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Playing with Complex Systems? The Potential to Gain Geographical System Competence through Digital Gaming

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Abstract: The current socio-ecological challenges and phenomena that are major topics of geography education, like climate change and migration, are highly complex. Maturity in these contexts requires a networked way of thinking, and a systemic competence that is difficult to develop in geography classes alone. Digital games that simulate complex systems which include the pressing issues of today's challenges may be a useful supplement to foster systems thinking. In this study, we develop a framework to assess the complexity of in-game systems. A subsequent analysis of a selection of current commercial strategy and simulation games shows how system complexity is designed differently in the various games. Based on these results, we make recommendations for the selection and use of different games in formal and informal learning contexts.

Keywords: digital game-based learning; video games; systems thinking; system competence; geography education research

1. Introduction

The challenges in today's society are complex. Dealing with global phenomena, such as climate change, migration, and the reasonable handling of resources or problems associated with city development, requires an understanding of the underlying systems with consideration of all their elements, interrelations, and dynamics. As a basis to foster maturity in these fields, a competence in analyzing the dimensions of complex systems and including them into problem-solving strategies needs to be developed, known as 'system competence'. More precisely, system competence can be defined as the ability to identify, comprehend, describe and model a complex part of reality as a system regarding its organization and behavior, and to base predictions, as well as measures for regulation and usage of the system on this cognition [1,2]. The way of thinking required from systemically competent people is termed 'system(s) thinking'. This understanding of complex systems is gaining an increasing amount of attention, such as through the efforts to implement the Sustainable Development Goals [3], in the context of education for sustainable development [4], or in a general attempt to tackle the problems of our century [5,6].

In geography education, complex systems and system competence have a special significance, as the discipline is centered around interrelations between physical subsystems of the main complex system of 'Earth' and its respective human-geographic subsystems [2,7,8]. Geography (as a school subject) is predestined to impart a systemic competence connected to the complex problems of today's society, with worldwide socio-ecological challenges being major topics in geography classes. However, as many subject matters in geography textbooks for pupils are covered by a mere double page [9], analyzing the complexity of these topics, identifying interconnections between problems and discussing spatiotemporal dynamics is given little, if any, time in class. Thus, current socio-ecological challenges are not regarded in their integrity with little focus on interconnection and controversy and a lack of a multi-perspective approach, all of which are indispensable to build system competence. Digital games, many of which now include complex systemic issues, such as climate change, migration, urban development, and resource usage, may be able to fill in this gap—in case they are simulating systems which are complex enough to foster systems thinking.

In times where we have a generation of 'digital natives' in the education system, which use digital tools for both entertainment and information-gathering on a daily basis [10], overlooking digital games as a medium with educational potential is behind the times. Around 58% of adolescents aged 12 to 19 in Germany engage in digital gaming at least several times a week, with only 10% of teenagers not gaming at all [11]. At the start of the millennium, Prensky [12] had already identified that learners have changed, due to growing up with digital media and that they increasingly demand fun in learning, so teaching and learning methods should be adapted to accommodate this—i.e., through the use of digital games. This proposal is supported more recently by a number of authors that have tested the use of digital games in class [13] or have specifically examined their motivational potential [14–17].

In the course of this study, the virtual systems in a broad selection of strategy and simulation games are analyzed to determine whether gaming can complement geography education for gaining system competence. The main questions we strive to answer are: Do digital games provide the requirements necessary for the development of geographical systems thinking and competence? How complex are their modelled systems, and how do the games differ with respect to their complex game design? Are there groups of games that are more suitable for acquiring geographical system competence than others? Therefore, following an outline of current research on the use of games in learning contexts and system understanding in geography, we will deliver a model of complex systems in games. This model is used to investigate the complexity of the in-game systems in a selection of games. Ultimately, the aim is to group games according to the extent that they require systemic thinking from their players.

2. Theoretical Basis and Model Conception

2.1. State of Research: Games in Educational Contexts

Many studies on video games have attested an additional value of this medium in education. One benefit is engaging students who are less successful in traditional learning environments because they prefer "to develop understandings through building, tinkering, or more direct experiences" [13] (p. 5). The use of games in class had a particularly positive learning effect on these types of students—an example of which is the development of an understanding of historical events, and their spatial contexts through playing *Civilization III* [13]. Additionally, the motivational advantage of games over traditional learning methods is praised by a multitude of authors [14–18]. The source for intrinsic motivation is seen in various characteristics, contents and mechanics of games, such as the development of players' avatars and the narrative structure of game-quests [15] or the ability of game environments to promote challenge, curiosity, and fantasy, as well as to provide control, cooperation, competition, and recognition [18]. Games give rewards and feedback, enable players to master difficult situations and empower them to make decisions that shape the game world [16]. However, learning preferences vary, and there is no game that suits all learners equally [13]. Moreover, commercial and serious games have differing (dis-)advantages. Though serious games are often in need of improvement, regarding the extent to which they entertain players, and thus, in motivation to play, there is empirical evidence for their content-related learning outcome [19]. In contrast, a study by McFarlane et al. [20] showed that mainstream games rather develop players' general abilities, such as competences in planning and sequencing, social skills in communicating and negotiating, and numeracy skills. Each genre also has its own characteristics, and thus, distinct potentials for education. As an example, role-playing games (RPGs) offer a "next-level" experience of a perspectival change [21]: "You do not simply visit Williamsburg for an afternoon; you become part of that community" (p. 17) (referring to *Revolution*). The mass multiplayer versions of RPGs (MMORPGs) enable learning with and from other players [14], thus, allowing for social learning situations. Simulation and strategy games like *SimCity* or *Civilization* often cover longer timespans, and by making temporal developments visible on-screen playing these games can develop understanding of long-term system dynamics [22]. This condensed experience of time, and, as Gee [17] stresses, the lowered fear of failure or actions' aftermaths, also facilitates experiments with system interventions and their consequences, as well as an adaptation of measures according to the game feedback.

In summary, various types of digital games are able to motivate players through multiple means; they can trigger a plethora of learning processes, empower players to experiment with measures and roles that would be inaccessible to them in the real world, and they offer faster and more direct feedback to actions than most real-life processes would allow. With the potential development outcomes of these games in mind, a question arises as to whether this medium could be of constructive use in both formal and informal contexts for acquiring system competence in geography.

Games and System Competence

Studies on the potential of video games for promoting system competence are still surprisingly scarce. There are a number of studies and teaching material on the general use of games in educational contexts, for example, to instruct mathematical [23], and programming knowledge [24]. There are also resources regarding games for teaching geographical knowledge [19,25,26]. These studies share a commonality in that game-based learning is regarded as a way to transmit pure knowledge or problem-solving skills to find the exact solution to a precise problem, e.g., the correct physical-geographical terminology. However, (as in our increasingly complex world) there are often cases where there is no right or wrong answer to a problem, thus, games also need to be studied with respect to whether they require consideration of multiple variables and a creative mind.

Squire and Jenkins [21] present a more general understanding of problem-solving competence. The authors see the potential of games for the development of competence to gather information from the simulated environments to solve complex problems related to reality. Although the authors state that games can help players to build connections between different fields of knowledge and to recognize interdependencies between social processes, they do not explicitly make the link to systems thinking. This connection was made by Gee [17], who argues that "[g]ames encourage players to think about relationships, not isolated events, facts, and skills" (p. 16) and that "[i] n our complex global society, such system thinking is crucial for everyone" (ibid.). However, this perception is rather based on extensive personal engagement with a multitude of games than scientifically grounded, and as such leaves a research gap to fill. A study on the adoption of systemic thinking through gaming was carried out by DeVane et al. [27], in which the authors deduced, through observation of a discussion between gamers, how people playing *Civilization* use systems thinking to solve in-game problems. A valuable outcome of the discourse analysis was that, in fact, the players engaged in systemic thinking; an analysis of the strategy game itself did not take place.

Studies of city builder games also found evidence for fostering of systems thinking. An article on the educational use of *SimCity* in urban geography by Adams [22] found that by working with the game, students became aware that the relationships within a city are so complex that changing one detail will lead to subsequent changes of processes and patterns in it. How the simulated system itself works is only touched upon. Another work on *SimCity* by Gaber [28] did consider the complex systems depicted in the city builder. He identified examples of interconnected variables and how systemic solutions may look in the game (e.g., addressing traffic congestion by changing zoned land uses). Gaber [28] also identified limitations of the simulated urban system, amongst which was a strong focus on economic growth and a generic depiction of the city's inhabitants that does not allow for a representation of social issues. However, the aim was not an analysis of the game, but a summary of how *SimCity* can be used by planning instructors; therefore, a structured insight into the game system is not provided.

In a recent study Endl and Preisinger [29], though not explicitly referring to complex systems, explore how the ecologic discourse around climate change is integrated into the games *Urban Empire*, *Anno 2070*, and *Fate of the World*. The authors evaluated how many and how abstract variables regarding ecological quality were incorporated into the games, the types of measures that are available for interventions and the ways in which these influence the environment. Many of the criteria they assemble can be used for an evaluation of the simulated system from a geographer's point of view, though complex systems and system thinking are not directly addressed.

While these studies show that in both education and media studies there is a developing trend to connect digital games and systemic thinking, as well as the first evidence that gaming could be able to foster system thinkers, there has currently been no extensive comparison of the complexity of multiple up-to-date digital games' systems, especially not based on the geographical system understanding. As digital games, just like any other medium, "are crafted portrayals of the world shaped by innumerable decisions" [22] (p. 49) about what and who is shown how and what isn't included at all, an analysis of how complex in-game systems are designed is required before one is able to assess the medium's potential for the acquisition of system competence in a real-world context. The following study strives to fill this research gap by developing a framework for analyzing the extent to which complex systems are realized in games, and applying it to a selection of games that include core socio-ecological challenges relevant for geography education today. For that purpose, the study focuses on strategy and simulation games, since most of the previous studies on games and system thinking concentrate on these genres [22,27–29], and because of the abovementioned genre-specific potentials, e.g., for modeling system dynamics [22]. The development of the analysis framework is based on the theoretical concept of complex systems in geography.

2.2. Complex Systems and System Competence in Geography

The theoretical foundation of this study is the current understanding of complex human-environment-systems in geography, formulated, for example, by DGfG [7], Frischknecht-Tobler et al. [1], Rempfler and Uphues [2], and their follow-up studies [30,31]. Though Steiner [32] pointed out that due to epistemological discrepancies in the different theoretic approaches, there is yet no precise definition of human-environment-systems, there are some basic traits of those systems we can agree upon. Systems, in general, are constructs of multiple elements (like actors and factors) on different hierarchical levels that are interrelated, and thereby form temporally and spatially dynamic structures [33,34]. Open complex systems are additionally in constant interaction with their environment [30,31], though no system is ever fully independent of its surrounding [1]. Thereby, system boundaries are artificial and depend on perspective and research question [1]. Ecosystems and social systems are both classified as 'open' [1]. As a result of their openness, those systems are able to create and restructure their elements themselves, a characteristic termed autopoiesis, thus, enabling new structures and characteristics to emerge [31]. As a consequence of this, the behavior and further development of complex systems are difficult to predict.

A widespread system understanding in Geography distinguishes three classifications for geographical systems [30,35]: a physical geographical one (e.g., the physical aspects of climate change or soil erosion), a human geographical one (e.g., the anthropological aspects of urban development and migration), and, as a consequence of the inevitable interconnection between these two, a human-ecological one (e.g., human actions influencing climate change and vice versa, climate migration, human-driven desertification, urban development affecting nature and vice versa). In our world that is now so extensively influenced by humankind, physical and human geographic systems are never purely one or the other. Just the focus of examining the respective system can shift between a human-centered and a nature-centered one, or it can explicitly lie within socio-ecological interconnections. As one of the core tasks of geography as a school discipline is to develop the link between the natural and the social sciences by conveying the interrelations of society and nature in spaces of different kinds [7], this overarching, socio-ecological view on systems will be adopted for the study herein.

Based on the aforementioned concept, a definition of system competence can be determined. Frischknecht-Tobler et al. [1] describe competence, in general, as the willingness and ability to face challenges and solve problems, and to meet respective requirements in a variety of fields. In line with the described concept of complex geographical systems, a core ability of systemically competent people is seen in being capable of describing systems' elements, interrelations and borders, as well as their temporal dynamics [1,2]. Furthermore, being systemically competent involves the ability to make well-founded prognoses, and to develop action strategies accordingly [1,2]. While system competence refers to abilities and proficiencies, system thinking (also: systems thinking or systemic thinking) is the corresponding mindset and the holistic way systemically competent people think (though the two terms are often used synonymous, e.g., in Reference [31]). Thus, system thinking can be defined in contrast to the 'conventional thinking' in simple relations of causes and effects [6], also called monocausal thinking [31]. In other words, if someone, when addressing a complex problem, automatically looks for the underlying and connected systems, tries to identify how they work and takes them into account when making decisions, this person has adopted systemic thinking. The capability to then analyze system structures successfully and to reasonably use these insights is system competence. This makes systemic thinking a precondition for system competence. Of course, describing a single system and developing a strategy to solve a complex problem does not make one systemically competent, and sporadically engaging in systemic thinking does not mean one has become a 'system thinker'. Instead, system thinkers adopt specific habits, such as always trying to look at a problem from a number of different perspectives and considering both long- and short-term consequences of system interventions [1].

However, Frischknecht-Tobler et al. [1] point out that there is still disagreement as to whether system thinking (and competence) is bound to a certain field and context or whether it is a cross-specialism qualification, relevant in both professional and private contexts. As the complex problems of the 21st century underlie multiple interconnected systems, we consider the transdisciplinary, integrative approach to the systemic mindset and perspective, as well as to abilities and proficiencies essential to comprehend them. Only with a general system competence, it is possible to develop long-term solutions based on comprehensive analyses of systems and their interrelations that current global problems call for, instead of 'trial and error' approaches [30] or 'quick fixes' that aim to cure symptoms rather than the often obfuscated causes [6]. Having this in mind, how can a person gain such a way of thinking and competence? Video games may have the potential to confront the player with system elements, structures and dynamics and to make a habit of taking a whole system into account when developing measures for altering certain parts of it. Additionally, this interactive medium may provide the spatial context that is essential to the geographical system understanding [7]. It may also offer multiple perspectives onto systems, which are needed to develop systemic solutions [5], and to understand the influence of different actors on systems, such as if players are confronted with other players and non-player-characters. A framework to facilitate assessing the extent to which digital games really do this, is developed in the following section.

2.3. Framework for Assessing System Complexity in Digital Games

We developed the following model on the basis of the presented theoretical works about geographical systems and system thinking/competence ([30,31,33,34] amongst others) by applying the concepts they present to video games, while taking the specific characteristics of the medium into account. Its purpose is to facilitate the analysis of how complex geographical systems are depicted in games, such as the urban system in city builders like *Cities: Skylines* or *SimCity*. The model shall indicate the most important aspects of the system complexity of strategy and simulation game-systems as a means to compare the digital games and to derive assumptions about their educational potential with regards to systems thinking. It can be used as a framework to assess the complexity of any digital strategy or simulation game from a geographer's point of view, yet we do not claim the model to be exhaustive. The main model components to regard when analyzing complex systems in games are their elements, their degree of cross-linking and the offered measures for system intervention (Figure 1). Those components are explained in the following paragraphs.

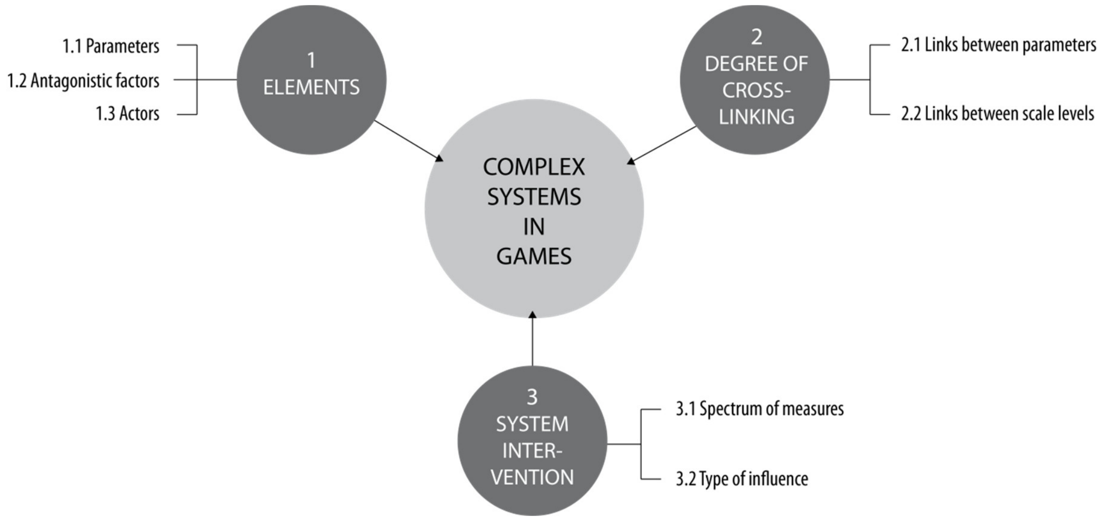

Figure 1. Model of complex systems in games (own design).

2.3.1. Elements

As described above, real-life complex systems consist of multiple elements, including actors and factors [33]. Such elements can also be found in digital game systems, as is explained below.

Parameters

Parameters are typical elements of strategy and simulation games. They are variables, such as the 'happiness' of the virtual population or the 'pollution' of the in-game environment. Their values change due to the player's actions, and the main goal of strategy and simulation games is to keep them on a good level. The parameters' status is clearly communicated on the user interface, most often as icon + value and less often via statistics. As system complexity is both tied to the number of elements and their diversity [36]—meaning that a system that consists of predominantly similar elements is less complex than one with elements that differ from each other—both aspects should also be regarded in the game analysis. 'Diversity' in the case of game parameters refers to how many and which topics they cover, in terms of whether the games focus on only one or few topics, such as the economy, or whether the systems include a number of fields at once, e.g., combining economic aspects of the system with aspects of demography, ecology and infrastructure. A high level of parameter variety requires different approaches to solve problems within the various topics, and it may be impossible to keep all parameters at a reasonable level. This results in so-called 'polytely' [37], so conflicts of objectives, which contributes to complexity. Topic diversity may also produce a more complex network of interconnections, which is addressed in Section 2.

Antagonistic Factors

Additional to parameters, there are factors to be considered in the simulated system of most games which do not appear as icon or statistic, but pose an antagonism in the game world, nonetheless. These factors can either be random events, such as natural disasters and fires, or pre-set conditions that limit the player's power, such as challenging topography, scarcity of space or the finite nature of resources. Along with parameters, they are considered as the in-game counterpart of the 'factors' shaping geographical systems [33,34]. As in real complex systems, these factors define and alter the system state and players are required to react to them, which means their occurrence contributes to the complexity.

Actors

Actors are central elements for shaping the dynamics of real-world human-environment-systems, as they can (de)stabilize and manipulate a system [33,34]. Thus, every actor, be it an individual or a group, increases the complexity of the system, especially in cases of collective behavior and adjustments of actors' decisions according to system change [38]. Hence, solutions to complex socio-ecologic problems often require compromises between different actors, and bringing together multiple perspectives also helps to solve them [5]. Such actors can likewise be identified in video games and could either be non-player characters or other players. In city builders, such as *SimCity*, an actor is the virtual city population, for example, and in political simulations like *Democracy 3* different voter groups appear as actors. As with real-life systems, the more actors that are included, the more complex the virtual system becomes. Each actor increases the multi-perspectivity in the game by bringing in their own goals and interests, which can be contrasting and conflicting to the player's goals. The player needs to take them into account while making decisions. Moreover, other players and non-player characters may intervene in the system in ways that are beyond the player's control, causing effects that players need to deal with and making the system less predictable.

To fully assess the influence of in-game actors, it is also necessary to regard negotiation mechanics, as in negotiations, the actors' perspectives actively influence the measures taken in the game system. Examples of such mechanisms are instruments of voting, virtual congresses or discussions with other players. Endl and Preisinger [29] stress that when dealing with real-life socio-ecological challenges (in their example climate change) measures are always discussed by a multitude of actors. As such, in their study, they consider whether decisions in games are negotiated as well or generally dictated by the player. We adopt and modify this category by looking at how negotiation mechanics in the selected games work. An inclusion of negotiation mechanics limits the players' control over the system further, as it puts their decisions to debate—they cannot make decisions all by themselves anymore. This increases the complexity of handling the in-game system, as positions of other actors have to be anticipated and results that deviate from a player's own position have to be accepted. As with real negotiations, their outcomes may change the status of the system different from the way the player intended. Consequently, the integration of negotiation further raises the difficulty to predict a game system's development, which is also a major component of real-life system complexity [31].

The players themselves, who have their own motivations, reactions and interests, are also important actors. However, since this model is intended to be a tool to analyze the complexity of games, the players are not explicitly included herein. However, the options for player's action offered by the games (the parameters they can control and the measures by which they can intervene in the system) are covered by other categories in the model.

2.3.2. Degree of Cross-Linking

As systems are not only defined by their elements, but also by the interconnections between them [2], and as the ability to describe relations within systems is an integral part of system competence [1], the model includes connections within the game system. When applying the geographic system theory to games, the central relations for assessing system complexity are the links between parameters and between scale levels.

Links between Parameters

According to Müller [34], the degree of cross-linking in a system is determined by the mutual influence of system elements and the hierarchy between them. In simulation and strategy games, the degree of interconnection between parameters contributes substantially to the complexity of the game. The more links are made between parameters, i.e., the more they influence each other, the higher the complexity. For example, if 'environmental pollution' decreases, due to a rise in 'education', the player needs to use a much more networked approach to sustain the game system than in cases in which such topics are treated completely separately. Such interconnectedness allows for both more complex problems ('why is the environment in bad condition despite there being few polluting industries?') and more complex solutions ('instead of building a bigger landfill site, why not opt for universities?'). Such connections between in-game parameters are included in this category.

Links between Scale Levels

Systems in games operate on various spatial scale levels, including on local, regional, national and global scales, which is especially relevant to the concept of systems presented in the German standards for geography education [7]. Another basic characteristic of complex systems is that alterations on one scale level will most likely lead to changes on other scale levels, which is termed system emergence [30], grounded on the butterfly effect [33,34]. Hence, it is relevant for assessing a game's system complexity from a geographer's point of view to regard which of, and how many, scale levels the player influences, and how they are interconnected, i.e., whether actions on one level affect others. For example, in *Fate of the World*, policies on national levels can increase or decrease global temperature rise. In summary, the more scale levels a player needs to manage and the more the actions on different levels affect each other, the more complex the game system becomes.

2.3.3. System Intervention

As digital games are an interactive medium, it is vital to consider the possibilities that each game offers to players that enable them to intervene in and regulate the system. For this game-specific category, we have borrowed and modified criteria from Endl and Preisinger [29], who sort, in their case for analyzing the depiction of the ecologic discourse, intervention methods in games, inter alia, by the offered spectrum (monothematic vs. holistic), the predominant logic of the intervention (curative vs. preventive) and the way they influence the system (the potential for unintended resultant effects). How these categories are modified to assess general (system) complexity is explained in the following section.

Spectrum of Measures

Within the category 'spectrum of measures' how the digital games differ in their offered range of options for player actions within the system is considered, including whether they offer one or a variety of approaches (e.g., political measures, infrastructure, changes of mindsets) to intervene in the system. The greater the number of approaches for system influence offered in a game, the more thought has to be given to the measures chosen, which increases the complexity the player needs to handle. For example, in the mobile game, *SimCity BuildIt*, players can only influence the game system by designating zones and placing special buildings, while in the PC-Version *SimCity 4* one can additionally pass regulations (such as a 'paper waste reduction program') to intervene in the system. This increases the complexity of choices ('which measure is the best to solve a problem in the game system?'), as well as the complexity of the system itself, as the possible reactions of the system to a player's action increase (e.g., 'does the game react differently to approaching urban crime with a police station or with a 'junior sports program'?').

An additional aspect to consider when looking at the spectrum of measures is the 'logic of interventions' in a game. This logic can either be curative, if a player mostly reacts to symptoms of problems, or preventive, if the avoiding and mitigation of problems are possible. For example, a curative intervention would be to implement filter technologies following pollution of air, and a preventive measure would be to use renewable energy sources to avoid air pollution. Preventive measures require anticipation of possible reactions of the system—an ability of systemically competent people [1]. The way in which the intervention logic in a game is designed, therefore, should be included when assessing the complexity of the offered intervention spectrum.

Type of Influence

In the category 'type of influence' we classify whether measures in the game have simple and direct effects (the cause-and-effect relations that are typical to be regarded by monocausal thinkers), or whether they may produce follow-up effects (chains of influence, or the even more complex spheres of influence, which lead to unintended side-effects). The latter are typical of real-life complex systems (also called 'correlated system relations', see Reference [34], pp. 40–41). Therefore, it is crucial to analyze whether games include complex spheres of influence or whether they are on a simpler level. An example of a simple type of influence would be that building a police station prevents all crime in the game. A more complex causal chain would be where financial crises cause job losses, which lead to increased crime rates. An even more complex example would be a sphere of influence where multiple factors cause crime, while e.g., the building of police stations leads to acts of defiance among criminals. The higher the number of the latter type of system relations simulated in a game, the more of a complex virtual system it becomes.

Overall, the greater the extent to which a game fits this model, the more their game system resembles a complex system. For these complex games it is then required that players think systemically to be able to complete them effectively. Thus, the described model can be used to assess the potential of digital games for fostering system thinking, and ultimately, system competence.

Non-Included System Characteristics

While this framework seeks to adopt categories that are necessary to analyze real-world complex systems, not all characteristics of real systems can be transferred to games. The described autonomous system regulation, identified as basic system trait e.g., by Müller [34], also called 'autopoesis' [31], does not work in the same way in-game environments: In most games, the system will either crash (in real-time games) or stand still (in turn-based games), if the player does not act. Even in-game types, in which the internal algorithms can alter the system state, external input (the players') is still required at some point for interrupting and shaping the game world. Otherwise, it would not be a game that needs to be played, but a simulation that can be solely observed. Furthermore, the irreversibility of changes in a system's status (as, for example, described by [33], p. 180, and [30], p. 151) is not applicable to games, because actions can be reversed easily (e.g., by tearing down buildings without further consequences, or by loading an earlier savegame). Likewise, the concept of openness [30,31] is irrelevant, i.e., the interaction with the system's surrounding, as we regard the in-game system as a whole and it cannot interact with systems outside of the game; except for the interaction with the player, which is not regarded in the study herein. Hence, those traits of real-life systems are excluded from this framework.

Although spatiotemporal dynamics, which are an integral part of real-life complex systems [34], are applicable to games, they cannot be used as criteria to compare the complexity of different games, and are therefore left aside in this study. It is evident that game systems are temporally dynamic because a static environment would not work. In strategy and simulation game genres, spatial dynamics are also natural, as these genres are precisely about altering the gamespace. Thus, a rating of complexity, as is pursued with our framework, cannot be based on the existence of spatiotemporal dynamics. For the study of digital games, it is more relevant in the context of space to compare the connection of different scale levels and the opportunities offered to alter the systems. Nevertheless, as different forms of realization and visualization of virtual spatiotemporal dynamics may support system understanding and other learning goals in various ways, those dynamics remain a research object for future studies.

3. Material and Methods

Using the described framework, we conducted a game analysis that collects both qualitative and quantitative data. The analysis was undertaken while playing all of the selected games. To reduce the bias resulting from the personal and the researcher's perspective, each game was played by 2–3 researchers with additional insights from non-scholarly 'Letsplays' (videos of people playing games) and online-wikis also included. The selection criteria and the application of the analysis tool are explained further in the following sections.

3.1. Selection of Games

A total of 18 strategy and simulation games were considered relevant for the study. To ensure that teachers can place the games in a thematic context where systems thinking is particularly relevant in geography, the games had to contain at least one of the following topics: City development, migration, climate change and/or resource usage. Furthermore, to focus the study to the most influential and presumably motivating games of the genres, additional criteria used to identify the games were high popularity (anticipated by high levels of sales on the corresponding platform, threshold 50.000 copies sold) and/or positive user critics (on Steam/Google Play and Metacritic), meaning we could assume a broad or at least a supportive community of players. Where sales were below or close to our set threshold or in case the data was insufficient, the user critics needed to be respectively higher (*Anno 1800, Rise of Industry*) or the game content had to be particularly relevant (*ECO, Fate of the World—Tipping Point*); with these exceptions to the criteria, we could also include valuable niche or new products. Table 1 shows the selected games, and the selection criteria applied. Many of the resulting games (or their predecessors) have either been included in studies on games and (geography) education previously, such as *SimCity* [22,28], *Civilization* [13], and *Anno* [29] or have received awards for their outstanding content that closely tied to our geographical topics (e.g., *ECO*).

Table 1. Selected games, their respective year of publication and selection criteria (included topics: (a) City development, (b) climate change, (c) migration, (d) resource usage; copies sold: as of June 2019; user critics: (1) Metascore on Metacritic, (2) recent reviews on Steam, (3) Google Play, as of June 2019).

Game	Year of Release	Included Topics	Copies Sold	User Critics
Age of Empires II HD	2013 (remade 2019)	(a), (d)	5,000,000–10,000,000	(1) 65/100 (2) ‘overwhelmingly positive’
Anno 1800	2019	(a), (d)	no data yet	(1) 81/100
Anno 2070	2011	(a), (b), (d)	500,000–1,000,000	(1) 83/100 (2) ‘mixed’
Banished	2014	(a), (c)	1,000,000–2,000,000	(1) 73/100 (2) ‘very positive’
Cities in Motion 2	2013	(a)	500,000–1,000,000	(1) 72/100 (2) ‘mixed’
Cities: Skylines (incl. Add-Ons ‘Natural Disasters’ and ‘Green Cities’)	2015 (N. D. 2016, G. C. 2017)	(a), (d)	5,000,000–10,000,000 (base game; no data on Add-Ons)	(1) 85/100 (2) ‘very positive’
Civilization VI (incl. Add-On ‘Gathering Storm’)	2016 (G. S. 2019)	(a), (b), (d)	2,000,000–5,000,000 (base game)	(1) 81/100 (2) ‘mostly positive’
Democracy 3	2013	(b), (c), (d)	200,000–500,000	(1) 70/100 (2) ‘mostly positive’
ECO (Early Access)	Early Access	(a), (b), (d)	no data yet	no data yet
Fate of the World—Tipping Point	2011	(b), (c), (d)	50,000–100,000 (base game; no data on ‘Tipping Point’)	(1) 70/100 (2) ‘mostly positive’
Frostpunk	2018	(a), (b), (c), (d)	2,000,000–5,000,000	(1) 84/100 (2) ‘very positive’
Pocket City (mobile game)	2018	(a), (d)	>1,000,000 (free version) >100,000 (paid version)	(3) 3.9/5 (free) 4.5/5 (paid)
Rise of Industry	2019	(d)	50,000–100,000	(1) 80/100 (2) ‘very positive’
Settlers 7	2010 (remade 2019)	(a), (d)	>150,000 (in Europe)	(1) 79/100

SimCity 4 (Deluxe Edition)	2003	(a), (d)	1,000,000–2,000,000	(1) 84/100 (2) 'very positive'
SimCity BuildIt (mobile game)	2014	(a), (d)	>50,000,000	(3) 4.5/5
Transport Fever	2016	(a)	200,000–500,000	(1) 71/100 (2) 'very positive'
Tropico 6	2019	(a), (c), (d)	200,000–500,000	(1) 78/100 (2) 'very positive'

3.2. Application of the Analysis Framework in the Empirical Study

The following section describes how the game analysis was conducted using the aforementioned model of complex systems in games (see Figure 1).

3.2.1. Elements

The overall category 'elements' was predominantly approached in a quantitative way. Within the sub-categories (parameters, antagonistic factors, actors), the number of each item per game was counted to enable a statistical comparison between the games. The way in which each item within the sub-categories was identified is explained in what follows.

Parameters

As the parameters are organized hierarchically (e.g., 'support' in *Tropico 6* is on a higher level than 'unemployment', as the latter feeds into the first), we distinguished between first and second levels. Parameters classified as being on the upper level are the ones which are game-deciding, so are closely tied to winning conditions. For example, if the objective of the game is economic success, the overall 'wealth' parameter that is influenced by multiple sub-parameters would belong to the first level. Commonly, such first level parameters are directly visible on the user interface when starting the game. For example, the parameters 'budget', 'population size' and 'happiness' in *Cities: Skylines* are visible as icons on the bottom of the screen. First level parameters can influence each other, but are on the same hierarchical level.

All parameters that directly influence the first level of parameters are herein classified as second level parameters. Most often they can be found in sub-menus that are not automatically visible on the interface. They are more directly controlled than the game-deciding parameters. Figure 2 shows an example from the game *Cities: Skylines*. In this game, there are three main parameters (budget, population size, satisfaction) and a larger number of second level parameters. The first level parameters (e.g., budget) cannot be directly controlled by the player; yet the second level parameters can. For example, 'attractiveness for tourism' can be enhanced by building parks and monuments. If the value of this parameter is high, tourists will visit and buy products in the virtual city, leading to a higher tax income, thus, increasing the first level parameter 'budget'.

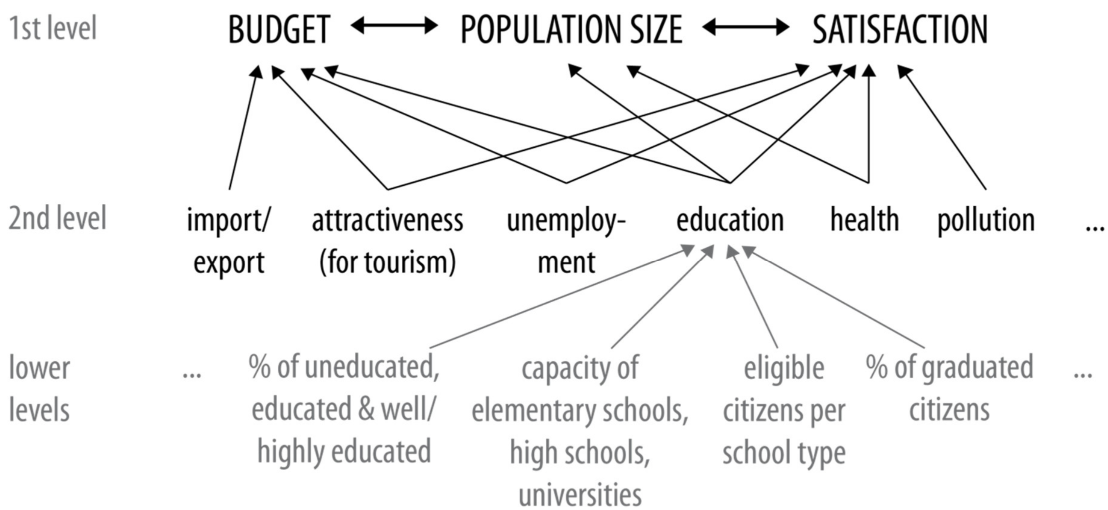

Figure 2. Differentiation between first and second level parameters, here in *Cities: Skylines* (cross-links between second level parameters left out for readability) (own design).

Sub-parameters of these second level variables, e.g., the 'percentage of highly educated', which is a sub-parameter of the overall 'education' parameter, are not included here, and are therefore greyed out in Figure 2. We defined these lower level parameters by their characteristic of having no cross-links to other parameters, i.e., they influence one second level parameter only, and they do not enhance the topic diversity (for example, the sub-parameters of 'education' all belong to the topic of education). Another differentiation criterion between second and lower level parameters was that the latter are found in sub-menus of the former.

The amounts of different resources (e.g., amounts of stored wood and coal), as well as industrial and agricultural products, were only counted as one parameter each if they are not interchangeable, i.e., only if each of the resources or products is important for game progression in a distinctive way and is produced differently. For example, in the economy-centered city builders *Anno 1800* and *Anno 2070*, each good has its own production chain and serves different needs, thus, their abundance and number matters for game success. In contrast, in *Pocket City* and *SimCity BuildIt*, goods are interchangeable, and it does not matter whether one produces food, chemicals or clothing, as they all serve the purpose of increasing wealth, and each product is generated in the same way. In this case, unrelated goods can be produced in the same factory. For these games, we counted all these products as one collective parameter.

In addition to the number of parameters, it was counted which, and how many, topics they cover and sorted by categories. Topic categories were deduced from the games and include 'health, education and demographics' (e.g., life expectancy, Human Development Index, population size), 'recreation and city attractiveness' (e.g., island beauty, recreational value), 'natural resources, industrial and agricultural products' (e.g., amount of coal/wood etc.), 'mentality, social values and attitudes' (e.g., number of religious citizens, equality, militancy), 'economy' (e.g., currency strength, GDP), 'political situation' (e.g., political stability), 'standard of living' (e.g., homelessness), 'environment and nature' (e.g., pollution), 'climate' (e.g., CO2 emissions), 'infrastructure' (e.g., traffic flow, fire safety), 'approval' (e.g., mayor rating) and 'others' (game-specific parameters such as skill points).

Antagonistic Factors

As explained in the framework, as 'antagonistic factors', we counted all the factors that limit the players' power in the game system and are, to a certain extent, beyond their control. Categories for the antagonistic factors were identified from the forms of challenges found in our game selection, which include a challenging geomorphology/terrain, the scarcity or finite nature of natural resources, natural disasters, scarcity of space, fire outbreaks, epidemics and outbursts of crime. The restriction of space and the terrain were only considered to be factors if they severely limited the player's power.

Actors

To identify actors within the game system, we looked at the non-player characters (NPCs) of the games, grouped them by categories determined by the games and identified their appearance in each game. Categories identified were (representatives of) interest groups/factions, representatives of nations, the city's population (as a collective) and NPC-individuals. Additionally, if there was a multiplayer option available, other real players were counted as actors as well.

For each game, we additionally investigated whether negotiation mechanics were included, i.e., whether the players need to put their intended actions up for discussion with these in-game actors, for example, via votes or congresses. If this was the case, we qualitatively described how such mechanics are realized in each of the games.

3.2.2. Degree of Cross-Linking

The interrelations in the virtual system were evaluated both qualitatively and quantitatively, with the aim of identifying differences between the games.

Links between Parameters

Within this category, we determined whether parameters were predominantly interconnected and influenced each other, or whether changes in one parameter's value do not affect others. For example, parameters, such as the growth rate of the population and their health, may or may not be connected in the games. It is evident that second level parameters influence the first level ones, so we only focused on the larger group of the second level parameters and the connections between these.

Links between Scale Levels

To analyze how links between different spatial scale levels are realized, we first quantitatively determined which and how many scale levels are included in each game. For this, we differentiated between local, regional, national and global scales. Additionally, as the interconnections between scale levels are particularly relevant, we included the categories 'interregional' and 'international'. Following this, we qualitatively analyzed whether actions on one scale level had a significant effect on other scale levels, as would be the case in real complex systems.

3.2.3. System Intervention

Within this category, we investigate the options given to players to manipulate the game system. We approached this category qualitatively to be able to describe the disparate realization of system intervention in the different games. Consequently, we identified similarities and differences between the games. As we are particularly interested in current socio-ecological challenges, we predominantly took anchor examples regarding measures affecting urban development, migration, climate change and resource use.

Spectrum of Measures

In line with the study undertaken by Endl and Preisinger [29], which primarily examined environment-relevant measures, we investigated whether the offered means to manipulate the game system are predominantly similar (e.g., mostly technological-infrastructural, like building energy infrastructure) or whether there is a wider spectrum (e.g., a balance between technology, political instruments and societal change options). While investigating this spectrum, we also considered whether players mostly react to symptoms of the current socio-ecological challenges or whether they can avoid and mitigate problems as well. As this is at times hard to distinguish (e.g., are the 'integration programs' offered in *Fate of the World* a curative or a preventive measure?), we only highlight extreme examples—i.e., whether a game solely requires reactions to problems or offers many possibilities for prevention. In summary, this category exposes whether the spectrum of possible measures allows different approaches to system intervention. We then grouped the games accordingly.

Type of Influence

The measures offered in the different games were additionally compared according to the effects they have on the system, depending on whether it is clear from the start of the action how the system will react to the applied measures, or whether subsequent effects can be triggered. We identified those (groups of) games that showed predominantly simple and those that had the most complex types of influence, again focusing on extreme examples.

4. Results and Discussion

In the following section, we present the results of applying the model to the 18 selected strategy and simulation games. The structure of this section is aligned with the model (Figure 1).

4.1. Elements

4.1.1. First Level Parameters

When comparing first level parameters, which are most influential to winning or losing the game, in many of the selected games they resembled one another. As Table 2 shows, in most of the analyzed games the size of the virtual population, their 'approval' of the player's action and the financial balance are the game-deciding parameters. Other first level parameters only occur in 44% of the games.

Table 2. Number and topics of first level parameters.

Game	Finances	Population Size	Approval Parameters	Others	Sum (Param.)
Civilization VI	x			Science, culture, faith, tourism, diplomatic favor, era score	**7**
Democracy 3			x	GDP, health, education, unemployment, crime rate, poverty	**7**
Fate of the World	x	x	x	Emissions, GDP, temperature, atmospheric concentration of greenhouse gases	**7**
Age of Empires II	x	x		Wood, stone, food	**5**
Anno 1800	x	x	x	Influence, city attractiveness	**5**
Settlers 7	x	x		Winning points, prestige	**4**
Anno 2070	x	x	x		**3**
Banished		x	x	Health	**3**
Cities:Skylines	x	x	x		**3**
Frostpunk		x	x (2x)		**3**
Pocket City	x	x	x		**3**

SimCity 4	x	x	x		**3**
SimCity BuildIt	x	x	x		**3**
Tropico 6	x	x	x		**3**
Cities in Motion 2	x		x		**2**
ECO				Personal nutrient intake, skill points	**2**
Rise of Industry	x		x		**2**
Transport Fever	x				**1**
Sum (games)	**14 (78%)**	**12 (67%)**	**13 (72%)**	**8 (44%)**	**Ø 3.7** parameters

Financial parameters, such as 'budget', 'gold' etc. were the most common first level parameters, with 78% of the games including these. When running short of virtual money, the player is restricted in action, as most measures have to be paid for (e.g., financing buildings and roads in city builders, the workforce in *Tropico*, subventions and research in *Fate of the World* or vehicles in *Cities in Motion*); thus, the cash inflow (either by taxes connected to the population size or by a flourishing economy) is game-deciding– the more wealth players can accumulate, the better.

Population size likewise belongs to the main parameters in a majority of games (67%). In all of these games (except for the mobile ones), the population is further divided into groups of specific professions or by the sector they work in. Without exception, a bigger population is considered more successful. Often this parameter is tied to winning or losing the games, where reaching a specific number of inhabitants unlocks new buildings (e.g., *Cities: Skylines*) or a large reduction in population results in the game ending (e.g., *FOTW*, *Banished*). In games with a military component, the population size also contributes to military strength (e.g., *Settlers 7*, *Age of Empires II*). As with the finances, a greater number is better. This shows that a majority of the games promote growth.

Additional to growth-related parameters, 72% of the games include a parameter that measures how content the in-game population is with the decisions made, thus far, such as 'support', 'approval rate', 'happiness' or 'satisfaction'. As with the 'population size' parameter, in many games, the approval can be viewed for different groups of people, e.g., sorted by profession or income. As such approval parameters are influenced by various second level parameters (such as in *SimCity 4*, where it is influenced by the opinion polls on the environment, health, safety and three others), they can be used to check whether all the important aspects in a game system are being managed successfully, according to the game's logic.

Table 2 also shows that the number of game-deciding parameters ranges between 1 and 7, with an average of 3.7, and 8 of 18 games having three. The first level parameters (concerning both number and topics) are too similar between games to differentiate their complexity based on this criterion. This similarity is thought to stem from the games having the same underlying capitalistic logic, where growth and expansion are considered to be positive. These games may follow this logic because it is familiar and easy to understand. It is also thought that game designers are likely to copy concepts found in existing games, as experimental concepts may not sell as well. Both growth-related topics and a low number of first level parameters have already proven to be marketable characteristics of a game. However, differences between games appear when looking at the second level parameters.

4.1.2. Second Level Parameters

The numbers of second level parameters vary significantly between games (Figure 3). With an excess of 40 parameters, the political simulations *Democracy 3* and *Fate of the World (FOTW)*, the economy simulations *Anno 1800*, *Anno 2070* and *Rise of Industry*, the politics-centered economy simulation *Tropico 6* and the likewise politics-centered open world simulation *ECO* are at the top of the range. All games in our selection that focus on politics belong in this group. The games with the least second level parameters (0–9) to be managed are *Age of Empires (AoE) II* and *Cities in Motion 2*. Both center on one specific aspect to manage—*AoE* on military, *Cities in Motion* on public transport.

Other games with a specific focus (*Transport Fever*—transport; *Banished* and *Frostpunk*—survival) and the two mobile games (*SimCity BuildIt* and *Pocket City*) also have a comparatively low number of parameters (10–19). The mobile games may include fewer parameters to be playable while on the move and to keep the small smartphone screens uncluttered. When differentiating between all the city builders in our selection (*SimCity*, *Anno*, *Settlers*, *Tropico*, *Cities: Skylines* and the mobile games), those with an elaborate economic system (e.g., *Settlers* and *Anno*) generally include more parameters than those without (e.g., *SimCity* and *Cities: Skylines*), as they offer a broad range of commodity chains to manage, and thus, a lot of parameters connected to them. All things considered, although the strategy and simulation games are similar in their main parameters, they differ in the number of second level parameters. Generally, the analyzed games with a political or economic focus tend to offer more manageable parameters than 'pure' city builders, mobile games or games with strong foci on topics other than economy or politics. We will, therefore, take a closer look at the parameters' topics in the following section.

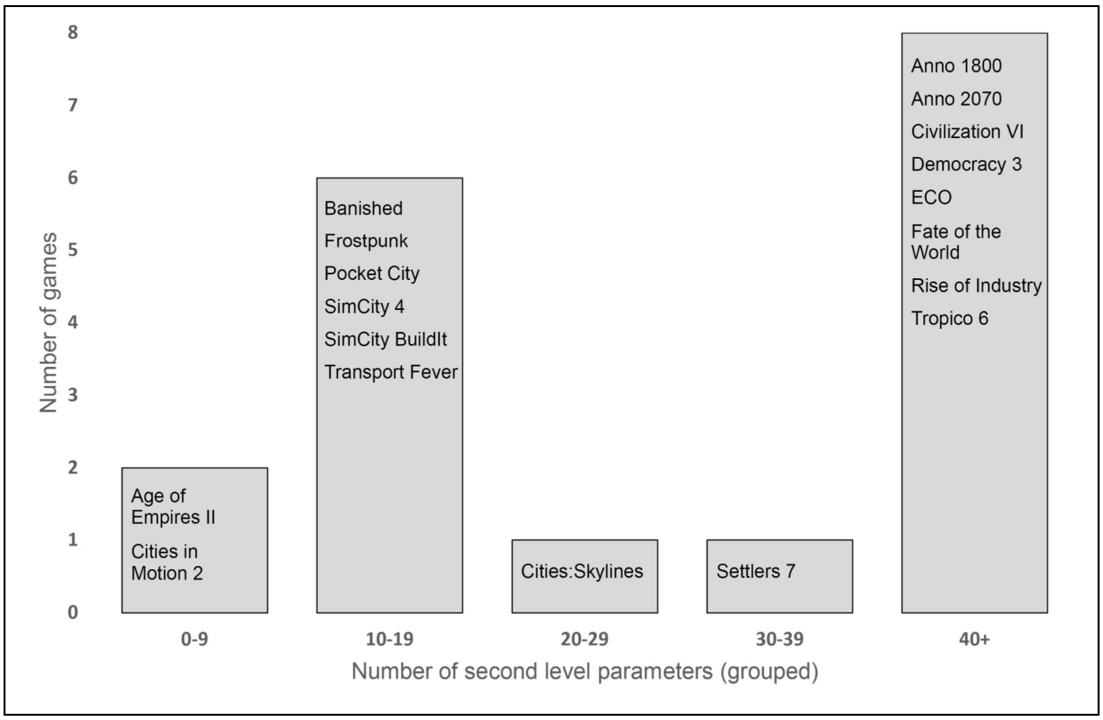

Figure 3. Classified numbers of second level parameters in the selected games (own design).

4.1.3. Topics of Parameters

Table 3 shows how many and which topics are covered by both first and second level parameters in the selected games, showing whether the parameters of a game are, for example, about environmental issues (e.g., the parameter 'pollution' in *Cities: Skylines*), infrastructural issues (e.g., 'traffic congestion' in *Pocket City*) or others. The topics that are covered by 40 or more parameters are marked blue. By far the most important parameter topics are economy (in 94% of games studied; represented by parameters, such as 'weekly cash flow' in *Cities in Motion 2* or 'food price' in *Democracy 3*), and the amounts of different resources or goods (in 83% of games studied). The importance of these topics confirms the finding made earlier that most of the games follow a capitalist logic. The games differ most from each other when considering other topics. 'Education, health or demographics' and 'approval' (mostly due to the mentioned first-level parameters about population size and the satisfaction of the population), as well as 'infrastructure' (represented, for example, by parameters such as 'electricity' or 'disaster detection' in *Cities: Skylines*), are included in some form in 72% of the games. Building infrastructure and economy, thus, have a higher priority in the selected games than the quality of living resulting from it (which is only included in 56% of the games, e.g., via parameters such as 'average wages' in *Democracy 3* or the 'number of homeless' in *Frostpunk*). This may be because setting up infrastructure is one of the core gameplay actions in the majority of games studied (also see Section 4.3.1). Though overall environmental parameters (such as 'environment' in *Pocket City* or 'ecobalance' in *Anno 2070*) are relatively frequent (56%), those explicitly related to climate change are rare (22%, like 'CO_2 levels' and 'sea level' in *Civilization VI*). This is probably because climate change is an extremely complex topic that requires much research to be integrated properly. Likewise, the topics 'recreation and city attractiveness', 'mentality, social values and attitudes' and the 'political situation' are only found in a few of the games. They define sub-genres of the selected strategy and simulation games—e.g., parameters of city attractiveness typically play a role in city builders, while the political situation of the governed territory (such as the political stability in *FOTW*) is particularly relevant for politics-centered games.

When now considering the number of topics per game, additional differences begin to show. Table 3 indicates that the politics-centered games (*Democracy 3*, *FOTW*, *Tropico 6*) are not only the ones with most parameters, but also those offering the broadest range of topics to manage (10–11 topics per game), without putting too much emphasis on any one topic. This may be because real-life politics need to cover a plethora of topics as well. Unsurprisingly, games with a strong focus on one specific overall theme, be it economy, ecology or transport infrastructure, are found at the bottom of the range (6–2 topics). Moreover, games with a large number of parameters are revealed to occupy a thematic niche: *ECO* has a dual focus on the environmental and product parameters, and covers only three other topics, which reflects the game's focus on tinkering and influencing biodiversity in a simulated ecosystem, while showing that these topics can be explored with a large number of parameters. *Rise of Industry* shows a strong focus as well, with over 40 parameters each categorized into 'economy' and 'products'. In this game, it is possible to explore, in-depth, how commodity chains work. Classic city builders, such as *Cities: Skylines*, *SimCity* and their mobile counterparts, as well as hybrids of a city builder and economy simulations (*Anno 1800* and *2070*) are found in the upper middle of the range when it comes to parameter diversity (7–8 topics). This can be explained by the fact that many aspects have to be considered in cities in order for them to function, as the game logic suggests.

Overall, many of the selected games include a variety of topics, with *Democracy 3*, *Fate of the World* and *Tropico* on top of the range, and naturally, the games with a narrow focus (e.g., *Transport Fever*) at the bottom. The games confronting the player with a plethora of topics are insofar more complex, as the simultaneous management of diverse issues, just as in real-life complex systems, leads to the already mentioned polytelic situations. Additional insight into parameter complexity can be gained by a joint examination of the quantity and diversity of parameters.

Table 3. Topics covered by first and second level parameters; topics covered by 40 or more parameters are marked blue (A = education, health, and demographics, B = recreation and city attractiveness, C = nat. resources, industrial, and agricultural products, D = mentality, social values, and attitudes, E = economy, F = political situation G = standard of living, H = environment and nature, I = climate, J = infrastructure, K = approval, L = others).

Game	A	B	C	D	E	F	G	H	I	J	K	L	sum
Democracy 3	x		x	x	x	x	x	x	x	x	x	x	11
Fate of the World	x		x	x	x	x	x	x	x	x	x		10
Tropico 6	x	x	x		x	x	x	x		x	x	x	10
Anno 2070	x	x	x		x	x	x	x		x	x		9
Anno 1800	x	x	x		x	x	x	x			x		8
Cities: Skylines	x	x	x		x		x	x		x	x		8
Civilization VI		x	x	x	x	x			x	x		x	8
Pocket City	x	x	x		x		x	x		x	x		8
SimCity 4	x	x		x	x		x	x		x	x		8
SimCity BuildIt	x		x		x		x	x		x	x		7
Frostpunk	x		x		x		x			x	x		6
ECO			x		x			x	x			x	5

Settlers 7	x		x		x					x		x	5
Age of Empires II	x		x		x								3
Banished	x		x								x		3
Cities in Motion 2					x					x	x		3
Rise of Industry			x		x						x		3
Transport Fever					x					x			2
sum	13 72%	7 39%	15 83%	4 22%	17 94%	6 33%	10 56%	10 56%	4 22%	13 72%	13 72%	5 28%	

Table 4 shows the intersection of parameter number and topic diversity. With the help of this cross-table, the games were grouped according to their parameter complexity. Only 5 out of 18 analyzed games had neither a high topic diversity nor a high parameter count. We classify those games as less complex in regards to their parameters (marked in grey). Those are games that focus on other things rather than managing a lot of parameters, such as military interaction with other actors in the game system (*AoE II*) or surviving in a harsh environment (*Banished*, *Frostpunk*). Three games cover a high number of topics with comparably few parameters (marked as light green). This suggests that these games have aggregated parameters, i.e., parameters that unite many aspects of a topic in them. For example, rather than covering the topic 'ecology' with several precise variables, in *Pocket City*, everything related to that topic is included in the vague parameter 'environment'. These unspecific parameters may hinder logical connections between processes in human-environment systems; for example, why and how processes of city development influence the environment remains unclear if there is only one cumulated ecology-parameter without a unit of measurement. Therefore, we classify this group as 'superficially complex'. In contrast, three games in our selection include many parameters on a few topics, meaning that they address at least one of these topics in-depth. In addition to *ECO* and *Rise of Industry*, which have already been identified as games with strong foci, *Settlers* also focuses on one topic, in this case, product chains. In these three games, the player can concentrate completely on the influences on a certain part of the system—e.g., in *ECO* on the influence of climate change and other human activity on the population and distribution of various plant and animal species. We classify these games as topic-specific complex (marked in mid green). The largest group of games that can be identified in Table 4 are the ones with high parameter count and high topic diversity (7 of 18, marked dark green); these are the games classified as highly complex regarding their parameters, in which players need to handle many matters simultaneously. Besides the political games and economy-centered city builders, *Cities: Skylines* includes a relatively large number of topics and parameters as well, meaning this is the most complex city builder based on parameters.

Overall, there are significant differences in parameter complexity (both regarding quantity and topics) within the genres of strategy and simulation games. This is most likely due to the differing foci—a military-centered game such as *Age of Empires* does not need many parameters, and nor do transport- or survival-centered games (e.g., *Cities in Motion*, *Banished*). Classic city-builders, such as *SimCity*, have a high parameter topic diversity to cover the various issues of city development (e.g., infrastructure, environment, economy), but the numbers of parameters are typically relatively low, probably to allow their players to focus on designing their city. In contrast, the majority of the games have managing parameter complexity as a main game mechanic, either specifically regarding one or few topics (e.g., managing commodity chains in *Settlers* or *Rise of Industry*, or influencing ecosystems in *ECO*) or multiple ones (e.g., regulating the diverse causes and effects of climate change in *Fate of the World*). In summary, a number of strategy and simulation games encourage their players to improve their skill to deal with different issues and their effects on the game system (represented by parameters) at the same time. The increased diversity of system elements and resulting polytelic situations ('Should I tend to this parameter or another?') contribute strongly to system complexity.

Table 4. Cross-table between the number of parameters and the covered topics in the game selection (grey = less complex regarding parameters; light green = superficially complex regarding parameters, mid green = topic-specific complex r. p.; dark green = highly complex r. p.).

Topic Diversity / No. of Parameters	1–3	4–6	7–9	10–12	Sum
0–9	2 Age of Empires II, Cities in Motion 2	0	0	0	2 (11%)
10–19	2 Banished, Transport Fever	1 Frostpunk	3 Pocket City SimCity 4, SimCity BuildIt	0	6 (33%)
20–29	0	0	1 Cities: Skylines	0	1 (6%)
30–39	0	1 Settlers 7	0	0	1 (6%)
40+	1 Rise of Industry	1 ECO	4 Anno 1800, Anno 2070, Civilization VI, Tropico 6	2 Democracy 3, Fate of the World	8 (44%)
sum	5 (28%)	3 (17%)	8 (44%)	2 (11%)	18 (100%)

4.1.4. Antagonistic Factors

As explained in the method section, antagonistic factors are less controllable by the player than parameters and are additional elements to consider when assessing a game system's complexity. Table 5 shows the antagonistic factors that occur in each of the selected games. These include a challenging terrain/map (e.g., hardly cultivable mountains or difficult access to resources), limited space (e.g., due to a small space of action or pre-existing structures), depleting/limited resources (e.g., the finite nature of coal, the slow regeneration of forests or limited resource availability in the space of action), natural disasters (such as volcanic eruptions or extreme weather) and outbreaks of fire, epidemics or riots and crime.

Table 5. Antagonistic factors that occur in the selected games.

Game	Challenging Terrain/Map	Scarcity of Space	Depleting or Limited Resources	Fire	Diseases and Epidemics	Riots and Crime	Natural Disasters	Sum
Anno 2070	x	x	x	x	x	x	x	7
Frostpunk	x	x	x	x	x	x	x	7
Anno 1800	x	x	x	x	x	x		6
Banished	x	x	x	x	x		x	6
Cities: Skylines	x	x		x	x	x	x	6
Tropico 6	x	x	x	x		x	x	6
Fate of the World			x	x	x	x	x	5
Civilization VI	x	x	x				x	4
Pocket City		x		x	x	x		4
SimCity 4		x		x	x	x		4
SimCity BuildIt		x		x	x	x		4

Democracy 3					x	x	x	3
ECO	x		x				x	3
Settlers 7	x	x	x					3
Age of Empires II	x		x					2
Cities in Motion 2	x	x						2
Rise of Industry			x					1
Transport Fever	x							1
Sum	12 (67%)	12 (67%)	11 (61%)	10 (56%)	10 (56%)	10 (56%)	9 (50%)	

As Table 5 shows, the most frequent antagonistic factors are a challenging terrain/map (in 67% of games studied), limited space (67%) and depleting or limited available resources (61%). It is interesting for the geographic topic of 'resource use', that the limitedness of resources is one of the most common antagonisms in the games, enforcing a sustainable or at least considerate usage. This may be because unlimited resources would severely reduce the challenge for the player, and thus, the gaming fun. The additional challenge is also most likely the reason why the majority of games include more than one antagonistic factor; such external factors and random events are the aspects of a game that cannot be fully controlled or predicted by the player and can interfere with a player's plan. These factors gain more importance in the course of the game: As the virtual cities expand, the lack of space comes into effect, fires become more likely because the sources of fire are multiplied, and resources are depleting and/or their demand is increasing. These factors then demand interesting player decisions; when, for example, a city in *Anno* grows so much that space on the island becomes scarce, the player needs to decide whether it makes more sense to expand on new grounds, restructure the city or outsource some industries. Considering such factors while planning system interventions makes them more suitable in the long run. Taking external influencing factors into account when working with complex systems, anticipating their development and adapting measures accordingly is also a skill of systemically competent people [1].

Considering the rankings in Table 5, many of the games with a high parameter complexity (*Anno*, *Cities: Skylines*, *Tropico* and *Fate of the World*) are also among those that include the most antagonistic factors, which further enhances their complexity. In addition, some games rated less complex so far are also at the upper end of the scale, such as *Frostpunk* and *Banished*. They balance their lack of parameter complexity by adding multiple antagonistic factors. As these two build-up simulation games focus on survival in a harsh environment, it makes sense that they make use of antagonisms rather than of controllable parameters. In contrast, *SimCity BuildIt* and *Pocket City*, which appear to include multiple antagonistic factors, are not as complex as they seem: In those games events, such as fire, diseases, or riots, are almost completely in the player's control, the chance of occurrence can be set to zero by placing the respective infrastructure (hospitals, fire and police departments). This makes the games less suitable for teaching the player to understand that complex systems are not always controllable and that one has to expect sudden disturbances, as is the case with real-life complex systems [38]. Moreover, some other city builders hint at the probability of such events with their infrastructural parameters (such as 'fire probability' in *SimCity 4* and 'fire safety' in *Cities: Skylines*), yet in these non-mobile city builders disaster events are less easy to prevent. On the whole, many games confirm the previous impression of their system complexity through their antagonistic factors.

4.1.5. Actors

Further system complexity is added by actors, which need to be taken into account when manipulating the game system. As Table 6 shows, almost all games include another type of actor besides the player, yet few games involve more than one. The most common type of actor is the 'city population' (72%, see Table 6), treated as a mass, i.e., as one collective actor with collective interests.

This is problematic, as it does not reflect the real complexity and multi-perspective nature of a city's population. A reason for this simplification may be that individuals or factions with diverging concerns may be difficult to simulate. Still, there are games that include more elaborate actors. Other nations (or their representatives) are included in 22% of the selected games. For example, in *Fate of the World*, the player has to manage policies in various nations, which in turn react to the player's actions. In *Civilization VI* a leader represents nations (or civilizations) (e.g., Catherine de Medici representing the French), which act in the game system just as the player does. Interest groups/factions and NPC-individuals are both included in 17% of the games studied. Interest groups can be voter groups like in *Democracy 3* (e.g., socialists, retired, wealthy), or factions such as the eco-friendly and the industrialist factions in *Anno 2070.* NPC-individuals are virtual characters that do not represent a specific interest group or nation, such as trading partners in *Anno* or opponents in *Settlers.* Other real players mutually only occur as actors in one game (*ECO*) but are optional in the multiplayer-modes of seven other games. Overall, most variety of system participants is offered in *Tropico 6*, where the player is confronted with ten different factions (e.g., capitalists, communists, religious, environmentalists, industrialists), other nations to manage foreign relations with, the overall city population and (in multiplayer mode) other players. This fits the heretofore established typology insofar as *Tropico* is also classified as one of the most complex games in the previous categories.

Table 6. Types of actors influencing the in-game systems. (x) = in the optional multiplayer mode only.

Game	(Representatives of) Interest Groups or Factions	(Representatives of) Nations	NPC-Individuals	City Population (Mass)	Other Players	Sum
Tropico 6	x	x		x	(x)	3 (4)
Anno 2070	x		x	x	(x)	3 (3)
Age of Empires II		x		x	(x)	2 (3)
Anno 1800			x	x	(x)	2 (3)
Settlers 7			x	x	(x)	2 (3)
Cities in Motion 2				x	(x)	1 (2)
Civilization VI		x			(x)	1 (2)
Banished				x		1
Cities Skylines				x		1
Democracy 3	x					1
ECO					x	1
Fate of the World		x				1
Frostpunk				x		1
Pocket City				x		1
SimCity 4				x		1
SimCity BuildIt				x		1
Transport Fever				x		1
Rise of Industry						0
Sum	3 (17%)	4 (22%)	3 (17%)	13 (72%)	1 (6%) (8 [44%])	

For assessing a game system's complexity, it is worth considering to what extent such actors limit the player's control over the development of the game, e.g., via negotiation mechanisms. When analyzing how the actors intervene in a system, it was found that most of them influence the game passively. In the majority of the games studied, the actions the player decides on are implemented without discussion. In *Tropico 6*, this lack of negotiation links to the game narrative; the player embodies a dictator—thus, it makes sense to decide all measures on one's own. However, there are mechanics that cause the player to include the other actors' perspectives. For example, in *Tropico 6*, ignoring the interests of citizens or factions may cause them to take revenge in the next virtual election: If a player's actions are against the will of the majority of voters, the player loses the position as president, and thus, the game. Such an election mechanic is also included in *Democracy 3*. The 'approval' parameters used in the majority of games (see Section 4.1.1) contribute to including actors' demands similarly: In city builders, the dissatisfaction of the population leads to people moving out of the city, thus, dropping the other first level parameter 'population size' and bringing the player closer to losing the game. Another mechanic to include the actors are demands (e.g., the religious faction in *Tropico 6* demanding to build a church) or trade agreements. Whilst these are optional, they may influence the goodwill of the enquirers and other actors, particularly if different actors have conflicting demands, and a player needs to choose sides. However, true negotiation of players' actions in the game system is not carried out in such games.

A different mechanism to include system actors can be found in *Civilization VI*. After each 30th turn (starting in medieval times) a 'World Congress' is undertaken. In this congress, all civilizations come together to decide about resolutions. Additionally, nations can summon congress when an emergency occurs. Within the scope of this congress, a "currency" called 'diplomatic favor' is used to vote for certain resolutions, which can be used to steer the result of the vote according to the player's will. Diplomatic favor is won by doing favors for other civilizations or by holding alliances, and a small amount is won each turn. In this way, the game rewards the consideration of the interests of other system actors. Additionally, *Civilization VI* has implemented a system called 'grievance', which works in a similar way to the described 'approval' mechanisms. When acting against the will of other civilizations (such as settling next to them though they wished otherwise or, worst, declaring war), they pile up a grievance against the player's nation. This determines whether other nations act in a benevolent or hostile way towards a player.

ECO, a mutual multiplayer game, includes the mechanics closest to real negotiation. In this open-world simulation, every player is a settler with limited power, and players need to collaborate to build up functioning cities and economies in the virtual ecosystem. An in-game chat is used to exchange ideas, such as where to open which kind of store, where to mine next, where to plant what. Chatting seems to be one of few game mechanics that allow for true negotiation of players' actions. In the optional multiplayer modes offered in some of the other games studied (e.g., *AoE* or *Anno*) such direct negotiation can also take place. In *ECO* recently also another mechanic to include opinions of other players was implemented, which gives an option to formulate a form of constitution for the community. In this constitution, players define the basics of government, such as currency, but also propose laws and rules that are voted on. Such rules mostly focus on protecting the ecosystem; for example, players can agree upon protected areas for specific animals. The constitution is placed in a government building, which is relevant as players can "overthrow" an existing government by constructing a larger building and putting a new constitution up to vote. The idea behind this mechanic is that a player needs the back-up of several other players to construct the highest building, and the more people support their idea of a constitution, the easier it is to gain the power. With this system in place, the majority of players manages system intervention and restricts each player's power to manipulate the game system.

In conclusion, most of the analyzed strategy and simulation games include at least one type of actor in addition to the player, whose opinions on how the game system shall develop have to be included by the player in some way. Generally, programming actors that influence the game system may be complicated or too demanding with respect to the hardware, leading to most games including only one type—such as combining the city population to one collective mass. Still, as the given examples show, even a single type of actor can force the player to consider multiple opinions and perspectives; it depends on the implemented negotiation mechanics. Considering this, the findings, thus far, are interlinked: Many of the games which have been rated complex so far (*ECO*, *Tropico 6*, *Democracy 3*, *Civilization VI*) also add complexity to the game system through the integration of negotiation. This is because these politics-centered games logically contain a sort of voting mechanism. Thus, these games, in particular, offer the potential to train players in considering multiple perspectives when making decisions within human-environment systems, as is expected from systemically competent people. However, real negotiation only takes place in multiplayer games.

4.2. Degree of Cross-Linking

4.2.1. Links between Scale Levels

For geographic systems, it is particularly relevant that developments on different scale levels (from local to global) influence each other [30,33]. When regarding the scale levels, the game systems operate in (Table 7), it is found that only 56% of the analyzed strategy and simulation games include different scales. All the classic city builders operate solely on a local level, with no links made between a city's development and the development of its surrounding. This is convenient for mobile games because it would be difficult to provide an overview of developments on different scale levels on the move and on a small screen.

Links between scale levels are possible for PC city builders, as seen in the economy-centered *Anno* series and the politics-centered *Tropico*. In these games, players manage cities on several islands, influence their surrounding regions (e.g., with air pollution) and engage in interregional trade between islands. In *Tropico* international foreign relations add another scale level; for example, fulfilling demands of other countries leads to decreased prices when trading goods with them, which has positive effects on a local level (such as more budget for city development), while dismissing such tasks may ultimately lead to invasions. *Anno 2070* adds a global scale level with elections of a world president, which can have effects on the lower scales (e.g., special boni).

Two games in the selection cover all scale levels; *Civilization VI* and *ECO*. In *Civilization*, players plan their nation's cities on a local scale (e.g., where to settle and what to build), therein influencing and being influenced by the surrounding region (such as being disturbed by nearby volcanoes or deforesting the region) and contributing to the nation's development (e.g., the transition from industrial to modern times); they trade on interregional and international scales, cause climate change on a global level and have to negotiate and mitigate the issue internationally. In the open-world simulation *ECO*, each player can mine, harvest and build on local levels, thereby affecting the region (e.g., by depleting resources and shrinking animal populations) and ultimately causing global climate change. Recently (the game is still in development) the implementation of governments on all scales has also become possible (see Section 4.1.5), enabling political regulations on different scale levels. This strong interconnection between scale levels in *ECO* is relevant because the game is a simulated ecosystem; it is thought to be precisely about the fact that actions of individuals on lower scales influence the higher ones in real life.

Overall, again most of the games with a high parameter complexity are those that make links between multiple scale levels (*Civilization*, *ECO*, *Anno*, *Tropico*, *FOTW*), thereby increasing their complexity further. Exceptions are *Cities: Skylines*, as it is a classic city builder centered on local developments, and *Democracy 3*, which is only about national politics. Interestingly, *Transport Fever*, which has a low parameter complexity, is also among the games that link several scale levels. This game connects (inter-)regional developments with local city development, in which increasing the connectivity between different cities or regions by extending the transport infrastructure causes the cities to grow automatically. Hence, to foster a player's understanding of how systems cause developments on different spatial scales, it may also be worthwhile investigating games that are less complex in other regards, but can make the players focus on spatial interrelations.

Table 7. Scale levels to operate within the selected games.

Game	Local	Regional	Interregional	National	International	Global	sum
Civilization VI	x	x	x	x	x	x	6
ECO	x	x	x	x	x	x	6
Anno 2070	x	x	x			x	4
Tropico 6	x	x	x		x		4
Anno 1800	x	x	x				3
Fate of the World				x	x	x	3
Settlers 7	x	x	x				3
Transport Fever	x	x	x				3
Age of Empires II	x	x					2
Rise of Industry		x	x				2
Banished	x						1
Cities in Motion 2	x						1
Cities: Skylines	x						1
Democracy 3				x			1
Frostpunk	x						1
Pocket City	x						1
SimCity 4	x						1
SimCity BuildIt	x						1
sum	15 (83%)	9 (50%)	8 (44%)	4 (22%)	4 (22%)	4 (22%)	

4.2.2. Links between Parameters

As explained in the model, not only does each parameter itself contribute to complexity, but also the extent to which they are interconnected. As it is self-explanatory that second level parameters influence the main ones, we look at the cross-linking within the second level here. Extreme examples of games with little connectivity between parameters are the mobile city builders. In *Pocket City* and *SimCity BuildIt*, the players simply work through each parameter individually. For example, if there is crime then players can treat this issue separately from everything else that is happening in the city by simply building more police stations, without having to consider other parameters, such as education or the current job situation. Again, this may stem from making these games playable on the move and for "casual" gamers. However, including such interconnections between parameters is important for training system thinking in the context of real-life socio-ecological challenges, as systemic issues, such as city development and climate change, are highly interconnected phenomena and identifying regulations requires linking various social and environmental factors, which are both causes and effects [30]. Such links between parameters occur in all other games in our selection, to a certain degree. For example, *Cities: Skylines* links its 'education' and 'pollution' parameters; the better the educational level of the virtual population, the lower their waste production.

A game that is of note in regard to parameter connectivity is *Democracy 3*, particularly for its visualization; not only are the game's parameters highly interconnected, but their connection is visualized through the use of relational arrows that clearly show how parameters influence each other (i.e., whether an increase in value increases or decreases other parameters' values), as is shown in Figures 4 and 5. Hence, the game's interface resembles a concept map—a diagram showing interrelations within its components, often used to depict complex systems (as in References [8,30,31]). This visualization could be beneficial for educational contexts, as it makes the system's interconnection more understandable.

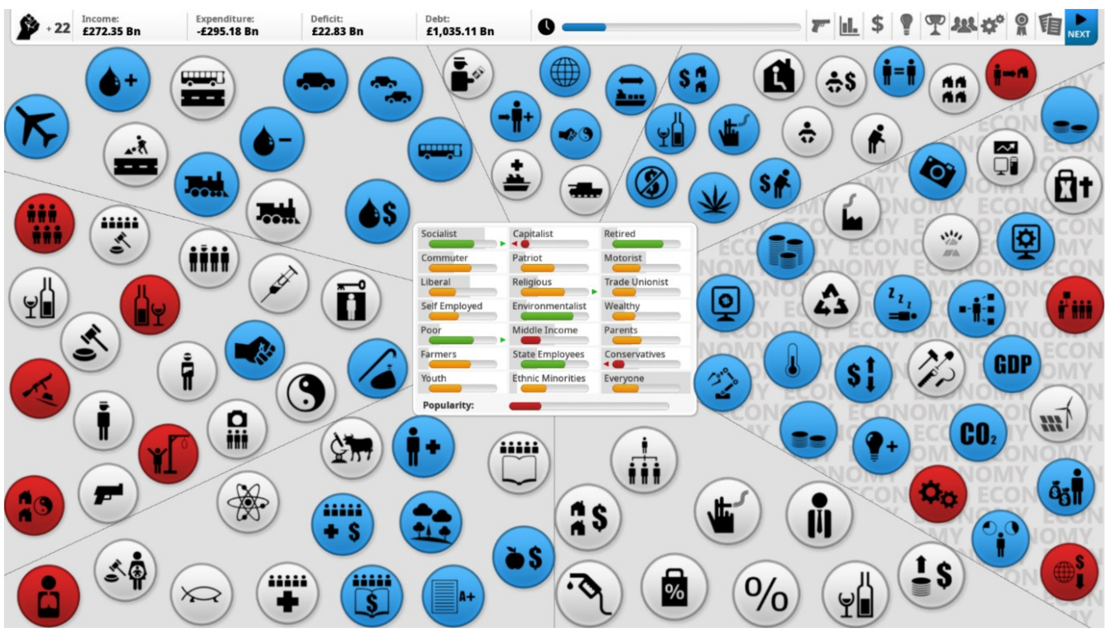

Figure 4. The interface of Democracy 3—blue and red buttons represent parameters, and white buttons represent measures to take (Screenshot).

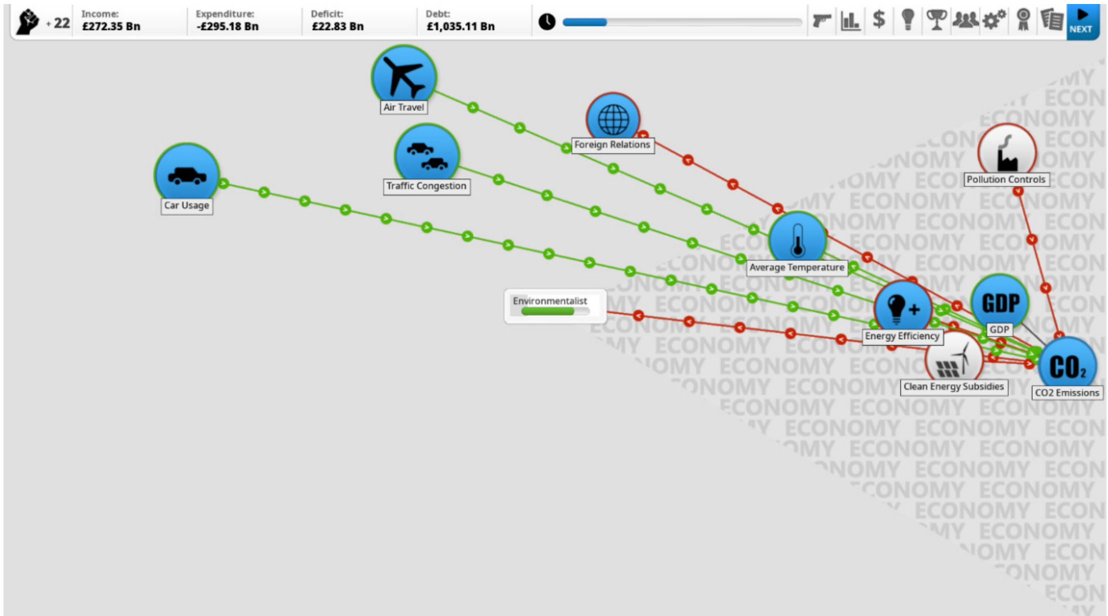

Figure 5. The interface of Democracy 3 when hovering over a button (here 'CO$_2$'). Green arrows indicate an increase, red a decrease (Screenshot).

Another game that is outstanding with respect to its parameter connectivity is *FOTW*. In this game, greenhouse gas emissions of a country, level of development, migration, parameters of life quality, distribution and direction of the sectors and a large number of other parameters all influence each other. For example, the further development of a country in the game leads to higher mobility and subsequently to increased transport-related emissions, which in turn influence a variety of parameters, such as the number of climate migrants.

Generally, we found that the games, including the highest numbers of parameters, are also most likely to make the most connections. Thus, the two groups 'topic-specific parameter complexity' (e.g., *ECO*, *Rise of Industry* etc.) and 'high parameter complexity' (e.g., *Fate of the World*, *Tropico 6*, *Democracy 3* etc.) contain most linkages between different parts of their game systems. Overall, several of the selected games have the potential to contribute to enhancing players' competence in solving complex problems as this involves, according to Dörner and Funke [37], being able to manage multiple interconnected variables.

4.3. System Intervention

4.3.1. Spectrum of Measures

When analyzing system complexity of games, it is important to consider that they are an interactive medium. Within this category, we determined the variety of possibilities given to players for manipulating and regulating these virtual systems. The wider the spectrum to choose from, the more players need to think systemically to find the appropriate measure for each situation, resulting in games becoming increasingly complex.

The measures players can implement to interact in these virtual systems vary considerably between the games studied. However, groups can still be identified. In games with a city-building component, such as *SimCity*, *Frostpunk* or *Tropico*, the measures are typically a mixture of buying and placing buildings or zones (belonging to the first, second or third sector, or housing) or other infrastructure, and choosing policies or edicts (for example, the "prohibition" in *Tropico* or a carpooling support program in *SimCity*), and in some of these games also gathering of resources (e.g., wood and coal in *Frostpunk*) is a typical player action. *ECO*, despite being an open-world simulation and not a city builder, includes similar measures: Gathering resources, constructing buildings, developing technologies and deciding on laws; but in collaboration with other players (see Section

4.1.5). The diversity of this spectrum of infrastructural and political options varies within this group, with games that were rated as more complex in previous categories also being most complex in terms of system intervention. For example, the choices of edicts and other policies in *Tropico* is greater than in *Cities: Skylines* and *SimCity*. In *Rise of Industry* and the transport-centered simulations *Cities in Motion 2* and *Transport Fever*, the political aspect of the game is limited to price policies; 'policies' in *Pocket City* are merely boosts for the city's growth; whilst *SimCity BuildIt* and *Banished* do not include policies at all—hence, the diversity of actions, and thus, the complexity in this category is lower in these kinds of games.

A second group to be identified are the political simulations that have no city building component, which includes *Democracy* and *Fate of the World.* No buildings have to be placed in these games, so they are not about an efficient city structure, and players' interaction with the system is solely focused on choosing political measures, but from a greater selection than in the city builders. However, these policies can also cover the same areas that are covered by buildings in other games, such as choosing a particular form of energy production or expanding the first, second or third sector. *FOTW* offers a diverse spectrum of policies and other political measures, particularly for tackling climate change, from campaigns for a climate-friendly diet, different directions of agriculture, industry and energy production, mitigation measures, such as coast protection, and experimental options, such as the release of additional aerosols into the atmosphere. Due to the game linking economic and social development to climate change, as identified in Section 4.2.2, measures not obviously related to climate change, e.g., funding job-sharing initiatives, also affect the climate—which widens the possibilities players have to influence this topic. A similar range of options is given in *Democracy 3*, with the policies players can implement ranging from subsidies (e.g., for organic farming) to societal change options (like an alcohol awareness campaign) to laws and taxes. This diverse mixture of measures (technology, education, societal change, structural choices, direct and indirect approaches) mean *FOTW* and *Democracy 3* are particularly suitable for training players to identify system-adequate measures, as players have the freedom of choice how to approach interventions in the complex game system. The resulting difficult decisions also make the games more complex.

Another aspect to consider is whether the measures players can implement are solely curative (so to solve already existing problems) or also preventive. This is relevant as systemically competent people are expected to make a well-founded prognoses for the system's development before acting [1], which can be taught in games, if players are given the opportunity to take precautionary action. Games that predominantly involve reactive actions are much less complex because they require little forethought from players, and less understanding of the game's system is needed. Measures can be both preventive and curative for the majority of games studied, with some differences in the dominance of either one or the other. In games that include climate change as a topic, most notably *Fate of the World, Civilization VI, ECO* and *Democracy,* players need to plan ahead (e.g., deciding for 'greener' energy early) as damage to the climate cannot be reversed (with the exception of the unrealistic carbon-dioxide recapture project in *Civilization*). In regard to precautionary actions also the survival simulations *Frostpunk* and *Banished* are notable; as they focus on the survival of their virtual population, and each occurring problem (such as an epidemic or harsh weather) can lead to the death of the population and to losing the game, solely curative approaches are not successful. Thus, players need to anticipate developments and implement measures accordingly (e.g., the timely procurement of resources). However, in city builders, players often react to the demands of the virtual citizens. The mobile city builder games demand the least anticipation of developments from their players. Players mostly react to problems rather than prevent them (e.g., simply placing a new landfill when the capacity is low, or a new source of energy when pollution becomes problematic) in these games. This may also be due to the 'one-by-one' unlocking of new buildings, which leads to a linear execution of tasks. Games that aim for post treatment of problems may be problematic for a use in geography education, as this approach is not very successful in real complex systems and should not be conveyed as the only way to solve systemic problems. All in all, with some exceptions (e.g., the survival games) the classification of games outlined, thus far, is confirmed, particularly in regard to the mobile city builders.

4.3.2. Type of Influence

Here we consider whether outcomes of player actions are clear from the start, so follow direct cause-and-effect relationships, or if the games confront their players with complex chains or spheres of influence and unexpected side-effects of their actions, which frequently occur in real complex systems [38]. Again, the mobile city builders are at the bottom of the range. It is obvious in these games, which player action has which effect on the virtual city. For example, when placing an educational building in *SimCity BuildIt*, it will cause an increase in population (though not directly logical, but the increment is communicated to the player even before placing the building) and in the citizen's satisfaction; there are no other effects to be expected. This is directly linked to the missing interconnection between second level parameters; as each of them only affects the main parameters 'budget', 'population size' and 'happiness', there are no follow-up-effects from influencing other second level parameters. Generally, we found that the more links are made between parameters in a game (see Section 4.2.2), the more likely they also include complex chains or spheres of influence. Moreover, a high number and topic diversity of parameters is the basis for the inclusion of many-faceted side effects. This confirms the typology of games established so far. For that matter, games with a lower parameter connectivity, such as *Age of Empires* or *Banished*, include more direct cause-effect relations (e.g., between the amounts of resources and the development of the settlements), while classic city builder games are in the middle of the range. For example, *Cities: Skylines* includes both simple relations (e.g., recreational facilities instantly raise the population's contentment) and effect chains (e.g., noise pollution negatively affects citizens, which become unable to work, and thus, a strain on the economy). In *FOTW* and *Democracy 3*, which have particularly high levels of interconnection and parameter complexity, measures produce the most complex effects on the game system. Endl and Preisinger [29] give an example of this for *FOTW*, where a hasty expansion of e-mobility can lead to an increased need of coal, and thus, contribute to climate change, in turn producing multiplied follow-up effects. Such spheres of influence enhance the system complexity significantly, as each action can trigger various unintended developments. Therefore, players need to plan carefully and think systemically to be successful in these games.

5. Conclusions: Implications for Training System Thinking in Geography Education

Within this study, a model of complex systems in digital games has been developed and introduced as a framework to analyze the system complexity of strategy and simulation games (Figure 1). The more complex game systems are, according to our model, the more they demand systemic thinking from their players to be successful—and thus, the more they are suitable for geography education, whose main topics (such as climate change and urban development) also require such a way of thinking to be successfully dealt with. A subsequent empirical application to 18 commercial games disclosed the (types of) games that have the most potential for training people in system thinking and ultimately developing system competence.

According to our analysis, the politics-centered games *Tropico 6*, *Civilization VI*, *Democracy 3* and *Fate of the World*, and the economy-centered city builders *Anno 2070* and *Anno 1800* are the most complex in our selection. In these games, players need to manage many parameters at once within a variety of topics by choosing between a profusion of different solution approaches on various scale levels, while taking into account multiple actors and causing complex chains or spheres of effects. These examples show that parameter complexity (number and topics of parameters) is a good indicator for the overall system complexity of a game—all of these games were rated as the most complex in that first category. There were slight deviations from this observation: The ecosystem-simulation *ECO* is, with the exception of its topic diversity, also among the most complex games, particularly regarding the integration of negotiation mechanics and the links between economic and ecologic parameters. The classic city builder game *Cities: Skylines* is not as complex regarding actors and the links between scale levels, but offers a high parameter complexity with high connectivity (e.g., between education, pollution, crime and the quality of living), so it is still suitable for furthering systemic thinking. Overall, there are a variety of commercial games which confront their players with high complexity, due to their system elements, system relations and the measures players can implement. It is also worth noting that many of the analyzed games resemble the serious simulations that are used to scientifically measure a person's ability to solve problems within complex systems [37], which are classed as simulations with multiple variables that are interdependent and have to be overseen together at one time. This is particularly interesting because the analyzed games are commercial entertainment games, and this, therefore, suggests that complexity seems to be marketable.

However, we also identified a minority of strategy and simulation games that are less complex when considering their virtual geographic systems. The games considered least suitable for engaging students in systemic thinking are the mobile city builder games *SimCity BuildIt* and *Pocket City*, as they link neither parameters nor developments on different scale levels and promote simple cause-effect relationships. This lack of system elements, interconnections and intervention possibilities may also occur in other mobile games because they are adapted for casual gaming on the go and on a small screen. Other games, such as *Age of Empires II*, *Banished* and *Cities in Motion 2*, are also rated as of minimal complexity according to the model presented, as they include fewer parameters, fewer topics and fewer types of actors, and are not outstanding in their degree of cross-linking or their offered spectrum of measures. This is because their focus is different—they center on military, survival, public transport or similar rather than on managing complex human-environment systems. Nonetheless, systemic components and interdependencies are included in these games to a certain degree and have to be considered in the playing strategy, so they still have the potential to serve as entry-level games for establishing the first steps of system thinking. The survival-games *Frostpunk* and *Banished* are particularly relevant for training anticipatory planning, due to the high number of antagonistic factors they include and their preventive intervention logic (see Sections 4.1.4 and 4.3.1). Additionally, as these games include socio-ecological challenges, such as the sustainable usage of resources, it may still be worthwhile investigating their geographic content in detail.

We also disclosed aspects of our selected games that need to be considered critically. As derived from the fact that in most of the games the increase of the parameters 'budget' and 'population size' leads to success, the underlying system seems to focus on growth—"the more the better". This is in line with Gaber's [28] theory, based on an older version of *SimCity*, in regard to its focus on economic growth (see Section 2.1). How this affects the in-game system, e.g., which effects it has on the consumption of resources, the development of the virtual cities and the treatment of the environment, should be reflected upon when playing or discussing these games. Additionally, the simplifications in many of the games, such as regarding a city's population as one uniform actor, or combining all impacts on the environment in a generic parameter, such as 'pollution', should be considered. In general, it should be noted that the systems modelled in the games are not necessarily realistic.

Playing the complex games in formal educational contexts offers opportunities for a school class to engage in dynamic decision-making [39] within the same game systems and to discuss resultant effects, thereby creating social learning situations similar to those in online multiplayer games [14], and contributing to developing system competence together. In case there is no opportunity to play the games in class, as homework or in an extracurricular course, geography teachers can build on experiences the adolescents develop in their free-time and reflect upon different in-game representations of socio-ecologic systems in class. The model presented in this study can serve as a guideline on which parts of a game's system to concentrate. One suggestion for reflection could be the system actors; for example, students could determine which actors have an influence on the urban system in a city builder, such as *Cities: Skylines* or similar, and in comparison, which actors are important in this context in real life. How the actors are presented (e.g., why it is over-simplifying to depict the city population as one collective mass) and how negotiation is integrated into games could also be discussed. Another idea is to reflect on the interconnection between scale levels in games and use this as a starting point for a discussion focused on how much real system changes at one spatial level can lead to changes at other levels. The same could be done with other components of the model.

Such discussions could lead to a higher understanding of the complexity of human-environment systems. Additionally, the model can help to determine which games are best suited for which grade level, where less complex games (according to the model) could be a good first step for lower grades, and later lessons could build on this.

Future studies should take a closer look at the geographical content of games to determine how realistic the current socio-ecological challenges presented in strategy and simulation games are, as they may influence players' concepts of reality. When doing so, the perspective of game developers on the realism of their games could also give valuable insights. Moreover, the games' content could be compared with the current education standards to further assess their value for geography education. Another next step would be to investigate how realistic pupils consider the game content to be. These studies would contribute to the research on the medium's potential to help develop students' understanding and ability to deal with the complex socio-ecological systems that are the most relevant challenges faced in the twenty-first century.

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References

1. Frischknecht-Tobler, U.; Kunz, P.; Nagel, U. Systemdenken-Begriffe, Konzepte und Definitionen. In *Systemdenken. Wie Kinder und Jugendliche Komplexe Systeme Verstehen Lernen*; Frischknecht-Tobler, U., Nagel, U., Seybold, H., Eds.; Pestalozzianum: Zürich, Switzerland, 2008; pp. 11–32.
2. Rempfler, A.; Uphues, R. Systemkompetenz und ihre Förderung im Geographieunterricht. *Geogr. Sch.* **2011**, *189*, 22–33.
3. Reynolds, M.; Blackmore, C.; Ison, R.; Shah, R.; Wedlock, E. The Role of Systems Thinking in the Practice of Implementing Sustainable Development Goals. In *Handbook of Sustainability Science and Research*; World Sustainability Series; Leal Filho, W., Ed.; Springer: Cham, Switzerland, 2018; pp. 677–698.
4. Bollmann-Zuberbühler, B.; Strauss, N.-C.; Kunz, P.; Frischknecht-Tobler, U. Systemdenken als Schlüsselkompetenz einer Bildung für nachhaltige Entwicklung–Eine explorative Studie zum Transfer in Schule und Unterricht. *Beitr. Lehr. Lehr.* **2016**, *34*, 368–383.
5. Lantermann, E.D.; Döring-Seipel, E. Probleme im Umgang mit komplexen Umwelten. In *Innovative Ansätze zum Schutz der Natur*; Erdmann, K.H., Mager, T.J., Eds.; Springer: Berlin/Heidelberg, Germany, 2000; pp. 151–164.
6. Stroh, D.P. *Systems Thinking for Social Change: A Practical Guide to Solving Complex Problems, Avoiding Unintended Consequences and Achieving Lasting Results*; Chelsea Green: White River Junction, VT, USA, 2015.
7. Deutsche Gesellschaft für Geographie (DGfG). *Bildungsstandards im Fach Geographie für den Mittleren Schulabschluss mit Aufgabenbeispielen*, 9th ed.; Self-Published: Bonn, Germany, 2017.
8. Viehrig, K.; Siegmund, A.; Funke, J.; Wüstenberg, S.; Greiff, S. The Heidelberg Inventory of Geographic System Competency Model. In *Competence Assessment in Education. Methodology of Educational Measurement and Assessment*; Leutner, D., Fleischer, J., Grünkorn, J., Klieme, E., Eds.; Springer: Cham, Switzerland, 2017; pp. 31–53.
9. Maier, V.; Budke, A. Politische Bildung durch Planungsaufgaben: Ein Vergleich deutscher und britischer Geographieschulbücher. In *Politische Bildung im Geographieunterricht*; Budke, A., Kuckuck, M., Eds.; Franz Steiner: Stuttgart, Germany, 2016; pp. 187-197.
10. Prensky, M. *Teaching Digital natives: Partnering for Real Learning*; Corwin: Thousand Oaks, CA, USA, 2010.

11. Medienpädagogischer Forschungsverbund Südwest (MPFS). *JIM-Studie 2018-Jugend, Information, Medien: Basisuntersuchung zum Medienumgang 12- bis 19-Jähriger*; Self-Published: Stuttgart, Germany, 2018.
12. Prensky, M. *Digital Game-Based Learning*; McGraw-Hill: New York, NY, USA, 2001.
13. Squire, K. Changing the Game: What Happens When Video Games Enter the Classroom? *Innov. J. Online Educ.* **2005**, *1*, 1–7.
14. Akcaoglu, M. Using MMORPGs in Classrooms: Stories vs. Teachers as Sources of Motivation. In *Cases on Digital Game-Based Learning: Methods, Models, and Strategies*; Baek, Y., Whitton, N., Eds.; Information Science Reference (IGI Global): Hershey, PA, USA, 2013; pp. 15-24.
15. Dickey, M. Game design and learning: A conjectural analysis of how massively multiple online role-playing games (MMORPGs) foster intrinsic motivation. *J. Educ. Psychol.* **2007**, *88*, 715–730.
16. Gee, J.P. *Why Video Games are Good for Your Soul: Pleasure and Learning*; Common Ground Publishing: Melbourne, Australia, 2005.
17. Gee, J.P. Good video games and good learning. *Phi Kappa Phi Forum* **2005**, *85*, 33–37. Available online: https://www.phikappaphi.org/docs/default-source/phi-kappa-phi-forum-documents/2005_summer.pdf (accessed on 4 May 2020).
18. Malone, T.W.; Lepper, M.R. Making learning fun: A taxonomy of intrinsic motivations for learning. In *Aptitude, Learning, and Instruction*; Snow, R.E., Farr, M.J., Eds.; Erlbaum: Hillsdale, NJ, USA, 1987; Volume 3, pp. 223–254.
19. Hébert, C.; Jenson, J.; Fong, K. Challenges with Measuring Learning through Digital Gameplay in K–12 Classrooms. *Media Commun.* **2018**, *6*, 112–125.
20. McFarlane, A.; Sparrowhawk, A.; Heald, Y. *Report on the Educational Use of Games. An Exploration by TEEM of the Contribution Which Games Can Make to the Education Process*; Teem: Cambridge, UK, 2002.
21. Squire, K.; Jenkins, H. Harnessing the Power of Games in Education. *Insight* **2003**, *3*, 5–33.
22. Adams, P.C. Teaching and Learning with SimCity 2000. *J. Geogr.* **1998**, *97*, 47–55, doi:10.1080/00221349808978827.
23. Orim, R.E.; Ekwueme, C.O. The roles of games in teaching and learning of mathematics in junior secondary schools. *Glob. J. Educ. Res.* **2011**, *10*, 121–124.
24. Gomes, T.C.S.; Falcao, T.P.; Tedesco, P.C.A.R. Exploring an approach based on digital games for teaching programming concepts to young children. *Int. J. Child-Computer Interact.* **2018**, *16*, 77–84.
25. Tüzün, H.; Yılmaz-Soylu, M.; Karakuş, T.; İnal, Y.; Kızılkaya, G. The effects of computer games on primary school students' achievement and motivation in geography learning. *Comput. Educ.* **2009**, *52*, 68–77.
26. Virvou, M.; Katsionis, G.; Manos, K. Combining software games with education: Evaluation of its educational effectiveness. *Educ. Technol. Soc.* **2005**, *8*, 54–65.
27. DeVane, B.; Durga, S.; Squire, K. 'Economists Who Think Like Ecologists': Reframing systems thinking in games for learning. *E-Learning Digit. Media* **2010**, *7*, 3–20.
28. Gaber, J. Simulating planning. *J. Plan. Educ. Res.* **2007**, *27*, 113–121, doi:10.1177/0739456X07305791.
29. Endl, A.; Preisinger, A. Den Klimawandel spielbar machen–Diskursive Strategien der Darstellung von Umweltproblemen und Strategiespielen. Available online: http://www.paidia.de/den-klimawandel-spielbar-machen-diskursive-strategien-der-darstellung-von-umweltproblemen-in-strategiespielen/ (accessed on 4 May 2020).
30. Mehren, R.; Rempfler, A.; Ulrich-Riedhammer, E.M.; Buchholz, J.; Hartig, J. Systemkompetenz im Geographieunterricht: Ein theoretisch hergeleitetes und empirisch überprüftes Kompetenzstrukturmodell. *Z. Didakt. Naturwissenschaften* **2016**, *22*, 147–163, doi:10.1007/s40573-016-0047-y.
31. Mehren, R.; Rempfler, A.; Buchholz, J.; Hartig, J.; Ulrich-Riedhammer, E.M. System Competence Modeling: Theoretical Foundation and Empirical Validation of a Model Involving Natural, Social, and Human-Environment Systems. *J. Res. Sci. Teach.* **2018**, *55*, 685–711, doi:10.1002/tea.21436.
32. Steiner, C. Mensch-Umwelt-Systeme in der Geographie: Zur metatheoretischen Möglichkeit einer grundlegenden Systemkompetenz. In *Mensch: Umwelt:System–Theorethische Grundlagen und Praktische Beispiele für den Geographieunterricht*; Gryl, I., Schlottmann, A., Kanwischer, D., Eds.; LIT: Berlin, Germany, 2015; pp. 23–42.
33. Budke, A.; Müller, B. Nutzungskonflikte am Rhein als komplexe Mensch-Umwelt-Systeme mit Hilfe von Argumentationen erschließen. In *Mensch:Umwelt:System—Theorethische Grundlagen und praktische Beispiele für den Geographieunterricht*; Gryl, I., Schlottmann, A, Kanwischer, D., Eds.; LIT: Berlin, Germany, 2015; pp. 177–189.

34. Müller, B. Komplexe Mensch-Umwelt-Systeme im Geographieunterricht mit Hilfe von Argumentationen erschliessen am Beispiel der Trinkwasserproblematik in Guadalajara (Mexiko). PhD thesis, University of Cologne, Cologne, Germany, 6 June 2016.
35. Weichhart, P. Physische Geographie und Humangeographie–eine schwierige Beziehung: Skeptische Anmerkungen zu einer Grundfrage der Geographie und zum Münchner Projekt einer "Integrativen Umweltwissenschaft". In *Integrative Ansätze in der Geographie–Vorbild oder Trugbild? Münchner Symposium zur Zukunft der Geographie, 28. April 2003, Münchener Geographische Hefte 85*; Heinritz, G., Ed.; Universitätsverlag: Passau, Germany, 2003; pp. 17–34.
36. Page, S.E. *Diversity and Complexity*; Princeton University Press: Princeton, NJ, USA, 2011.
37. Dörner, D.; Funke, J. Complex Problem Solving: What It Is and What It Is Not. *Front. Psychol.* **2017**, *8*, 1153.
38. Bolte, J.P.; Hulse, D.W.; Gregory, S.V.; Smith, C. Modeling biocomplexity–actors, landscapes and alternative futures. *Environ. Model. Softw.* **2006**, *22*, 570–579.
39. Czauderna, A.; Budke, A. How Digital Strategy and Management Games Can Facilitate the Practice of Dynamic Decision-Making. *Educ. Sci.* **2020**, *10*, 99.