environment* (it is also called ‘*game rules*’ in game design studies (Salen and Zimmerman 2004)).

Roles (enacted by players during the gameplay) affect the game environment that contains biophysical elements (such as rivers or land), physical infrastructure (e.g. dams), as well as economic and social relationships (e.g. transformation of resources into revenue streams). In our approach, actors (players) are delineated from the game environment: a simulated environment that can be seen as a scientific model of reality, which may include representations of other people (agents) (Mayer 2009). Game environment can be implemented using computational devices or various board game mechanics - it is an important design concern to ensure a smoothly functioning interface between players and the game environment: the decisions made by players should be easily transformed into specific changes in the game environment and these changes should be easily recognizable by the participants.

Action situation is a game setting “in which individuals (acting on their own or as agents of organizations) observe information, select actions, engage in patterns of interaction, and realize outcomes from their interaction” (McGinnis 2011 p.9, see also Ostrom 2010). The concept of an action situation allows designers to consciously shape interactions between participants. Such purposefully designed action situations create a number of opportunities for social learning (especially the relational aspects), as they require the players to, for example, confront their understanding of a given problem with another player's point of view.

It is important to note that unlike many persuasive games (Bogost 2007), characterized with precise winning/losing conditions (goals) and fixed rules within the game environment (Frasca 2003; Skolnik 2013), the CompleCSus approach advocates for creating an open learning environment for players who can discuss and decide their goals within a gameplay and in some situations even create or change the game rules. This reflects our values of transparency, autonomy, trust, and primacy of intrinsic motivation (Ryan and Deci 2000) as a pathway for meaningful self-directed learning and change.

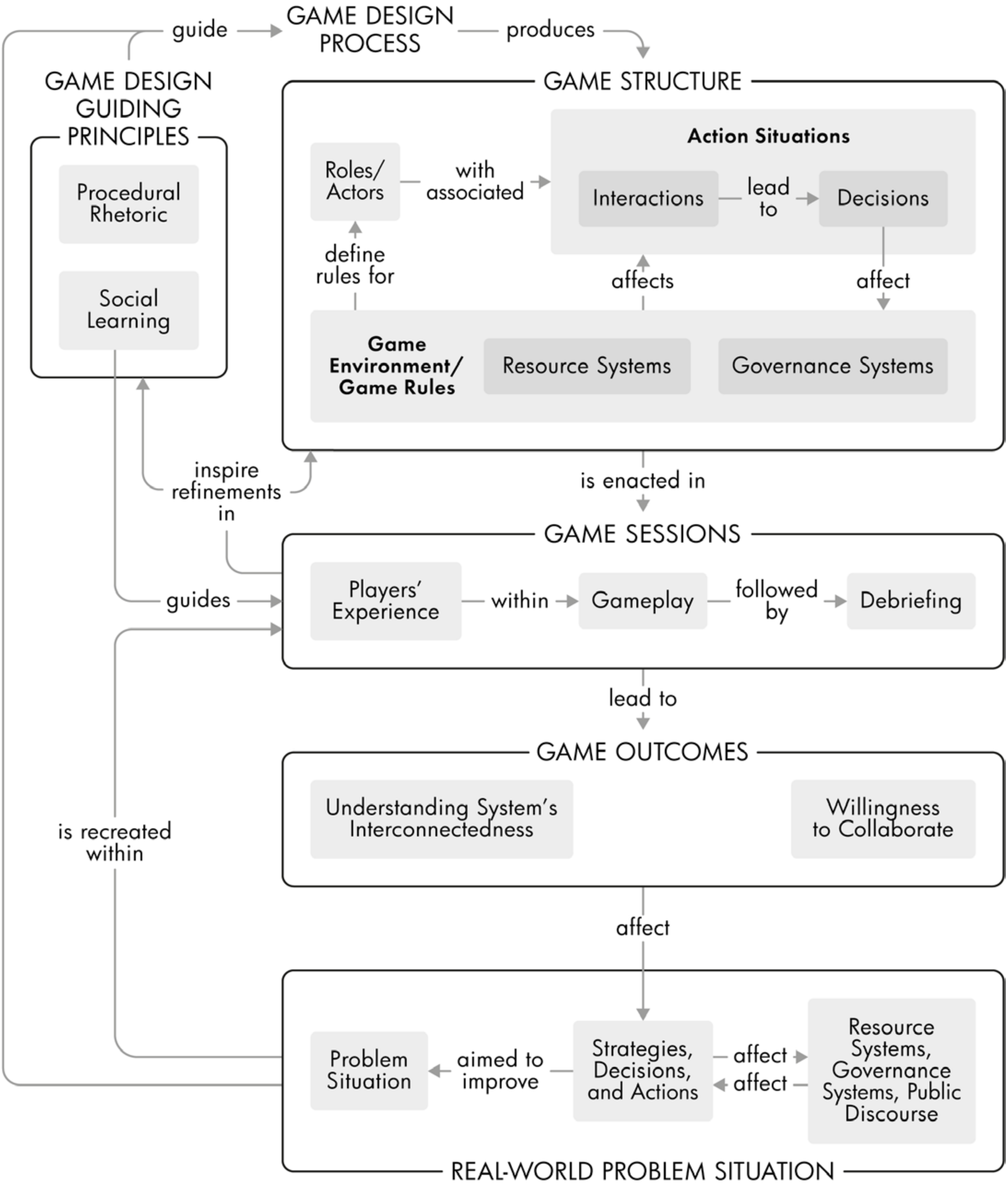

Figure 1: The CompleCSus (Complexity-Collaboration-Sustainability) Game Design Framework for Social Learning.
Source: Bartosz Naprawa, Centre for Systems Solutions

The choice and design of particular roles, action situations, decisions, rules, and game environment depends on the specific topics and goals to be achieved through the game. All elements of the game environment must be carefully selected to avoid "flooding" players with unnecessary details that can result in the "video game syndrome" which occurs when players "play too much and think too little"

(Sterman 2006)—namely, when they master the in-game tasks simply for the sake of improving their skill in solving these tasks, without further reflection. Understanding the concepts of procedural rhetoric and social learning, allows one to prototype and select appropriate designs including also pragmatic constraints (e.g., procedural complexity, time, and resources available for game development).

Game Sessions and Outcomes

Game structure is enacted via gameplay that generates an experiential space in which players are exposed both to existing challenges (i.e. understanding the world as it is) and alternative solutions (i.e., imagining the world as it could be). Within a gameplay both time and space are "compressed" to enable players to visualize desirable futures and socio-ecological transitions that would lead to them. By making decisions and observing their consequences in the game (e.g., depletion of natural resources or growth of social inequity), players may learn about the (in)effectiveness of their actions and adjust strategies accordingly. The gameplay is a space in which different policy options that have both immediate and long-term impacts are collectively explored. During the gameplay, players learn both about a specific social-ecological system (cognitive dimension) and its interconnections as well as about collaboration challenges at multiple levels (relational dimension).

Real World Problem Situation

Social learning should occur not only within the gameplay itself but also within the larger context of real-world decision making. With its explicit aim of stimulating social learning, the CompleCSus framework leads to the game design where participants move beyond a mere competition to "win" but instead motivate them towards a deeper and wider "double-loop" learning shared across a network of players and beyond, which occurs "when errors are corrected by changing the governing values and then the actions" (Argyris 2002, p.206). To this end the debriefing sessions (following the gameplay) are designed to activate reflection and learning that may lead participants to modify their mental models (normative dimension) and foster understanding within broader networks of actors and systems.

2.3. Translating of the CompleCSus framework into design process

Game development is an iterative process in which one (re)defines the scopes, aims, and objectives of the game, while ideating and prototyping particular elements and mechanics. The CompleCSus framework is applied in two distinctive yet iterative phases (Figure 2).

Phase 1 starts with a desk review of available literature on the issue of interest, and is followed by consultations with experts and stakeholders. This preliminary research activity allows to set the design goals and the main theme of the game. Often, these goals as well as the game theme are a subject of agreement between game designers and other parties involved in the process of game creation (for example, the other partners in the project that game is designed in). After this initial investigation effort, crucial subtopics and problems within the broader theme are selected to be included in the game. Narrowing down the area of interest allows the game designers to focus on detailed analysis of selected subtopics and problems.

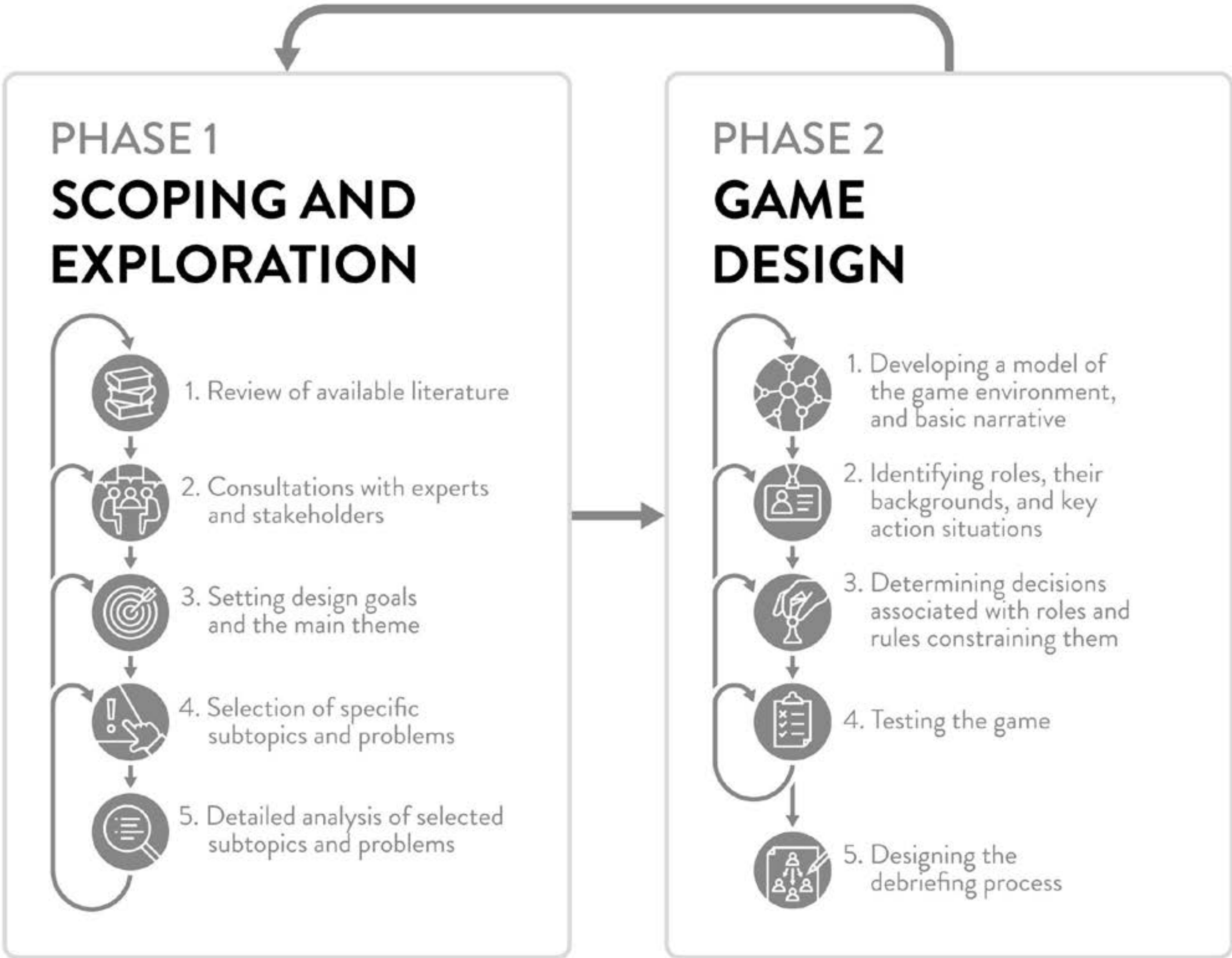

Figure 2. Process view of the CompleCSus framework
Source: Bartosz Naprawa, Centre for Systems Solutions

In Phase 2, the designers start with developing a model of the game environment and basic narrative, based on the work conducted in Phase 1. Such a model is then further analyzed to identify the roles to be played by the game participants, as well as the backgrounds of these roles, and key action situations that involve them. In the next step, designers determine decisions associated with selected roles and rules that constrain those decisions. Game structure, resulting from this process, is then prototyped and carefully tested in an iterative manner. Each iteration can lead to going back to one of the previous game design steps. The final step is designing the moderation and debriefing process.

In the following section we demonstrate the utility of our proposed framework with the case of the Water-Energy-Food Nexus Game.

3. The Case of the Water-Energy-Nexus Game

The CompleCSus framework described above was used to design and test the simulation game on the water-food-energy nexus. The Nexus Game represents socio-ecological systems challenges related to water, food, and energy production in a hypothetical pair of developing countries sharing a transboundary river (Figure 3). The aim of the game is to learn through experience how different water, energy, and food production, storage, and consumption technologies lead to the sustainable development of the respective countries. The target group of the game are policy makers, professionals from the food, energy, and water sectors, as well as students in related fields.

Table 1. Roles and decisions in the Nexus game. A game session consists of up to 4 rounds of decision-making and reflection phases, in which players collectively make investment decisions in the water-energy-food sectors, learning about their development, outcome, and environmental footprints. Gameplay takes approximately 3–4 hours, with at least one dedicated facilitator guiding players through introduction (conducted in an interactive manner for 30-40 minutes), gameplay (1.5-2 hours), and debriefing session (at least 30-60 minutes). The minimum number of players is 8.

Roles	Decisions
Prime Minister	Negotiates and decides how much funding should be allocated to each Ministry for different nexus investment options. Also negotiates international agreements with the neighbor country.
Ministry of Water	Decides how much water should be stored in the dams and how much should flow through the river and tributaries. Decides how to distribute stored water to different production sectors and populations. Negotiates and invests in water-efficient technologies and water-related infrastructure.
Ministry of Energy	Decides how to distribute power tokens throughout the population. Negotiates to invest in new power plants and efficiency-improvement options.
Ministry of Agriculture	Decides how much food should be consumed versus stored for next year. Invests in efficiency-improving technologies.
International NGO	Negotiates and decides on how to allocate additional funding for alternative investment options.
Journalist	Provides regular reports on actions of other roles and the situation of both countries.

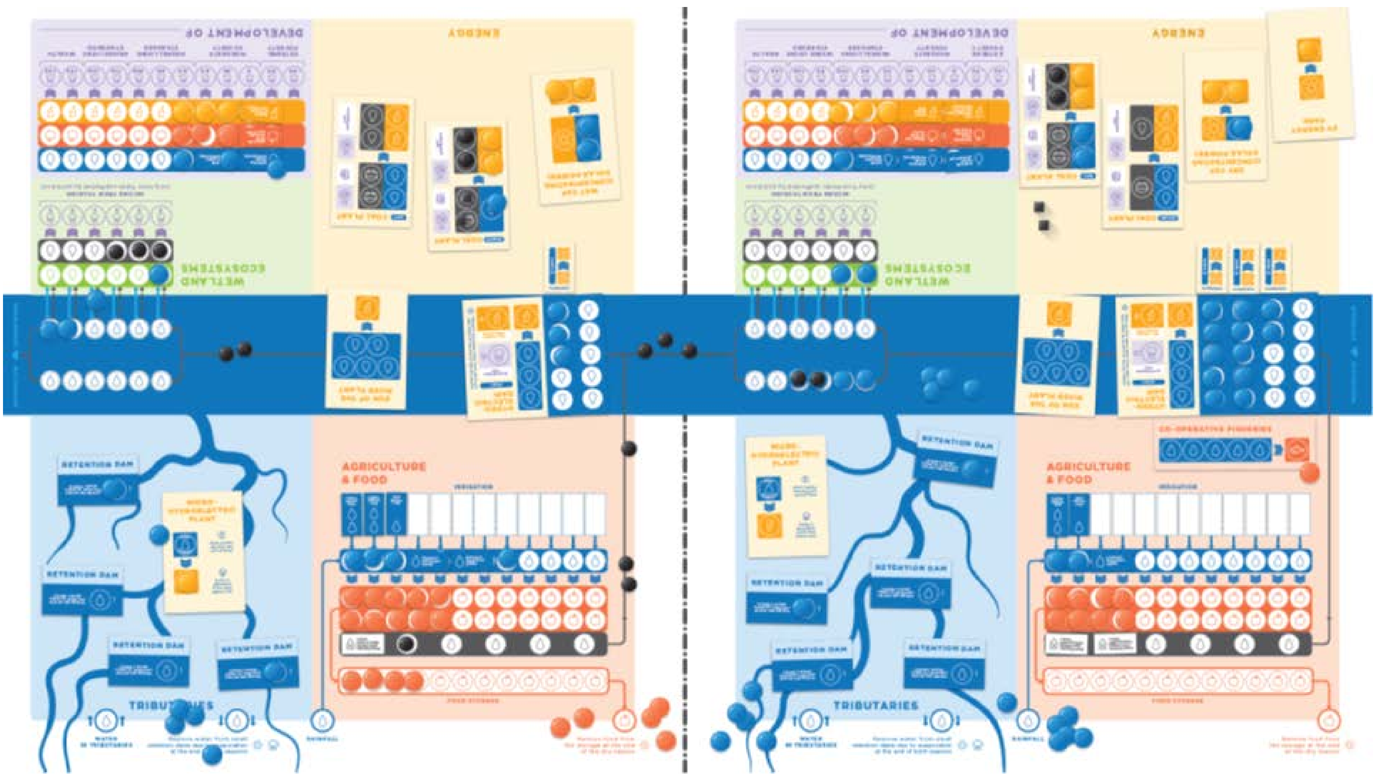

Figure 3: The Nexus Game board. The river is flowing from right to left, making the country on the right the upstream country. This shows the situation toward the end of the game when several different types of power plants have been developed.
Source: Bartosz Naprawa, Centre for Systems Solutions

3.1 Making the Nexus Game: Scoping and Exploration (Phase 1)

In Phase 1 of game development, the initial scoping was conducted together with the Sustainable Energy for All (SE4ALL)/UNDP-CAPNET initiative, which requested the game be developed to build the capacity of energy managers in the Southern African Development Community (SADC) countries. Learning objectives identified include:

- Need to establish coordination and collaboration between government, research, and business for more informed decisions on water, energy, and food production;
- Need to collaborate across government ministries with different goals by facilitating information sharing, sharing of resources, and collective decision-making;
- Need to balance energy supply and demand within given water availability;
- Need to lower energy consumption and optimize water-use efficiency.

This consultation process was then followed by a technical review of nexus challenge in the SADC region - one of the global hotspots for nexus challenges (Conway et al. 2015, Entholzner and Reeve 2016). Our major finding of this step was that the “nexus challenge” is highly diverse across the 15 SADC member countries: Per capita GDP, for example, varies widely from the lowest of $379 per capita in Malawi to the highest of $16,922 per capita in Seychelles. The region’s water- resource availability is highly variable, with the wetter northern countries (such as the Democratic Republic of the Congo [DRC]) having rainfall above 1,500 mm/year as opposed to the drier southern and western countries (such as Botswana and Namibia) which have less than 400mm/year of rain on average (SADC 2014; Davis-Reddy and Vincent 2017). Likewise, the stages of energy development, including electricity access and renewable energy penetration, are also different across the member countries, with the lowest electricity access of 8.7% in Malawi and the highest of 99.4% in Mauritius (REN21 2015). As such, identifying a single representative “nexus challenge” for the SADC region as a whole was not possible.

Based on this observation, the design team consulted with the SE4All and decided to choose transboundary river basin management as one example of relevant nexus issues in the region. This initial choice was made in view of the relative importance placed on the need for collaboration and coordination as a primary learning objective of this game.

Figure 4: Kariba dam situated between Zambia and Zimbabwe.
Source: Bartosz Naprawa, Centre for Systems Solutions

Subsequently, the design team studied in detail the transboundary areas surrounding the region's largest hydroelectric dam, the Kariba Dam, situated between Zambia and Zimbabwe to identify locally relevant gaming elements to be prototyped (Figure 4). The major environmental challenges surrounding this reservoir included: competing water uses (among hydropower generation, urban demand, agricultural/aquacultural needs, tourism and mining activities) and water pollution (due to urban and industrial uses, mining, and agricultural/aquacultural activities); potential adverse consequences of climate change (the mean annual flow of the Kariba Basin, currently estimated at approximately 929 m^3/s [748 m^3/s in the dry season]), is expected to decline to 595 m^3/s (405 m^3/s in the dry season) by 2050 (Beck and Bernauer, 2011). These elements were tested and evaluated in the subsequent game design phase.

3.2 Making the Nexus Game: Game Design (Phase 2)

Starting from the game environment (step 1), brainstorming was performed to identify key elements of the natural and built environment using gaming "blocks" representing elements such as hydropower plans, agricultural production, urban built environment, industrial production, ecosystem services, and tourism. Water was decided to be represented by blue game tokens moved along the transboundary river (see the prototype in Figure 3). For roles (step 2), major actors such as energy, water, and agriculture ministers were included, along with the Prime Minister. These roles were considered necessary to allow participants to affect the river system. An international NGO was also added to foster further collaboration across the two countries (application of procedural rhetoric).

Decisions (step 3) within specific action situations including government budget allocation meetings, were established in such a way that resources available to ministries were separated to represent "siloed" decisions that could potentially leading to conflict or mismanagement. In addition, decisions such as Water Minister altering storage and water release have both immediate and long-term consequences for the agricultural and energy sectors, designed to prompt discussions and reflections.

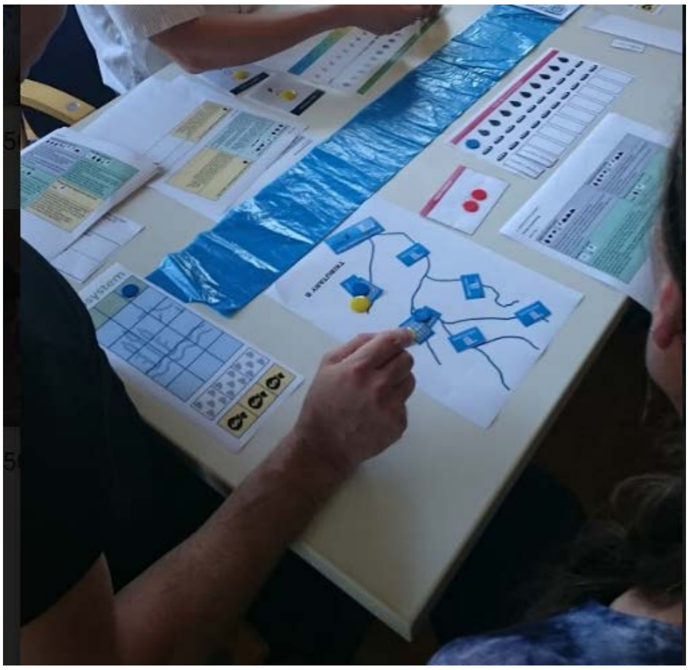

Figure 5: Water–energy–nexus prototyping and testing session

To operationalise the core aspects of the CompleCSus framework (procedural rhetoric and social learning), general good practices of game design was applied. For example, the design process began with low-fidelity prototyping using less expensive and replaceable materials such as paper and plastics (Figure 5). The team also crafted carefully the sequence in which different steps and elements are introduced so as to ensure that cognitive load remains manageable for players. This applies both to in-game experience as well as any pre- and post-game briefing and facilitation sessions

To immerse players in the game with a stronger connection to their responsibilities and the country they are asked to manage, it was decided that the Nexus Game, at the beginning, gives each player a letter from their fictional superiors, describing their terms of references. This application of procedural rhetoric, for example, not only serves as a short introductory instruction but also an immersive step to explore the in-game world on their own. To ensure that players pay sufficient attention to learn basic rules and mechanics of the game first, the team also decided to calibrate the gaming parameters (such as rainfall variability and flood threshold) to purposely make the game environment less challenging at the beginning. As players learn the rules and logic, the game progressively challenges them by introducing elements such as acute water shortages and flood risk.

3.3 Game design principles into practice

Procedural Rhetoric

To further illustrate the concept of procedural rhetoric, Table 2 shows the examples of how real-life system elements, roles, rules, and decisions were represented procedurally in the Nexus Game.

Table 2: Examples of procedural representation of system elements in the Nexus Game.

		System elements	*Game representation*
Game Environment / Game Rules	*Resource Systems*	The Zambezi river and its tributaries along the Kariba dam run through Zambia to Zimbabwe providing vital water	In each season, a fixed number of water tokens are placed in the upstream country on the game board and on river tributaries,

		source for riverine communities. The river faces a high variability in water levels depending on wet versus dry seasons and the variability will be affected by climate change in the future.	depending on wet or dry seasons scenarios.
	Governance Systems	Sufficient amounts of water, energy, and food is necessary to secure the well-being of the country's population.	Players need to provide Water, Energy, and Food tokens to their countries' communities in order to produce income. For every set of provided tokens (1 Water, 1 Energy, 1 Food), a specific amount of income is received.
Roles/Actors		Ministers and government officials are the key actors in the countries sharing transboundary water resources.	Players take roles of Prime Ministers, Energy Ministers, and Agricultural Ministers in two neighboring countries.
Action Situations	*Interactions*	As upstream and downstream countries share the water from the same river, the upstream country has an advantage over the downstream country as they can control the river flow. The water sharing issue is a subject of both bilateral and multilateral negotiations (ZAMCOM Agreement 2014; Agreement between the Republic of Zimbabwe and the Republic of Zambia concerning the utilization of the Zambezi River 2017). An example of an organization that enables cooperation between water sharing countries (Pearce 2013; ZAMCOM n.d.) is the Zambezi Watercourse Commission.	Players negotiate the regulation of water relations between the countries. A special space for such designed interaction is a meeting of transboundary water organization that allows the players to learn more about points of view and motivations of other roles.
	Decisions	The ministers of basin governments decide upon the strategic directions of their countries' development, such as policies and investments (ZAMCOM Agreement 2014), as well as upon ratifying agreements that regulate their actions in the transboundary context.	The ministers of both countries receive a number of possible investments in different types of infrastructure. For example, the Minister of Agriculture can choose between investing in building new farms, building drip irrigation systems, or reducing agricultural pollution; the Minister of Energy can choose between building new coal power plants or investing in solar power. Countries can also pursue diplomatic goals. They can, for example, reach an agreement on water sharing by declaring the

			amount of water secured each period. The game does not enforce such an agreement: It is for each country to decide if they want to honor the agreement.

The design of water flow and ecosystem pollution mechanics provides an easy to understand example of how different game elements were used to present and explain water and pollution dynamics in wetland ecosystems. Wetland ecosystems are an integral part of the game, providing two types of service: water storage (Figure 6 left) and pollution cleaning (Figure 6 right).

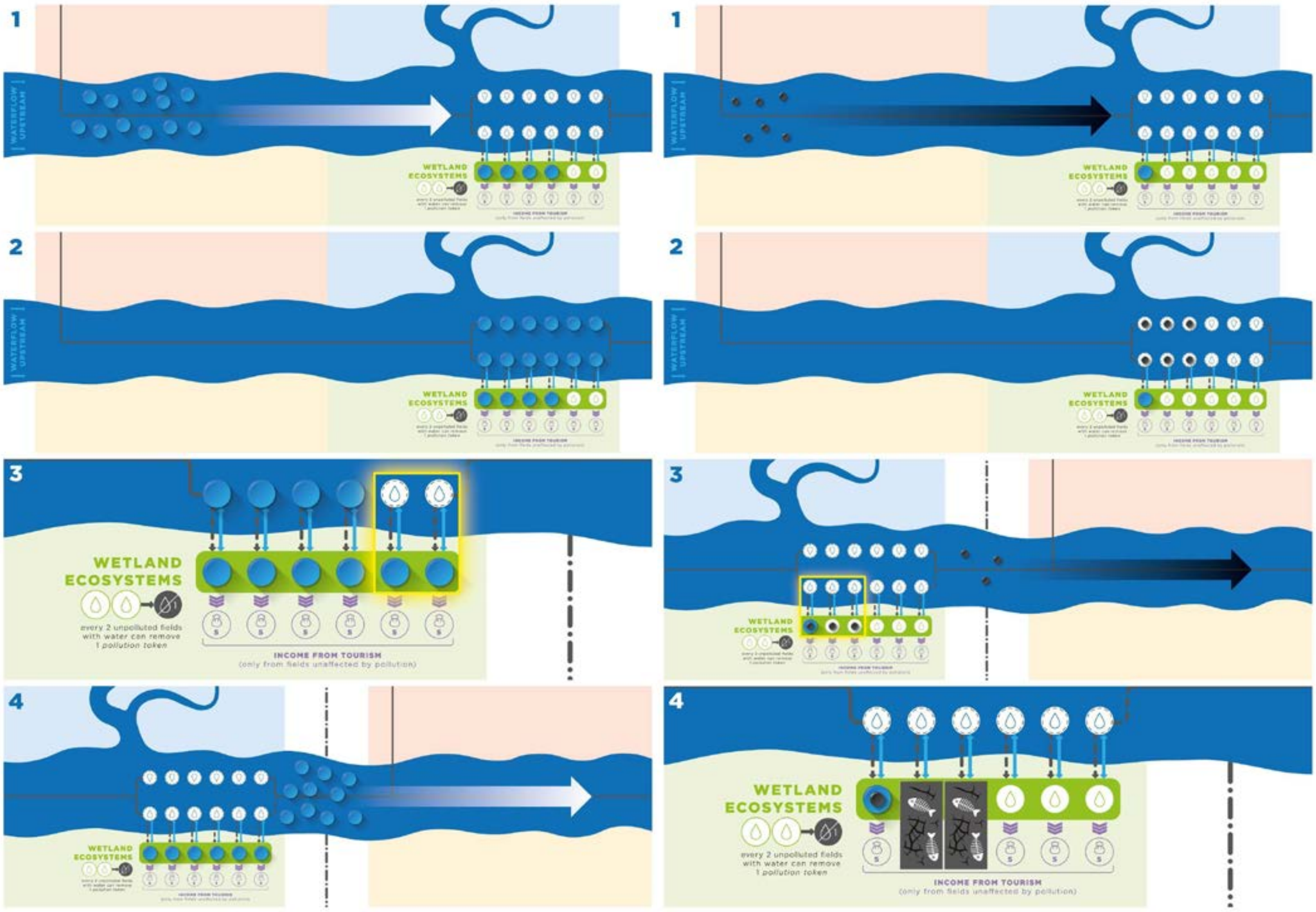

Figure 6: Procedural rhetoric of water flow during the wet season (left) and wetland ecosystem destruction (right)
Source: Bartosz Naprawa, Centre for Systems Solutions

The pollution cleaning process is represented using the following application of procedural rhetoric (Figure 6 right). Various activities of both countries (e.g., food and energy production) cause the release of pollution to the river. The Nexus game represents pollution by black tokens. First, players move the pollution tokens generated by production activities in the upstream country to the wetland area. Then, depending on the availability of water in the wetland system, half the pollution tokens may be absorbed by these wetlands (players place pollution tokens in water storage slots). If there is no water in the water storage slot, this part of the ecosystem is permanently destroyed (Figure 6, right-hand side). The remaining pollution tokens move downstream where they are added to the pollution produced by the downstream production activities. Then, players repeat and evaluate the pollution clearing capacities of the downstream wetland system.

Social learning

Different action situations are carefully incorporated in the game in order to create space and opportunities for social learning. An example of such a purposefully designed action area is the river basin organization meeting. During this meeting, representatives of different ministries from both countries discuss the issues associated with transboundary river management. The river basin organization meeting is organized in the later part of the game, when participants already have their own understanding of the system that the game describes.

Taking part in the meeting creates an opportunity for the participants to learn how others perceive the problems, share their own perspectives and to create a shared understanding of the complexity associated with transboundary water management. To facilitate exchange of information and subsequent learning, the conditions of up and downstream countries are designed purposely to differ: the upstream controls the water flow whereas the downstream receives pollution and the efficiency of food energy and water-related production facilities varies depending geographical circumstances. This creates different experiences for each country and exchange of information at the meeting challenges their own assumptions regarding the problem, leading to active reflection and collective learning.

Similarly, the game process is designed to guide participants into bilateral negotiations between the ministries of different countries, negotiations within the government, and negotiations within the ministries (between the participants that take the role of the members of ministries). During the talks and negotiations the participants share their understanding of the problems connected with water-food-energy nexus and work together to fully comprehend the issues. Sometimes it is a challenge for participants to realize that they are trapped into a series of bilateral deals while a multi-party agreement at the level of a whole river basin is needed (Vansina et al. 1998).

The focus on social learning aspects is also reflected by using the role of Journalist that was added to strengthen the participants' reflection. The main task of this role is to observe the gameplay, and to interview the participants, asking about their experiences and motivations. Based on these observations, the Journalist creates articles about her or his point of view on what happens during the gameplay. In addition, the Journalist can also present their work a number of times during the game. Including this role in the game allows participants to see how their actions are perceived from a neutral perspective and how they are interpreted in a wider context. This reflection starts during the gameplay and is continued during the debriefing session, when the Journalist account of events is often referred to.

3.4. Game Debriefing

As illustrated in our framework (Figure 1), debriefing activities provide essential steps of the process to foster both individual and collective reflection. Debriefing provides a space to "stop and reflect," offering players a much-needed opportunity to understand their own actions and mental models within the larger context of social and environmental challenges. Debriefing completes different modes of experiential learning: reflection and action, as well as feeling and thinking (Kolb 1984; Boud et al. 2013). During a debriefing session, players analyze their moves, share their thoughts and emotions with others and reflect on the whole experience (Crookall 2010).

Debriefing usually starts from, often emotional, sharing players experiences and reconstructing the sequence of decisions and events during the gameplay. Once players' emotional responses are clarified, debriefing questions guide players to make sense of what happened in the game, why it happened, and how behaviors and also the dynamics of the game changed over the course of the gameplay. Through a deeper understanding of the game environment and feedback loops between players' decisions and environmental changes including "surprises" and "shocks", they can understand the interconnections of the underlying water-food-energy-environment system. The game moderator may need to explain several design assumptions resulting from the particular implementation of procedural rhetoric - the goal of the workshop is to allow participants to reflect on their assumptions - therefore the moderator should make any assumptions transparent and allow participants to challenge them. With the deepened understanding of the system, participants are encouraged to reflect on the question “if you played the game again, what would you do differently?”. At this point a moderator encourages players to link their gaming experience to the real world. Both the gameplay experience and debriefing reflections allows them to see their real-world problem situation in a new light. Moderator supports participants in capturing their own insights from the game and translating them into actionable changes within their professional circle of activities.

4. Social Learning through the Nexus Game

Post-game evaluations were conducted to gather evidence regarding cognitive and relational aspects of social learning (see Appendix 1 for a list of countries in which the game has been played). We have gathered qualitative information using open-ended questions and applied the grounded theory approach (Glaser and Strauss, 2017). We excluded the normative dimension for two reasons. Firstly, the time frame of the game application is too short relative to the time scales necessary to foster the potential change of values (Heberlein 2012). It is also for this reason that existing studies evaluating social learning frequently do not report normative changes (see e.g. Munaretto and Huitema 2012).Secondly, when using questionnaires, the normative and statements tend to overlap with both relational and cognitive ones (it is difficult to distinguish between realizing that something is important in the cognitive sense and recognizing it as a value) therefore more elaborated methods would need to be used that was not possible at this stage.

After each gaming session, participants are asked several questions on two aspects: (1) change in understanding, (2) potential impact on the real world (see Appendix II). The data is then analysed through two-level coding. The categories derived from the first-level coding, based on the grounded theory approach, were clustered using the PESTLE framework (Political, Economic, Social, Technological, Legal, Environmental) (Perera 2017), corresponding to the main sustainability dimensions relevant to the Nexus Games. Further categories were then added including ‘systems thinking’ and ‘psychology’ (i.e. individual change) and ‘gaming/simulations’ better aligned to the game design goals.

The results of our evaluation indicate that ‘Systems Thinking’ (cognitive dimension) was the most relevant second level category covering, as defined by respondents, a wide range of sub-topics including: operating and management of complex systems, interdependencies, uncertainty, trade-offs, leverage points, cross-sectoral decision making, risk assessment, and scenario analysis of social-ecological systems. An example of this category include responses such as: “I saw how the elements of a system are interconnected and how this affects the overall behavioral pattern of the system. Other people can also learn the interconnectedness of a system and ask “what if” questions about possible future (Southern African Systems Analysis Centre’s Emerging Researchers Program 2018 Respondent #1. Limpopo, South Africa. 21.08.2018). We interpret systems thinking as the most important cognitive aspect of social learning through the Nexus Game, which is consistent with our design goals - the Nexus game is less intended as a way to convey specific knowledge about the water energy food subsystems but rather to help participants to understand the interdependencies between different elements. It is therefore not surprising that the categories like ‘Environment’ (including water, climate, ecosystems etc.) or ‘Technology’ had lower frequencies.

The second most-frequently populated category - ‘Society’ - includes collaboration, group work, conflict management, and diversity of stakeholders’ perspectives. A related ‘Governance’ category appears mainly in “real world impact” questions, and covers the issues of leadership, rules, institutions, and policies. An example of these categories include “The major thing I took from the simulation was that, as river basin managers, we often only think about our own causes. We don't appreciate the importance of communication and negotiation unless something goes wrong (GEF International conference respondent #5 Marrakesh, Morocco 03.11.2018).” Another player adds “I have learned how managing resources is a complex process, without the integration of sectors it can have side effects on water quality, on a large number of people…. relations have to be formed between countries for them to be efficient and effective in their decision-making. (Integrated Solutions for Water, Energy and Land (ISWEL) project meeting, respondent #8, Harare, Zimbabwe, 09.07.2018). These are the categories where we have expected the relational dimension of social learning to be reported more often (and they were although mostly with the 'impact' questions). The more individually-oriented category of 'Psychology' was used less often which is again consistent with our focus on social learning.

The answers classified into the category 'gaming & simulation' provided a direct participants assessment of the value of the game for them. Analysis of the collected answers indicates that both cognitive and relational learning were greatly facilitated by the gaming approach. Players often noted their own very high level of engagement. One player remarked for example that he was "surprised that [he] could take on a role and actually believe it and get emotional about it." Others also found it surprising the "emotional attachment of people with this imaginary power set up. They after a few moments started behaving like monsters or statesmen."

The ultimate goal of a simulation game for social learning is that in-game experience and learning inspires real-world reflection, change, and action shared by broader networks of actors. A player reflected, for example, "[The game] encourages closer relations in decision making and when required to make decisions, I will always consider other parties. (Integrated Solutions for Water, Energy and Land (ISWEL) project meeting, respondent #7, Harare, Zimbabwe, 09.07.2018). Another note: "I have learned a lot and I am inspired to change a number of things as a water manager myself: 1) to engage other water and environment-related organizations in …decision-making, 2) to avoid making rushed decisions without understanding what is on the ground, [and] 3) to support programmes that allow integrated use and management of water resources. (Integrated Solutions for Water, Energy and Land (ISWEL) project meeting, respondent #6, Harare, Zimbabwe, 09.07.2018)." Rigorous testing of gaming impacts beyond the simulation experience is beyond the scope of the present article, yet this initial evaluation gives a glimpse of the type of social learning outcomes that can be achieved.

5. Discussion and Conclusions

A focus on facilitating social learning (including players' mindset change beyond the game) distinguishes the CompleCSus framework from those in the available literature. Our framework combined social learning with the procedural rhetoric approach to designing game structure. While both approaches were used separately to construct design frameworks (e.g. Susskind and Rumore 2013 – social learning; Yusoff and Kamsin 2015 – procedural rhetoric), it is the combination of these two aspects that we find particularly effective for social learning on sustainability. Different learning frameworks or theories e.g. ARCS (Keller 1987), Nine Events of Instruction (Gagne 1985), Bloom's Taxonomy (Bloom 1956), theory of flow (Csikszentmihalyi 1990) have been incorporated into game design frameworks in the past (Gunter et al. 2006; Winn 2009; Aleven et al. 2010; Annetta 2010; Bachen and Raphael 2012; Kiili 2012; Arnab et al. 2015), however these theories give limited insights on the design of a multiplayer game that gives players a sense of the tensions inherent in decision-making on complex issues, such as trade-offs between individual and collective aims and interactions between human and natural systems. These elements are becoming increasingly important as policy issues facing our generation become highly interconnected necessitating academic, policy, and societal stakeholders to act together to learn and appreciate alternative problem-framings, as well as solution options to tackle 'wicked' policy issues such as climate and global change.

The particular combination of a) designing the action situations within the game based on social learning, and b) using procedural rhetoric to present complex systems within the gameplay is the key component of our framework. The term "rhetoric" can be understood both as *the act of persuading others* (classical approach), or as *an effective expression of ideas* (contemporary approach) (Bogost 2008). The CompleCSus framework assumes representing a system procedurally to allow the players experience how it works without enforcing any particular interpretation or judgment regarding the presented system.

However, the distinction between procedural *representation* and *rhetoric* is fluid (Voorhees 2009), as by, for example, an act of selection or interpretation of the system's elements to include in the game itself, game designers make particular assumptions about what is important in the system, and impose this view on the player (Frasca 2003). In the CompleCSus framework approach we try to counteract this effect by a) addressing the issue during the debriefing sessions and encourage the participants to express their point of view not only on the gameplay but also on the manner in which the system was represented, b) iterating the game development and include the key remarks from the participants in each new version of the game. While this approach cannot solve the problem of representing reality without persuasion, it allows game designers to be transparent about the issue. Another challenge to procedural rhetoric is formulated from the critical theory point of view (Sicart 2011) claiming that proceduralist approach leaves too narrow a space for players whose autonomy and creativity might be strongly restricted. In our approach, we try to combine the importance of the system representation with the players' contributions, who bring and express their own ideas, values, and worldviews, thus opening a rich dialogue between designers and participants.

Our preliminary evaluation observed qualitative evidence of social learning in the two focus areas where we concentrated our design efforts: (1) understanding complexity (cognitive aspects of social learning) of interconnections between social and ecological aspects of the water-food-energy nexus, (2) experience the role of collaboration (relational aspects of social learning), at different governance levels, as a key condition for identifying and implementing sustainable solutions. Participants also noted a wider variety of relational learning when asked to reflect on real world implications. A more rigorous evaluation is needed (Stokes 2015), by (1) comparing the effects of games through alternative methods (such as lectures or group exercises), (2) testing alternative game designs, identifying what works and what requires further improvement, (3) applying more elaborate methods to study the learning effects in cognitive, relational, and normative dimensions, and (4) assessing long-term impacts of gaming interventions in social networks of the participants.

The CompleCSus framework with its guiding principles have been applied (and refined while being applied) to a number of games focusing on social-ecological systems (REFS). In its current form it can be easily tailored to the characteristics of the target group (age, education level, or expertise on the game topic) through different designs of the game structure or variations of the debriefing process. However, it is important to note that our approach may not necessarily be suitable for every kind of educational or serious game. With its focus on social learning, it should be used primarily for designing workshop-oriented, multiplayer games that simulate complex environments and focus on integrating systems thinking with relational qualities.

As role-playing simulations gain renewed attention, further scientific efforts are certainly needed to improve both theoretical and empirical bases for appropriate simulation design. Our article is an attempt to both advance the theoretical foundations and, by sharing a specific design case study, encourage game development practice that fosters social learning.

References.

Abt, C. C. (1970). Serious Games. University Press of America.

Agreement between the Republic of Zimbabwe and the Republic of Zambia concerning the utilization of the Zambezi River, Zimbabwe-Zambia, Jul. 28, 1987, http://www.fao.org/3/w7414b/w7414b17.htm

Ahmad et al. (2016). A Multi-domain Framework for Modelling Educational Games: Towards the Development of Effective Educational Games. In: C.Y. Fook et al. (eds.), 7th International Conference on University Learning and Teaching (InCULT 2014) Proceedings, DOI 10.1007/978-981-287-664-5_34.

Aleven, V., Myers, E., Easterday, M., & Ogan, A. (2010, April). Toward a framework for the analysis and design of educational games. In 2010 third IEEE international conference on digital game and intelligent toy enhanced learning (pp. 69-76). IEEE.

Annetta, L. A. (2010). The "I's" have it: A framework for serious educational game design. Review of General Psychology, 14(2), 105-113.

Argyris, C. (2002). Double-loop learning, teaching, and research. Academy of Management Learning & Education, 1(2), 206-218.

Arnab, S., Lim, T., Carvalho, M. B., Bellotti, F., De Freitas, S., Louchart, S., ... & De Gloria, A. (2015). Mapping learning and game mechanics for serious games analysis. British Journal of Educational Technology, 46(2), 391-411.

Bachen, C. M., & Raphael, C. (2011). Social flow and learning in digital games: A conceptual model and research agenda. In M. Ma, A. Oikinomou, & L. C. Jain (Eds.), Serious games and edutainment applications (pp. 61-84). London: Springer-Verlag.

Baird, J., Plummer, R., Haug, C., & Huitema, D. (2014). Learning effects of interactive decision-making processes for climate change adaptation. Global Environmental Change, 27, 51-63.

Beck, L., & Bernauer, T. (2011). How will combined changes in water demand and climate affect water availability in the Zambezi river basin?. Global Environmental Change, 21(3), 1061-1072.

Berkhout, F., Hertin, J., & Jordan, A. (2002). Socio-economic futures in climate change impact assessment: using scenarios as 'learning machines'. Global Environmental Change, 12(2), 83-95.

Bloom, B. S. (1956). Taxonomy of educational objectives. Vol. 1: Cognitive domain. New York: McKay, 20-24.

Bogost, I. (2007). Persuasive games. Vol. 5.

Bogost, I. (2008). The rhetoric of video games (pp. 117-140). MacArthur Foundation Digital Media and Learning Initiative.

Boud, D., Keogh, R., & Walker, D. (2013). Reflection: Turning experience into learning. Routledge.

Bouwen, R., & Taillieu, T. (2004). Multi-party collaboration as social learning for interdependence: Developing relational knowing for sustainable natural resource management. Journal of community & applied social psychology, 14(3), 137-153.

Braad, E., Žavcer, G., & Sandovar, A. (2016). Processes and models for serious game design and development. In Entertainment Computing and Serious Games (pp. 92-118). Springer, Cham.

Castella, J. C., Trung, T. N., & Boissau, S. (2005). Participatory simulation of land-use changes in the northern mountains of Vietnam: the combined use of an agent-based model, a role-playing game, and a geographic information system. Ecology and Society, 10(1).

Coleman, S., Hurley, S., Koliba, C., & Zia, A. (2017). Crowdsourced Delphis: Designing solutions to complex environmental problems with broad stakeholder participation. Global Environmental Change, 45, 111-123.

Conway, D., Van Garderen, E. A., Deryng, D., Dorling, S., Krueger, T., Landman, W., ... & Thurlow, J. (2015). Climate and southern Africa's water–energy–food nexus. Nature Climate Change, 5(9), 837-846.

Cornell, S., Berkhout, F., Tuinstra, W., Tàbara, J. D., Jäger, J., Chabay, I., ... & Otto, I. M. (2013). Opening up knowledge systems for better responses to global environmental change. Environmental Science & Policy, 28, 60-70.

Costanza, R., Chichakly, K., Dale, V., Farber, S., Finnigan, D., Grigg, K., ... & Magnuszewski, P. (2014). Simulation games that integrate research, entertainment, and learning around ecosystem services. Ecosystem Services, 10, 195-201.

Csikszentmihalyi, M. (1990). Flow. The Psychology of Optimal Experience. New York (HarperPerennial) 1990.

Culyba, S. (2018). The Transformational Framework. A process tool for the development of Transformational games

Cundill, G., & Rodela, R. (2012). A review of assertions about the processes and outcomes of social learning in natural resource management. Journal of environmental management, 113, 7-14.

Davis, C. L., & Vincent, K. (2017). Climate risk and vulnerability: a handbook for Southern Africa (2nd Ed), CSIR, Pretoria, South Africa.

de Suarez, J. M., Suarez, P., Bachofen, C., Fortugno, N., Goentzel, J., Gonçalves, P., ... & van Aalst, M. (2012). Games for a new climate: experiencing the complexity of future risks. Pardee Center Task Force Report.

Dillon, R. (2013). Serious games and fun: an analysis. International Journal of Innovative Research and Development (ISSN 2278–0211), 2(5).

Entholzner, A., & Reeve, C. (Eds.). (2016). Building climate resilience through virtual water and nexus thinking in the southern African development community. Springer.

Fazey, I., Bunse, L., Msika, J., Pinke, M., Preedy, K., Evely, A. C., ... & Reed, M. S. (2014). Evaluating knowledge exchange in interdisciplinary and multi-stakeholder research. Global Environmental Change, 25, 204-220.

Fazey, I., Schäpke, N., Caniglia, G., Patterson, J., Hultman, J., Van Mierlo, B., ... & Al Waer, H. (2018). Ten essentials for action-oriented and second order energy transitions, transformations and climate change research. Energy Research & Social Science, 40, 54-70.

Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). Adaptive governance of social-ecological systems. Annual Review of Environment and Resources, 30, 441-473.

Frasca, G. (2003). Simulation Versus Narrative: Introduction to Ludology. In M. Wolf and B. Perron (Eds.), The Video game Theory Reader (pp.221-236). New York: Routledge.

Gagne, R. (1985). The Conditions of Learning (4th ed.). New York: Holt, Rinehart & Winston.

Gampell, A. V., & Gaillard, J. C. (2016). Stop Disasters 2.0: Video Games as Tools for Disaster Risk Reduction. International Journal of Mass Emergencies & Disasters, 34(2), 283-316.

Glaser, B. G., & Strauss, A. L. (2017). Discovery of grounded theory: Strategies for qualitative research. Routledge.

Gunter, G., Kenny, R. F., & Vick, E. H. (2006). A case for a formal design paradigm for serious games. The Journal of the International Digital Media and Arts Association, 3(1), 93-105.

Harteveld, C. (2011). Triadic game design: Balancing reality, meaning and play. Springer Science & Business Media.

Hassenforder, E., Ferrand, N., Pittock, J., Daniell, K. A., & Barreteau, O. (2015). A participatory planning process as an arena for facilitating institutional bricolage: example from the Rwenzori region, Uganda. Society & Natural Resources, 28(9), 995-1012.

Heberlein, T. A. (2012). Navigating environmental attitudes. Oxford University Press.

Holling, C. S. (1978). Adaptive environmental assessment and management. John Wiley & Sons.

Huitema, D., Cornelisse, C., & Ottow, B. (2010). Is the jury still out? Toward greater insight in policy learning in participatory decision processes—the case of Dutch citizens' juries on water management in the Rhine Basin. Ecology and Society, 15(1).

Hunicke, R., LeBlanc, M., & Zubek, R. (2004, July). MDA: A formal approach to game design and game research. In Proceedings of the AAAI Workshop on Challenges in Game AI (Vol. 4, No. 1, p. 1722).

Jones, L., Grist, N., Ludi, E., & Carabine, E. (2014). Planning for an uncertain future: Promoting adaptation to climate change through flexible and forward-looking decision making.

Keller, J. M. (1987). Development and use of the ARCS model of instructional design. Journal of instructional development, 10(3), 2.

Kiili, K. (2005). Digital game-based learning: Towards an experiential gaming model. The Internet and higher education, 8(1), 13-24.

Kiili, K., De Freitas, S., Arnab, S., & Lainema, T. (2012). The design principles for flow experience in educational games. Procedia Computer Science, 15, 78-91.

Kimmich, C., Gallagher, L., Kopainsky, B., Dubois, M., Sovann, C., Buth, C., & Bréthaut, C. (2019). Participatory modeling updates expectations for individuals and groups, catalyzing behavior change and collective action in water-energy-food nexus governance. Earth's Future.

Kirkley, S. E., Tomblin, S., & Kirkley, J. (2005). Instructional design authoring support for the development of serious games and mixed reality training. In Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) (No. 2420, pp. 1-11).

Kristjanson, P., Harvey, B., Van Epp, M., & Thornton, P. K. (2013). Social learning and sustainable development. Nature Climate Change, 4(1), 5.

Kolb, D. A. (1984). Experiential learning: Experience as the source of learning and development. Prentice Hall.

Krolikowska, K., Kronenberg, J., Maliszewska, K., Sendzimir, J., Magnuszewski, P., Dunajski, A., & Slodka, A. (2007). Role-playing simulation as a communication tool in community dialogue: Karkonosze Mountains case study. Simulation & Gaming, 38(2), 195-210.

Magnuszewski, P., Krolikowska, K., Koch, A., Pająk, M., Allen, C., Chraibi, V., ... & Pan, D. (2018). Exploring the role of relational practices in water governance using a game-based approach. Water, 10(3), 346.

Mauser, W., Klepper, G., Rice, M., Schmalzbauer, B. S., Hackmann, H., Leemans, R., & Moore, H. (2013). Transdisciplinary global change research: the co-creation of knowledge for sustainability. Current Opinion in Environmental Sustainability, 5(3-4), 420-431.

Mayer, I. S. (2009). The gaming of policy and the politics of gaming: A review. Simulation & Gaming, 40(6), 825-862.

McGinnis, M. D. (2011). An introduction to IAD and the language of the Ostrom workshop: a simple guide to a complex framework. Policy Studies Journal, 39(1), 169-183.

McGinnis, M. D., & Ostrom, E. (2014). Social-ecological system framework: initial changes and continuing challenges. Ecology and Society, 19(2).

Mitgutsch, K., & Alvarado, N. (2012, May). Purposeful by design?: a serious game design assessment framework. In Proceedings of the International Conference on the foundations of digital games (pp. 121-128). ACM.

Mochizuki, J., Magnuszewski, P., & Linnerooth-Bayer, J. (2018). Games for aiding stakeholder deliberation on Nexus policy issues. In Managing Water, Soil and Waste Resources to Achieve Sustainable Development Goals (pp. 93-124). Springer, Cham.

Molenda, M. (2003). In search of the elusive ADDIE model. Performance improvement, 42(5), 34-37.

Munaretto, S., & Huitema, D. (2012). Adaptive comanagement in the Venice lagoon? An analysis of current water and environmental management practices and prospects for change. Ecology and Society, 17(2).

Norström, A. V., Cvitanovic, C., Löf, M. F., West, S., Wyborn, C., Balvanera, P., ... & Campbell, B. M. (2020). Principles for knowledge co-production in sustainability research. Nature sustainability, 1-9.

Olsson, M. O. (2001). Participatory Forest Policy Development-Experiences from a IIASA Policy Exercise in Tomsk, Russia.

Olsson, P., Folke, C., & Berkes, F. (2004). Adaptive comanagement for building resilience in social–ecological systems. Environmental management, 34(1), 75-90.

Ostrom, E. (2007). A diagnostic approach for going beyond panaceas. Proceedings of the national Academy of sciences, 104(39), 15181-15187.

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. Science, 325(5939), 419-422.

Ostrom, E. (2010). Beyond markets and states: polycentric governance of complex economic systems. American economic review, 100(3), 641-72.

Parson, E. A., & Clark, W. (1995). Sustainable development as social learning. Barriers and Bridges to the Renewal of Ecosystems and Institutions. Columbia University Press, New York, NY.

Parson, E. A. (1996a). What can you learn from a game. Wise Choices: Games, Decisions, and Negotiations. Harvard Business School Press, Boston.

Parson, E. A. (1996b). A global climate-change policy exercise: results of a test run, July 27-29, 1995.

Parson, E. A. (1996c). How Should We Study Global Environmental Problems? A Plea for Unconventional Methods of Assessment and Synthesis.

Pearce, F. (2013, September 12). Zambezi: The Mekong’s diplomatic debacle on repeat. Thrive blog. https://wle.cgiar.org/thrive/2013/09/12/zambezi-mekongs-diplomatic-debacle-repeat

Perera, R. (2017). The PESTLE analysis. Nerdynaut.

Reed, M., Evely, A. C., Cundill, G., Fazey, I. R. A., Glass, J., Laing, A., ... & Stringer, L. (2010). What is social learning?. Ecology and society.

REN21 (2015) SADC Renewable Energy and Energy Efficiency Status Report https://www.unido.org/fileadmin/user_media_upgrade/What_we_do/Topics/Resource-efficient__low-carbon_production/UNIDO-REN21-SADC_RE_and_EE_Status_Report.pdf

Rodela, R., & Gerger Swartling, Å. (2019). Environmental governance in an increasingly complex world: Reflections on transdisciplinary collaborations for knowledge coproduction and learning. Environmental Policy and Governance, 29(2), 83-86.

Rodela, R., Ligtenberg, A., & Bosma, R. (2019). Conceptualizing serious games as a learning-based intervention in the context of natural resources and environmental governance. Water, 11(2), 245.

Rooney, P. (2012). A theoretical framework for serious game design: exploring pedagogy, play and fidelity and their implications for the design process. International Journal of Game-Based Learning (IJGBL), 2(4), 41-60.

Rumore, D., Schenk, T., & Susskind, L. (2016). Role-play simulations for climate change adaptation education and engagement. Nature Climate Change, 6(8), 745-750.

Ryan, R. M., & Deci, E. L. (2000). Intrinsic and extrinsic motivations: Classic definitions and new directions. Contemporary educational psychology, 25(1), 54-67.

SADC (2014) SADC Statistic Yearbook 2014 https://www.sadc.int/information-services/sadc-statistics/#Indicators

Salen, K., & Zimmerman, E. (2004). Rules of play: Game design fundamentals. MIT press.

Salvini, G., Van Paassen, A., Ligtenberg, A., Carrero, G. C., & Bregt, A. K. (2016). A role-playing game as a tool to facilitate social learning and collective action towards Climate Smart Agriculture: Lessons learned from Apuí, Brazil. Environmental science & policy, 63, 113-121.

Schenk, T., & Susskind, L. (2014). Using role-play simulations to encourage adaptation. Action research for climate change adaptation: Developing and applying knowledge for governance, 148.

Sicart, M. (2011). Against procedurality. Game studies, 11(3), 209.

Siebenhüner, B., Rodela, R., & Ecker, F. (2016). Social learning research in ecological economics: A survey. Environmental Science & Policy, 55, 116-126.

Skolnik, M. R. (2013). Strong and weak procedurality. Journal of Gaming & Virtual Worlds, 5(2), 147-163.

Solinska-Nowak, A., Magnuszewski, P., Curl, M., French, A., Keating, A., Mochizuki, J., ... & Jarzabek, L. (2018). An overview of serious games for disaster risk management–Prospects and limitations for informing actions to arrest increasing risk. International journal of disaster risk reduction, 31, 1013-1029. DOI: https://doi.org/10.1016/j.ijdrr.2018.09.001.

Stanitsas, M., Kirytopoulos, K., & Vareilles, E. (2019). Facilitating sustainability transition through serious games: A systematic literature review. Journal of cleaner production, 208, 924-936.

Stefanska, J., Magnuszewski, P., Sendzimir, J., Romaniuk, P., Taillieu, T., Dubel, A., ... & Balogh, P. (2011). A Gaming Exercise to Explore Problem-Solving versus Relational Activities for River Floodplain Management. Environmental Policy and Governance, 21(6), 454-471.

Sterman, J. D. (2006). Learning from evidence in a complex world. American journal of public health, 96(3), 505-514.

Stokes, B. (2015). Impact with games: A fragmented field.

Suškevičs, M., Hahn, T., Rodela, R., Macura, B., & Pahl-Wostl, C. (2018). Learning for social-ecological change: A qualitative review of outcomes across empirical literature in natural resource management. Journal of Environmental Planning and Management, 61(7), 1085-1112.

Susskind, L. E., & Rumore, D. L. (2013). Collective climate adaptation: can games make a difference?.

Tschakert, P., Das, P. J., Pradhan, N. S., Machado, M., Lamadrid, A., Buragohain, M., & Hazarika, M. A. (2016). Micropolitics in collective learning spaces for adaptive decision making. Global Environmental Change, 40, 182-194.

van Asselt Marjolein, B. A., & Rijkens-Klomp, N. (2002). A look in the mirror: reflection on participation in integrated assessment from a methodological perspective. Global environmental change, 12(3), 167-184.

Vansina, L., Taillieu, T. C., & Schruijer, S. G. (1998). 'Managing' multiparty issues: learning from experience. Research in organizational change and development, volume 11, 159-183.

Verweij, M., & Thompson, M. (Eds.). (2006). Clumsy solutions for a complex world: Governance, politics and plural perceptions. Springer.

Villamor, G. B., & Badmos, B. K. (2016). Grazing game: a learning tool for adaptive management in response to climate variability in semiarid areas of Ghana. Ecology and Society, 21(1).

Voorhees, G. (2009). The character of difference: Procedurality, rhetoric, and roleplaying games. Game Studies, 9(2).

Wals, A. E., & Rodela, R. (2014). Social learning towards sustainability: Problematic, perspectives and promise. NJAS-Wageningen Journal of Life Sciences, 69, 1-3.

Walsh, A., Magnuszewski, P., & Slodka-Turner, A. (2012). Can Banks Self-Regulate? Voluntary Agreements, Intrinsic Motivation and Games. Economic Affairs, 32(3), 58-64.

Walters, C. J., & Holling, C. S. (1990). Large-scale management experiments and learning by doing. Ecology, 71(6), 2060-2068.

Weichselgartner, J., & Kasperson, R. (2010). Barriers in the science-policy-practice interface: Toward a knowledge-action-system in global environmental change research. Global Environmental Change, 20(2), 266-277.

Winn, B. M. (2009). The design, play, and experience framework. In Handbook of research on effective electronic gaming in education (pp. 1010-1024). IGI Global.

Yusoff, Z., & Kamsin, A. (2015, August). Game rhetoric: interaction design model of persuasive learning for serious games. In International Conference on Learning and Collaboration Technologies (pp. 644-654). Springer, Cham.

ZAMCOM Agreement, Jul. 13, 2004, http://www.zambezicommission.org/sites/default/files/publication_downloads/zamcom-agreement.pdf

ZAMCOM (n.d.) Retrieved September 19, 2020, from http://www.zambezicommission.org/

Appendix 1

Game Use and Adaptation

The Nexus Game was played on a number of occasions to foster collaborative learning on transboundary resource management. As of this writing, the game has been played by more than 150 people with various backgrounds in academia, public administration, and business. Through workshops organized in different cultural settings in Asia (e.g. Lahore, Pakistan), Africa (e.g. Harare, Zimbabwe; Marrakech, Morocco; Johannesburg, South Africa; Cairo, Egypt) and Europe (e.g. Vienna, Austria; Dresden, Germany), the learning outcomes of the Nexus Game were proven to be translatable and transplantable to different environments (Figure 7). The characteristics of specific relationships and countries within the SADC region can be easily translated into different scenarios. The simulation can be adapted to showcase the biggest issues and gaps and support the understanding of the defined problems.

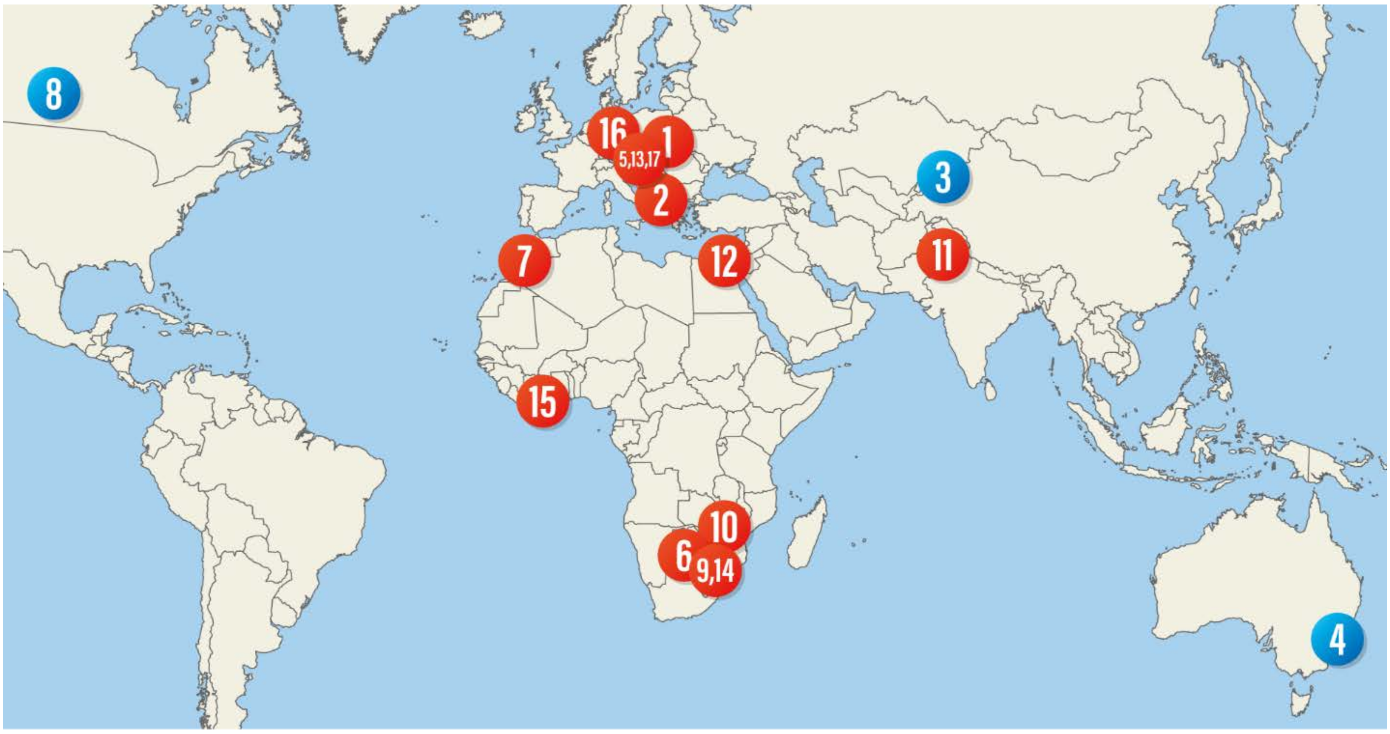

Figure A1: Locations in which the Nexus Game has been played
Source: Bartosz Naprawa, Centre for Systems Solutions
Note: Workshop names, locations and dates are listed in Table A1 (the numbers in red are workshops and in blue are training activities conducted).

It is important to highlight that players are not required to have any background in the SADC region to meaningfully engage in the gameplay. For example, Nexus Game proved to be adaptable to reflect the challenges of the water-food-energy nexus management in Europe. In doing so, the game was adopted to the nexus challenges of the Balkan's Drin River basin highlighting, for example, the locally relevant renewable energy potential of the region (i.e. the seasonality present in the original version of the simulation was kept, but the team adjusted renewable potential according to the European weather conditions). Similarly, the contents and various scenarios can be easily adjusted to fit other settings, while keeping original rules and mechanics.

Table A1. Summary of Nexus Game Applications

#	Workshop	Date	Location	Participants	No. of participants

1	Workshop “Nexus Game for the Nexus Dialogues Team”	18.02.2020	Frankfurt, Germany	Researchers, professionals, students	10
2	Workshop “Social simulations as a tool for sustainable development”, Jagiellonian University	19.10.2019	Cracow, Poland	Researchers and post-doctoral students.	~26
3	3rd Regional Nexus Roundtable in South East Europe	16.10.2019	Tirana, Albania	Representatives from sectoral ministries, private and non-governmental organizations	~40
4	The Regional Environmental Centre for Central Asia – CAREC	16-17.09.2019 (online training) 18.09.2019 (workshop)	Almaty, Kazakhstan	Representatives from sectoral ministries and academia	(~3 training) ~30
5	University of New South Wales	16-17.09.2019 (online training) 24.07.2019 (three simultaneous games)	Sydney, Australia	Undergraduate students	(~4 training) ~54
6	The Nexus Game and its potential application in stakeholder participation processes workshop, ÖFSE Headquarters	25.06.2019	Vienna, Austria	Researchers, development practitioners, teachers, students	12
7	Nexus Game at the 5th Targeted Regional Workshop for GEF:IW projects in Africa	27-28.05.2019	Gaborone, Botswana	Representatives from sectoral ministries, private and non-governmental organizations	22
8	9th Global Environment Facility Biennial International Waters Conference	03.11.2018	Marrakesh, Morocco	Representatives from government, multilateral, private and non-governmental organizations.	~25
9	University of Saskatchewan	09.10.2018 (online training)	Saskatoon, Canada		~5
10	Southern African Systems Analysis Centre’s Emerging Researchers Program 2018	21-22.08.2018	Johannesburg, South Africa	Researchers and post-doctoral students.	~20
11	Integrated Solutions for Water, Energy and Land (ISWEL) project meeting	09.07.2018	Harare, Zimbabwe	Representatives from National Stakeholders’ Coordination Committees of the Zambezi	~18

				Watercourse Commission (ZAMCOM)	
12	Workshop at Lahore University of Management Sciences	27.03.2018	Lahore, Pakistan	Local stakeholders and post- and pre-doctoral students.	~10
13	Workshop at IIASA's introduction of Water Modelling Approaches to Egyptian academics: Introduction and exploration of projects and training in modelling approaches	28.01.2018	Cairo, Egypt	Researchers and water management professionals.	~20
14	Workshop at the University of Natural Resources and Life Sciences	12.12.2017	Vienna, Austria	Masters-level students.	~15
15	Southern African Systems Analysis Centre's Emerging Researchers Program 2017	31.08-1.09.2017	Johannesburg, South Africa	Researchers and post-doctoral students.	~30
16	Workshop at African Development Bank	1.-2.06.2017	Abidjan, Ivory Coast	Development professionals.	~10
17	Dresden Nexus Conference	18.04.17	Dresden, Germany	Researchers and development professionals.	~20
18	Workshop at International Institute for Applied Systems Analysis	17.03.2017	Vienna, Austria	Researchers	~13

Appendix 2

A2.1 Questions investigating change in understanding

Table A2.1. Coding results for questions regarding learning (What have you learned? What do you think other people can learn by playing this game? What has changed in your understanding and opinions as a result of playing this game? What new facts or connections did you find while playing this game? What has changed in your understanding of the issues represented by this game as a result of this experience?

First-level coding	*Frequency*	*Social learning dimension*	*Second-level coding*	*Frequency*
System thinking in general	13	C	System thinking	132
Optimization of resources management (e.g. balancing, trade-offs)	19	C		
Scenario analysis/risk assessment/predicting future impact of decision making	15	C		
Interconnections/interdependencies/ complexity	27	C		
Significance of uncertainty	9	C		
Cross-sectoral, interdisciplinary and multi-dimensional decision-making and collaboration	47	C		
Importance of leverage points	2	C		
Group dynamics	10	R	Society (social psychology, social mechanisms)	82
Diversity of perspectives (needs, expectations, values, and viewpoints of different actors/stakeholders)	13	R		
Importance of common goals and cooperation	23	R		

Social skills (collaboration/group work/conflict management tools like mediations, negotiations, proper communication)	36	R		
Impact of natural/geographical/spatial factors (like location) including non-equivalence of upstream-downstream relations	9	C	Environment	45
Water related environmental knowledge	16	C		
Ecosystems related environmental knowledge	5	C		
Climate change related environmental knowledge	1	C		
Nexus related environmental knowledge	2	C		
Environmental management tools and skills	12	C		
Impact of personal attitudes and skills	15	C	Psychology	15
Significance of new technologies	12	C	Technology	12
Economic mechanisms and financial management aspects (including importance of proper planning, funding and investing)	16	C	Economy	19
Significance of ecosystem services/limited natural resources in gaining wealth	3	C		
Significance of governance structures (leadership, rules, institutions, policies, procedures)	16	C	Governance, Policy, and Politics	39
Challenges of international cooperation	23	C		
The role of simulations and games in learning	27	C	Gaming/Simulations	27

A2.2. Questions investigating impact of the gaming experience on the real-world situation of participants

Table A2.2. Coding results for questions regarding real world impact (Has this experience inspired you to change anything in the real world? If yes, please provide us with more details; Has this experience inspired you with new creative ideas on how to tackle your problems in the real world? If yes, please provide us with more details; Has the experience inspired you to take action in the real world? If yes, please provide us with more details; Do you think it is possible that playing this game could change something in policy making with regard to water management challenges? In what way?; How can you apply it in your work or in your life?; Do you think it is possible that playing this game could change something in policy making with regard to water management challenges? In what way?)

First-level coding	*Frequency*	*Social learning dimension*	*Second-level coding*	*Frequency*
To leave silos in order to understand complexity, to think transdisciplinary, holistically	16	C	System thinking	32
To use system analysis/thinking in own professional activity	7	C		
To consider complexity/feedback loops/uncertainty	5	C		
To enhance scenario analysis	4	C		
To enhance personal knowledge and skills	12	C	Psychology	19
To work on own's personality traits	7	C		
To change/improve working with groups schemes	5	R	Society (social psychology, social mechanisms)	10
To change project management schemes	5	R		
To gain/disseminate more environmental knowledge	2	C	Environment	11
To incorporate nature in water management	3	C		
To consider environmental impact	6	C		
To gain/disseminate more technological knowledge	4	C	Technology	5
To enhance technological means of water management	1	C		

To be aware of economic impact of water management	2	C	Economy	2
To enhance cooperation with media/press	1	R	Governance, Policy and Politics	60
To leave the silos in order to understand other perspectives/to enhance multi-sectoral cooperation	17	R		
To demand responsibility/information from governing persons/bodies	1	C		
To optimize SD goals	1	C		
To generally change practice in policy making	4	C		
To enhance cooperation between stakeholders/parties/interest groups	14	R		
To enhance international cooperation	9	R		
To base decisions on knowledge and deeper insight	5	C		
To support integrated management approach based on nexus	6	C		
To concentrate on long term solutions	2	C		
To use game in education & research	10	C	Gaming/Simulations	35
To use game in real life for scenario analysis	3	C		
To use game in real life to enhance cooperation & social learning	10	C		
To apply in management practice	12	C		
To change the way of thinking	6	C	General ideas	8
To apply & develop own ideas	2	C		
Other	10			