



## Article

# Serious Gaming for Climate Adaptation—Assessing the Potential and Challenges of a Digital Serious Game for Urban Climate Adaptation

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**Abstract:** Serious gaming has gained increasing prominence in climate change communication, and provides opportunity to engage new audiences and new platforms for knowledge co-creation and dialogues. This paper presents the design and evaluation of a serious game on climate adaptation, primarily targeted towards high school students, practitioners and politicians. The game aims to provide an experience of the impact of climate adaptation measures, and illustrates links with selected Agenda 2030 goals, which the player has to consider, while limiting impacts of hazardous climate events. The game design builds on the key goals in Education for Sustainable Development combining comprehensive views, action competence, learner engagement and pluralism. This study draws on game sessions and surveys with high school students in Sweden, and aims to assess to what extent different aspects of the game can support an increased understanding of the needs and benefits of adaptation actions. The results of this study indicate that the game can engage players to reflect upon challenges related to climate adaptation decision making, but also point towards the challenge of including a high degree of complexity which can make it difficult to grasp consequences of individual measures, as well as to link these to the natural variability of the occurrence of extreme climatic events.

**Keywords:** serious gaming; computer-based; climate adaptation; Agenda 2030; Education for Sustainable Development

## 1. Introduction

Climate adaptation involves measures to adapt society to the climate changes we already notice today and those that we cannot prevent in the future. In the field of climate adaptation, knowledge co-creation and enabling a joint understanding of the inherent complexity is essential [1]. While challenges for adapting society to climate change are plenty, and span over multiple sectors, awareness of these challenges, how to address them and how to balance contrasting aims that arise is still low [2,3].

Research on climate change education has largely addressed mitigation, with less focus on the equally necessary need for education related to the demand of adaptive actions [4]. Misconceptions exist among many, including adolescents, with regard to the purpose and complementary roles of adaptation and mitigation [4]. The progress of the interest for education on climate change can be mirrored in the increasing number of climate-related serious games, that more recently also include games with focus on climate adaptation [5–9]. The potential of serious games for climate change communication, commonly defined as games that are “designed to have underlying objectives beyond

mere entertainment such as instructional goals” [6] p. 414, has been addressed in a number of recent studies. Given the complexity of climate adaptation, referred to as a “wicked problem par excellence” [10] (p. 28), scientific knowledge, rivalling social interests as well as ethical consideration need to be recognized, and hence demand new types of educational tools. Enhancing science education by contextualizing the content as socioscientific issues is argued to increase understanding as well as to train ethical reflection and personal judgement needed in modern societies [11,12]. This is also in line with the core of Education for Sustainable Development (ESD) that strives for systems thinking and democratic action competence in a world full of conflicting interests [13,14]. In this capacity, serious games can support teachers to strengthen their Education for Sustainable Development as it provides an experience of climate adaptation, based on systems thinking and action orientation. Inspired by these two strategies, we argue that digital games can be a valuable resource in climate communication and education.

Climate change games cover a wide range of related topics, such as urban development [15,16], personal action [3], land use models [17], agriculture [18–20], water management [21–25], climate risk attribution [26] and simulations of climate negotiations [27]. In their review of climate adaptation games, Flood et al. [7] present a large number of more recent games with focus on climate adaptation, and discuss their efficiency for “engaging with diverse publics and enable social learning” [7] (p. 18) as well as the role of serious games to facilitate dialogue and adaptation action. Climate change related games can have different formats and technical features [6]. While the development of games in digital formats has increased during the most recent period, Reckien and Eisenach [5] indicated in their review of climate change related games that roleplay and management games were the most common designs. Rumore et al. [9], found in their study of two roleplay simulations (RPS), a “strong evidence that participation in RPSs can increase readiness to adapt by cultivating literacy about climate change adaptation, enhancing collaborative capacity, and facilitating social learning”. They also pointed towards the potential of integrating roleplay with simulation or digital game elements.

The interest in digital games as a tool for education in schools has increased over the last two decades [28,29]. The initiative “Playing for the Planet”, launched by the United Nations Environmental Program [30], provides an example of the potential for digital games in sustainability education. Designing serious digital games for education in schools can be described as an area characterized by multiple benefits but also barriers. Integrating a game into the setting of a classroom has proven to be a challenge since the game design and content has to fit the curriculum, in terms of relevance and efficiency. Games also have to match local conditions such as teachers’ and students’ understanding of gaming as a learning activity [31]. A meta-analysis by Lamb et al. [32] problematizes the assumptions of positive effects as observed in multiple studies and highlights that teachers have to take into consideration how effective games are in relation to expected learning outcomes in their specific courses, emphasizing the demand on the game design to relate to the school curriculum for the intended target group.

Recent studies on the effects of using digital games in schools [33–35] have identified several benefits for education in schools, and point to at least three aspects: (i) digital games tend to increase the students’ interest in the topic compared to other forms of learning (ii) digital games have the potential to engage students that are not so fond of school in general, (iii) the challenge that games provide has been identified to be an important factor for the learning outcome. The latter, while implying a direct challenge to the game developers, also relates to the role of games, providing clear progression towards higher levels of complexity, allowing the student to play at their own pace, and to progress to their individual highest level. In order to reach a high learning outcome, games should be comprehensive and challenging but not beyond the students’ capacity. However, increased complexity and game content can make it difficult to integrate a game in the school context due to curriculums and local practicalities. Consideration to participants’ attitudes towards gaming [31] is necessary in order to facilitate the gaming experience strategically. As Alklind Taylor [36] argues, it is in the discussions

after the game, i.e., the debriefing [37], where most of the learning takes place. Hence, games cannot be expected to compensate for teachers' lack of knowledge in a topic.

Numerous studies have discussed tools and frameworks to assess serious games (e.g., [38–45]). Mitgutsch and Alvarado [44] argue that serious games, having an 'intention-based design', also require to be analyzed in relation to their purpose. They propose a number of core elements in their Serious Game Design Assessment Framework, including the content, fiction and narrative, game mechanics, aesthetics and graphics and framing of the game. Ouariachi et al. [46] propose similar aspects as part of their criteria for the evaluation of serious games for climate change communication, including aspects related to the narrative, gameplay, content and didactics of the game.

This study presents the design and development of a digital serious game on climate adaptation, aiming to support knowledge co-creation and to increase the understanding of the complexity of climate adaptation, as well as the results of the evaluation of gaming sessions with high school students in Sweden. The aim of the study is to assess to what extent different aspects of the game can support an increased understanding of the needs and benefits of adaptation actions.

## 2. The Climate Adaptation Game

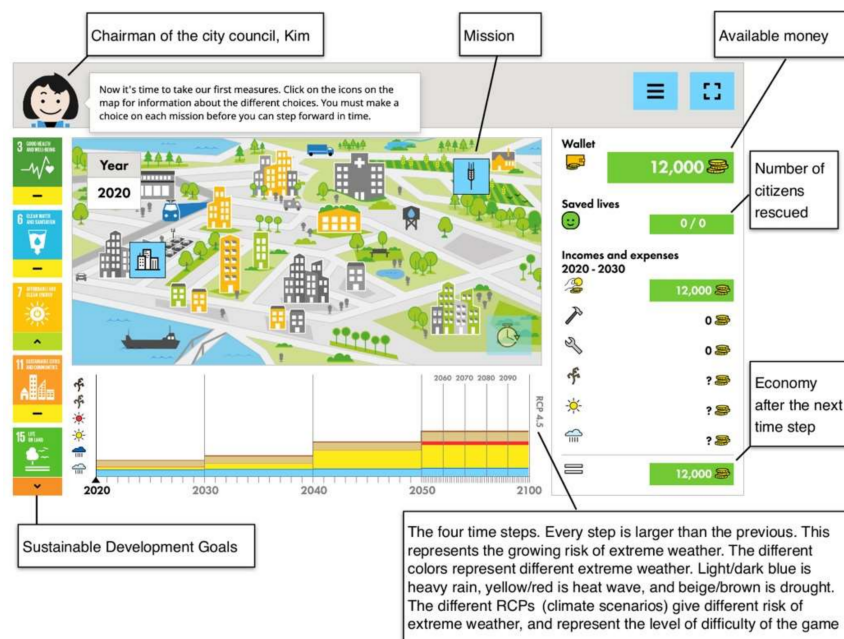
The Climate Adaptation Game was developed by the Swedish National Knowledge Center for Climate Change Adaptation, based at the Swedish Meteorological and Hydrological Institute (SMHI), together with researchers at Linköping University and high school teachers. The center has the mission to provide tools and information to support society in coping with a changing climate. The focus of the game development was to provide a tool suitable for high school education in sustainable development, as well as for municipal officers and politicians that are starting to work with climate adaptation. The operational goal was to make needs and opportunities for climate adaptation tangible by providing an experience that increases the understanding of what climate adaptation means in practice and why it is necessary, hence contextualizing the content as a socioscientific issue. The game development was also based on the operational goal to increase the target groups' understanding of links between climate adaptation and selected sustainable development goals [47]. The research objective of the project was to assess the potential of the serious game to fulfill the operational goals set by SMHI.

The game has been developed in two versions—version (1) is based on a modification (mod) to the sandbox video game Minecraft and version (2) is web-based. The web-application was written with Ecma script and Sass. Several application programming interfaces (API) were used: React for developing the user interface of the single page application, Redux for managing the application state and Velocity for handling the animations. The Minecraft Mod was written in Java using the open-source modding API Minecraft Forge in combination with Minecraft Java Edition version 1.12.2. The tools for helping with localization and textures were written in Typescript. Both games are hosted and maintained internally at SMHI, and continuously introduced to new users as part of the governmental mission at the Swedish National Knowledge Centre for Climate Adaptation.

While the Minecraft version allows for a better visual representation of adaptation measures in the urban environment, and a first-person experience of exploring the urban space, the web-based version has a more static, two-dimensional design but allows for a quicker progressing and easy access since no prior game experience is required to navigate the game. In this study, solely the web-based version (Figure 1) was used in the evaluated gaming sessions.

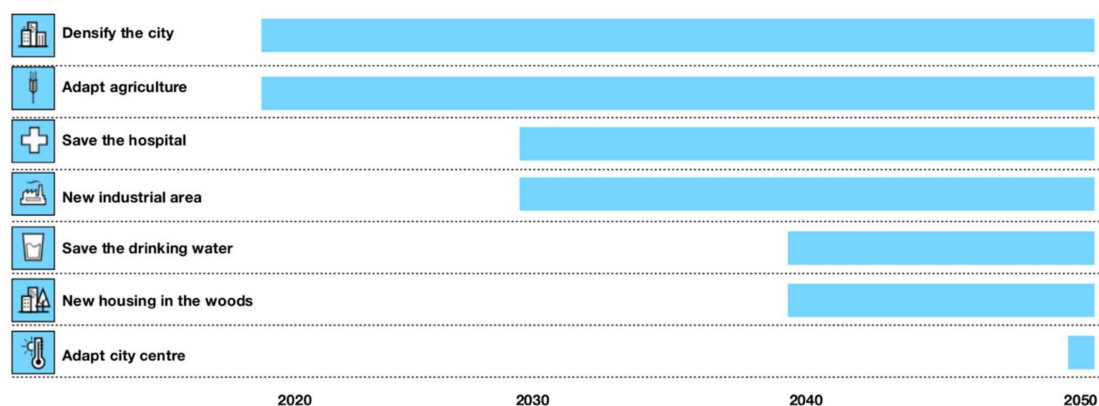
The game mechanics of the Climate Adaptation Game comprise hovering and clicking. When hovering on different graphical components of the game, a tooltip with an explanatory text and, in some cases, descriptive graphics of the component are displayed. The player is required to select a specific mission by clicking on one of the mission icons that are displayed on the city map. Once a mission icon is clicked, a modal window is shown displaying four different alternatives. By clicking on the icon for a specific action, more information is presented, and the player has the possibility to select one of the proposed alternatives. After the player has made a selection for each of the available

missions for the current timestep, the clock button in the bottom right corner of the city map can be clicked to advance in the game (Figure 1).



**Figure 1.** The interface of the climate adaptation game (available at [www.smhi.se](http://www.smhi.se)).

The player, who acts as the climate adaptation coordinator in Weatherton, a fictional city, encounters seven different climate related missions. These missions are successively introduced during a number of time steps as shown in Figure 2. Two missions are introduced in the beginning of the game (year 2020): (1) densify the city; and (2) adapt agriculture. After the first 10-year time step (to the year 2030) two new missions are introduced (3) build a new industrial area; and (4) save the hospital from flooding. The next time step takes the player to year 2040 when the missions (5) save the drinking water; and (6) new housing area in the woods are introduced. After the next time step (to year 2050) the final mission—(7) adapt city center is added. The missions, once available, are accessible in each successive time step until the year 2050, and can subsequently be upgraded.



**Figure 2.** Timeline of the missions.

For each challenge, the player chooses between different alternatives, which imply different degrees of climate adaptation with different costs and consequences for the city's sustainability, or



to ‘do nothing’ (Figure 3). In conjunction with each time step, climatic events (the number of heat waves, floods, droughts with two different recurrence intervals) occur that affect the game result. These climate change related events reflect the trend for climate change, depending on the climate scenario (RCP 2.5, 4.5 or 8.5) that the player chooses at the beginning of the gaming session, as well as the natural variability. As such, no gaming session has the same results.

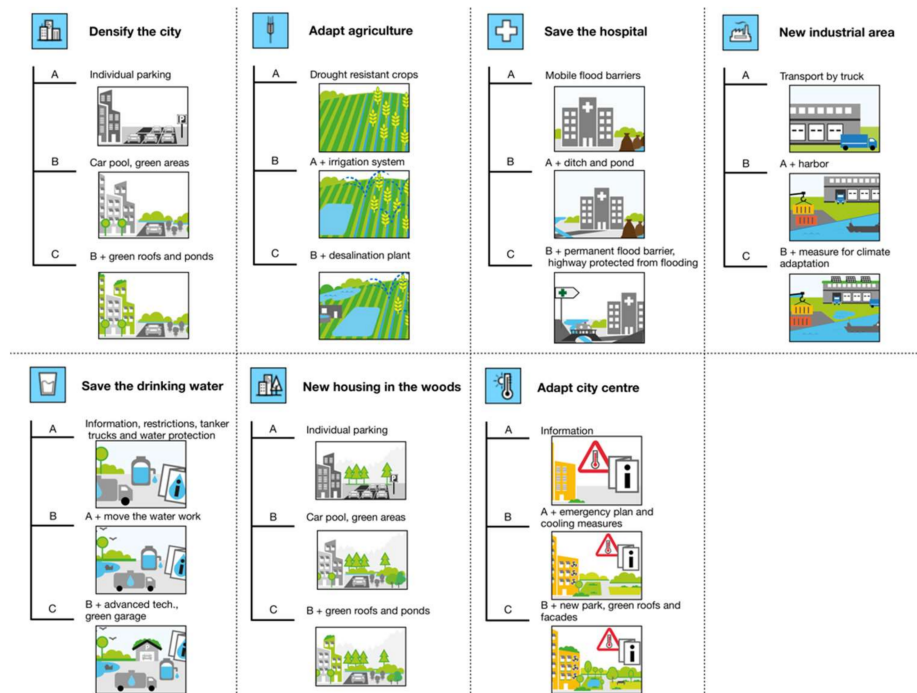


Figure 3. Game structure for each mission.

Apart from adapting the city to climate change (defined by how many lives and ‘coins’ that are saved due to successful adaptation), the player also needs to keep the city’s economy in shape, and simultaneously reach five selected global sustainable development goals. Included goals are health, water and sanitation, sustainable built environment, energy and biodiversity [47]. In order to obtain a high final score, the player must take into account how decisions in the virtual city affect these goals.

The main rationale behind the game development was motivated by the governmental operational mission of the Swedish National Knowledge Center for Climate Adaptation at SMHI, to raise awareness of the need and possibilities for climate adaptation. Consequently, the game was developed to integrate knowledge on climate adaptation to facilitate insight into decision making while acknowledging complexities, such as climate variability and change, costs and potential benefits of actions, conflicting demands from different stakeholders, as well as impacts on sustainable development. The missions and alternative climate adaptation actions were selected in cooperation with experts from national authorities and regional climate adaptation coordinators from county boards. The implementation costs for actions, maintenance (added as recurring costs for each time step for selected actions), costs related to damage, as well as lives lost due to extreme climate events were based on expert assessments. As highlighted in dialogues with experts, real life costs and selection of best measures are highly dependent on local conditions, and thus the game can only provide examples of climate adaptation rather than optimal solutions. If the player selects to build new housing or industrial areas, a tax income will be generated to Weatherton for each time step. In addition, the player is provided with coins in the beginning of each time step. Costs for construction, maintenance and tax income, as well as potential damage costs in connection to various extreme weather events, are presented to the player as a basis for their decision.

Estimates of probabilities (0–100%) that heavy rainfall, heat waves and agricultural drought (a prolonged period with soil moisture deficit) could occur during a year were based on data provided by the SMHI's climate modeling unit, the Rossby centre, for climate scenario RCP 2.6, 4.5, and 8.5. The geographical location was assumed to be in South-Eastern Sweden. One set of estimated probabilities was defined for each of the four time steps. Costs for potential damage was then estimated as the randomized number for each type of extreme event, multiplied with the damage cost provided for each type of extreme event. The balancing of the game was done by adjusting the costs and benefits of different choices in the missions, as well as the costs related to extreme weather events, in order to make the game playable with a desired distribution of “win” and “lose” situations depending on the selected climate scenario. As such, the game aims for a balance between ‘play, meaning and reality’ [48] in terms of real-life elements and climate models, to ensure meaningfulness while supporting learning and sensemaking regarding the challenges and conflicts of interest related to climate adaptation for the target groups.

In the final summary of the results, the player can gain up to five stars, depending on how well missions were completed, calculated as a function of the players' choices of adaptation actions and the occurrence of damage due to extreme events. One star is achieved for economic benefits of the adaptation actions. One star is received if the player saves more due to reduction of damage costs than what was spent on the climate adaptation actions. An additional star is received if the saving was more than twice than the costs for adaptation. If all global sustainability goals are fulfilled, an additional star is provided. A star is also given if there are coins in the wallet at the end of the game. Finally, a star is provided if 75% or more lives that potentially could have been saved by adaptation actions actually were saved.

The game is designed as a single-player game, but has also been operationalized for a roleplay setting. In both versions, the ambition is to highlight relevant conflicts of interests, since ESD places such conflicts, and their exploration, at the center of educational strategies [49]. In the single-player mode, the player is offered some information to be considered in the choice of actions. This includes arguments from two opposing ‘citizens’, as well as an overview of impacts of different actions on climate-related risks and sustainable development goals.

Earlier evaluations [50] have shown that roleplay in which the participants defend a particular view of sustainable development, challenged by other views, helps students to grasp the complexity of the topic. Similarly, van der Meij et al. [51], argue that collaborative play alone does not increase the learning outcomes, and indicate the potential of scripted dialogues to increase the ‘level of dialogic acts’, and in turn learning outcomes.

The aim of the roleplay design of the climate adaptation game is to create a setting for dialogue, by simulating a decision making process during a local council meeting with participation from a number of interest groups. The roleplay hence allows addressing conflicts of interests, which are not directly embedded in the digital game, including social dimensions, such as demand for low cost apartments or unwillingness to implement change which is perceived to have an impact on lifestyle. A moderator divides the participants into seven interest groups (Table 1). Each group receives confidential information regarding their role and position in general, but also a specific scoring system with credits that they receive for attaining a certain level for each Sustainable Development Goal. For one of the groups, the economic balance is an additional source of scores.

The moderator guides all participants of the roleplay jointly through each of the options for each challenge, navigating the game interface on a large screen. Financing sets the limit of what is possible. Each interest group has an internal discussion, debating—from their specific perspective—which option they would like to vote for. After a short sequence of informal negotiations between the interest groups (during which representatives from all groups circulate and discuss with other groups to lobby for their favored option), the moderator calls for a ‘council meeting’, in which each interest group has one vote. A majority decision is made, and the moderator makes the selection in the game.

**Table 1.** Description of roles and opinions.

Roles	Opinions
Business and Trade Association	<ul style="list-style-type: none"> <li>• More land is needed for industries and better infrastructure for trade</li> <li>• The economy needs more educated labor</li> <li>• New residential areas are desired</li> </ul>
Agricultural Society	<ul style="list-style-type: none"> <li>• Good conditions for farming</li> <li>• Land is a limited resource that should be used for food production</li> <li>• Biodiversity is important but needs to be balanced by global economic realities</li> </ul>
Union of Tenants	<ul style="list-style-type: none"> <li>• Important with cheap housing in climate-safe areas</li> <li>• A good economy is the basis for jobs</li> <li>• Access to recreational areas is needed</li> </ul>
Property Owners Association	<ul style="list-style-type: none"> <li>• Design the city so that houses do not lose their value</li> <li>• A thriving economy is a prerequisite to be able to implement climate adaptation and other important goals.</li> </ul>
Senior Organization	<ul style="list-style-type: none"> <li>• Health issues are important. Heat waves among other things can be a matter of life and death.</li> <li>• Available recreational areas are important for good health.</li> </ul>
Society for Nature Conservation	<ul style="list-style-type: none"> <li>• The city is growing at the expense of biodiversity</li> <li>• A green city is valuable for wildlife habitat and human health</li> <li>• A sustainable economy must stay within the limits of nature</li> </ul>
Citizen Association—do not touch my lifestyle!	<ul style="list-style-type: none"> <li>• The climate issue is a trick for pushing through uncomfortable decisions</li> <li>• Ordinary people need affordable housing</li> </ul>

After the council meeting has concluded how to invest in climate adaptation for the current time period, the subsequent time step shows which climatic events are happening, and their costs (lives and coins) for the city are presented. At the conclusion of the game, the council considers the overall result for the city as well as the feedback from the ‘chair of the city council’, and each interest group can calculate their own scores by means of the scoring system for their interest group. As such, the final outcome is concerning both the overall state of the city, but also which interest group has the highest score in reference to their scoring system.

All necessary workshop material and moderator guidelines are available, along with the game at the SMHI web-site (<https://www.smhi.se/en/climate/education/adaptation-game-1.153788>).

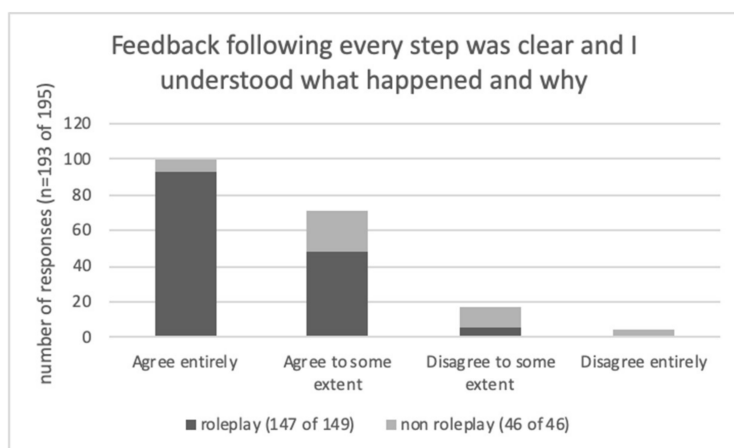
The roleplay moderation includes debriefing dialogues after the game experience, which several scholars emphasize as an essential element to ensure learning by gaming [36,37,52]. The debriefing dialogue is arranged around three themes (i) complexity and interconnectivity; (ii) interests and values; and (iii) decision making. The participants are asked to first reflect for themselves for a moment, then in pairs, and subsequently the entire group discusses what they learnt and what surprised them. It is highlighted that games have to reduce the complexity of the real world. Hence, finally and perhaps most importantly the participants are asked what they, based on their specific knowledge, are missing in the game. Throughout the final moderated discussion participants are invited to discuss from the perspective of their roles as well as from a more general perspective. Since the roleplay was designed to trigger tensions between groups, it is important to reflect upon where there has to be trade-offs and where innovative solutions might provide win-win situations.

### 3. Materials and Methods

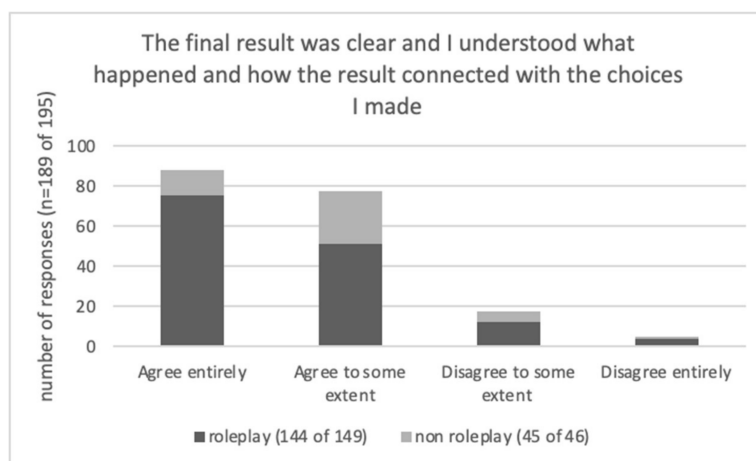
This study builds on data collected at five gaming events which were held during 2019. Sessions lasted 60–90 minutes, and were held as roleplay with a moderator who played the game on a big screen, except for two of the sessions that were conducted with students that tested the game in pairs, exploring the game during 60 min and providing feedback. During the sessions, experts from the Swedish National Knowledge Centre for Climate Adaptation were present to support the group discussions, and in one of the roleplay sessions, one or two local politicians participated in each roleplay group. The two groups that played the game in a non-roleplay setting played an earlier version of the game, and partly based on their feedback, additional textual explanations were added related to consequences of various options for each mission.

At the end of each session, participants were asked to conduct a survey covering a number of questions related to their understanding of climate adaptation, their assessment of the game content, structure and functionality. A total of 195 surveys were collected during these sessions, and the response rate for each question ranged between 85% and 99%.

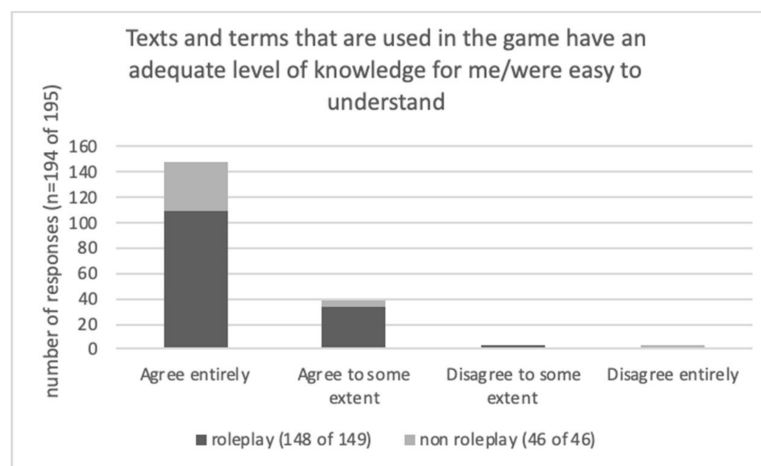
Participants were between 15 and 19 years old and were students attending Swedish high school. As students were from different high school programs, they represented different kinds of knowledge about climate adaptation. Participation in conducting the survey was voluntary and could be terminated at any time during the process. Surveys did not reveal the name or school of the participant, but were grouped according to the sessions. Data collected from roleplay sessions and sessions where the game was played in pairs were analyzed as one set of data, acknowledging that some of the responses might be influenced by different ways of playing the game. A quantitative analysis of 7 questions (cf. Figures 4–9, and Supplementary Material S1) was conducted for the entire material. The text responses that were requested as follow up, were analyzed by thematic content analysis, exploring the occurrence of specific themes, terms or notions. The collected material was analyzed for thematic aspects including reflections on the overall theme of climate adaptation, game content, game functionality, assessment and learning experience.



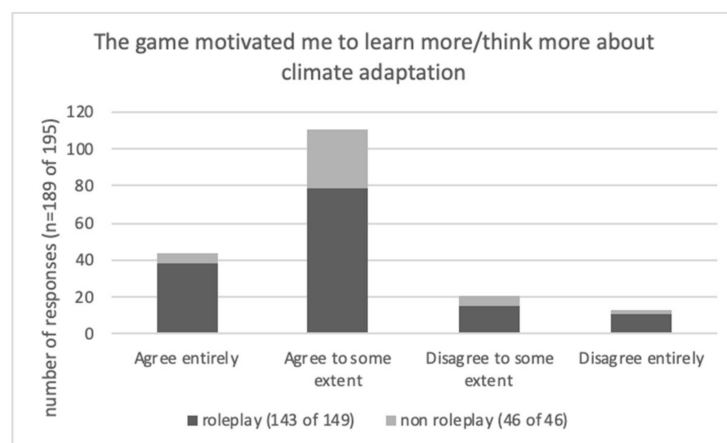
**Figure 4.** Distribution of responses to the question 'Feedback following every step was clear and I understood what happened and why'.



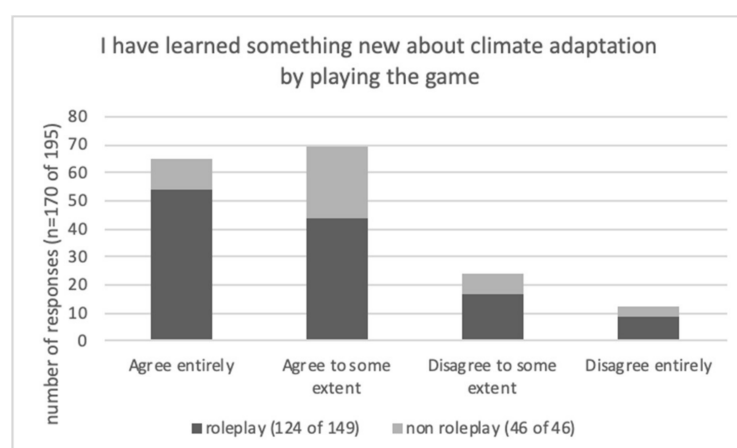
**Figure 5.** Distribution of responses to the question 'The final result was clear and I understood what happened and how the result connected with the choices I made'.



**Figure 6.** Distribution of responses to the question ‘Texts and terms that are used in the game have an adequate level of knowledge for me/were easy to understand’.

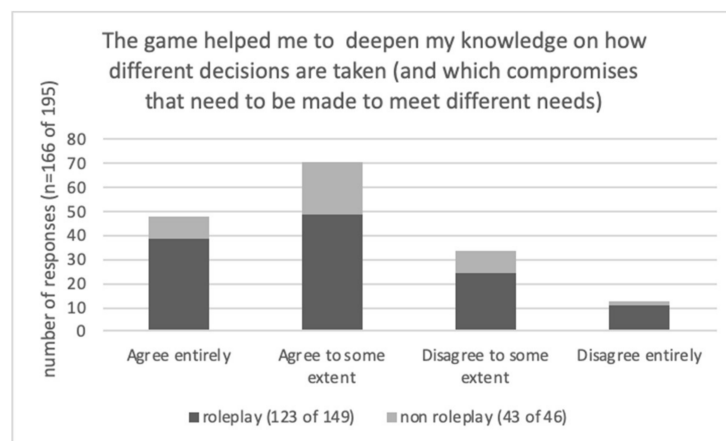


**Figure 7.** Distribution of responses to the question ‘The game motivated me to learn more/think more about climate adaptation’.



**Figure 8.** Distribution of responses to the question ‘I have learned something new about climate adaptation by playing the game’.





**Figure 9.** Distribution of responses to the question ‘The game helped me to deepen my knowledge on how different decision are taken (and which compromises that need to be made to meet different needs)’.

Results are presented in the following section, and structured in accordance with criteria for the assessment of climate change games, as proposed by Ouariachi et al. [46]; (i) Narrative, (ii) Content, (iii) Gameplay, (iv) Didactics (see Table 2), and assessed in relation to the purpose [44] of the game and its design.

**Table 2.** Criteria and examples for the analysis (adapted from Ouariachi et al. [46]).

Criteria	Definition
Narrative	Refers to the game narrative in terms of relevance, logics or causality, representation as well as temporal and spatial dimension.
Gameplay	Refers to the game design and formal structures, degree of interactivity, missions, feedback and reward systems.
Content	Refers to the analysis of the information, terminology, use of concepts and information sources.
Didactics	Refers to the knowledge, competences and abilities that can be attained, the challenges that can be addressed as well as the learning curve, availability and didactic guidelines.

## 4. Results

### 4.1. Narrative

The narrative of the climate adaptation game follows a sequence of challenges posed to the climate adaptation coordinator of the city. In the introduction of the game, the players are welcomed by the chair of the city council and presented to their first assignment, to ‘collect information about the most prioritized adaptation and what alternatives we have to choose from’. The players thereby obtain an active role in the game, however without being represented by an avatar. The physical space in which the players navigate and select measures for identified challenges is a city, represented by an illustrated two-dimensional map. Players do not move in the city, which has an abstract scale and boundary, limiting the experience to illustrations and information related to missions. The temporal dimension sets the player in an even more abstract setting—the missions in the game are presented and dealt with in four time steps—ranging from ‘today’ to 2030, 2040, 2050 and 2100. This enables a narrative on the risk of climatic impacts in the near and more distant future, as well as the implications for long-term planning, which challenges the imagination and reflection of the players. The extreme climate events that can occur during each time step, are an important part of the narrative, depicting to what extent the city is exposed to heat waves, floods, and droughts of different magnitudes, which influences the need and benefit of adaptation measures. The probability for an event to occur is shown in the user interface, and the uncertainty of occurring events during a time step, based on natural variability, is an additional factor that players need to account for. As such, the narrative does not only refer to the complexity of planning and decision making on a city level, but also to climate uncertainty.

While no specific survey questions were related to the narrative, players expressed reflections on the logics and provided feedback on the game, in their text responses to several of the questions. A thematic analysis of these responses revealed in particular three strains of reflections: (i) complexity and dilemmas, (ii) impacts and consequences and (iii) perspectives, priorities and compromises. Several participants commented that they increased their understanding of the complexity behind decisions, how issues are interconnected, and that several aspects need to be included when making climate adaptation decisions for the city. The term ‘dilemma’ was used by participants to describe conflicting approaches and goals between the interest groups, as well as stating that ‘there’s always a positive and negative side to all decisions’.

Impacts and consequences were mentioned with regards to how “things are connected” as well as the feedbacks of different decisions in the game. Participants reflected that any choice they made could have both positive and negative consequences for the city, and that the game presented the complexity of decision processes. As such, several respondents mentioned that they increased their understanding about the compromises that are required, both in relation to the potential impacts and consequences, but also to balance different perspectives and needs in the city. This was, in particular, evident in the reflections from the roleplay sessions, where the arguments of the different interest groups accelerated the understanding of different perspectives, and the need to understand “different aspects in decision making”.

Related to the logics of the narrative, some participants commented that it was not entirely clear to them why people died or were saved, why economic losses occurred or why they did not succeed, and reasons for negative consequences were sometimes questioned. These questions were predominantly raised by the participants of the non-roleplay sessions, indicating the importance of the moderator to reason and reflect upon the narrative, logics and causality of the game.

#### 4.2. Gameplay

The gameplay featured different characteristics depending on the playing mode. While based on a single-player mode, the roleplay setting enabled a multi-player experience, in which not only the different interest groups but also the debates between groups and the final council meeting in which each group had one vote, played a dominant role. The degree of interactivity was hence strongly dependent on the playing mode, and differed in terms of interaction with the game interface or the interactivity in terms of roleplay discussions and negotiations. The length of a gaming session differed from a few minutes for individual online gaming to 90 minutes for the full roleplay. Information about the game missions, impact of selected adaptation actions, as well as of probabilities for extreme climate events, as presented in Figure 2; Figure 3, were more vivid to the individual players, who were not dependent on an external moderator, and could individually select what information they wanted to explore. They did also have the possibility to run the game several times during the session to assess the impact of their choices.

In the survey, participants did not reflect about any specific game missions, but rather on the game dynamics, in terms of structure and rules as well as the feedback system. In response to the question whether the feedback provided by the game on each step was clear and facilitated an understanding in terms of what happened and why, 100 participants agreed entirely and 71 partially agreed, resulting in a total of 89% of responses (Figure 4).

The results and comments from the single player groups revealed some uncertainty regarding the consequences of their choices. Some did not understand why they obtained negative results or lost money. This group played an earlier version, and the difference in results might both be related to the difference in gameplay, as well as that additional textual explanations were later added to enhance the feedback related to each mission.

In the single-player groups, some participants expressed that they completed the game several times during the session, thereby noticing that they “did not really understand why in many cases where we made the same choices, the results differed”. This observation relates to the game mechanics,

i.e., that the occurrence of extreme events during a time step is not static, but linked to a trend based on the selected climate scenario, combined with a range based on natural variability. Hence, players that tried to ‘optimize’ the game ran the risk of frustration, since the unpredictability of the climatic events intentionally does not allow for a given optimization of the gameplay.

Comments about symbols and illustrations described them as in some cases clear, in others unclear. Furthermore, participants commented that some of the climatic impacts, such as heat wave or drought would benefit from a substantial explanation, such as “how the town is impacted by the various types of climate hazard”. This reflects the design of the game where impacts from climate hazards were related to the specific missions, rather than to the overall impact in the city.

A total of 88 of the participants agreed fully and 78 partially that the presentation of the final results was clear, and allowed them to understand what happened and how this was connected to the choices they made, representing a total of 88% of the responses (Figure 5).

In their reflection on the reward system, several participants noted it as unclear why they lost or gained money or how to reach the sustainable development goals, as the following comment illustrates: “I think it was a bit difficult to know exactly what one could have done to reach all [Sustainable Development] goals”. While some participants specifically noted the value of the summary score board to explain the overall achievements, others reflected on the graphical representation of achievements, and commented that more nuances, “rather than just red and green” could improve the feedback system.

#### 4.3. Content

Game content was strongly linked to explicit scientific concepts, in particular climate change terms, but also to urban planning related information, which were described both in the challenge description and discussed by the two in-game characters that argued for the pros and cons of each option. Several of the terms are explained in depth, while it has to be noted that the participants of the roleplay sessions were not provided with the opportunity to read the arguments of these in-game characters. In order to keep the players within the site, and not to leave the gaming session to look for information, no external links were included. Nevertheless, the website from which the game can be downloaded offers both a teacher guidance, an introductory presentation, as well as links to several information sites from national agencies and organizations. In addition, prior to all gaming sessions, participants had a brief introduction to climate adaptation by experts from the Swedish Knowledge Centre for Climate Adaptation.

In the survey, participants were asked to what extent the texts and terms that were used in the game had an appropriate knowledge level. A total of 76% of the respondents agreed entirely with this claim (Figure 6).

In the text responses, some participants listed a number of terms they were not familiar with, such as storm water or sedum covered roofs, while several noted that the level of required knowledge was appropriate or low. Comments on the individual knowledge level revealed a high self-rating in terms of prior knowledge on the subject. In response to the statement ‘I already had knowledge on climate adaptation prior to the gaming session’, the majority (88%) of participants expressed that they agreed or agreed to some extent that they already had knowledge on climate adaptation. It has to be noted that they were not asked to rank their understanding, and that several of the text responses to this question revealed connotations to climate mitigation, which indicates that their response might be related to knowledge on climate change in general rather than to climate adaptation specifically. In addition, the brief introductions on the topic prior to the start of the game session might have influenced the outcome of this question.

#### 4.4. Didactics

The development of the climate adaptation game was based on that the main target group was high school students (ages 15–19), and hence relevance to the high school curriculum and the Agenda 2030 was a prerequisite. The game design was guided by the didactical cornerstones of Education

for Sustainable Development, emphasizing conflicts of interests and democratic action competence in complex situations, as well as student engagement.

Different outcomes from the methodological approaches of the moderated roleplay and the single-player settings were to some extent indicated from the text responses, however, since the number of surveys from each group was not sufficient to show a statistically significant result, we did not attempt to make a quantitative comparison between these two groups. As a general assessment, the majority of players responded that they to at least some extent considered that the game motivated them to learn more or think more about climate adaptation in the future (82%), which corresponded to the overall purpose of the climate adaptation game (Figure 7).

In response to the statement ‘I have learned something new by playing the game’, 65 respondents agreed entirely and 69 agreed to some extent, representing 79% of all responses (Figure 8).

In response to the follow-up question ‘if you agree, what have you learned?’, a number of text explanations referred to specific content, such as the role of shades and dark surfaces or specific areas of urban planning or the importance of economic considerations in climate adaptation. The responses revealed that participants frequently reflected on the complexity of the subject, and stated that they obtained new perspectives. In particular the role of collaboration, understanding of conflicts and the need to make prioritizations, as well as the impact on “climate change in different sectors” were highlighted in the student’s responses.

The following question, whether the students agreed that the game helped them to enhance their knowledge on how different decisions are made and which compromises that are required, resulted in a wider distribution of responses, although the majority (72%) responded that they agreed or agreed to some extent (Figure 9).

Nevertheless, several participants expressed that the game provided e.g., “better insight into different perspectives and needs”, “how different decisions can have advantages and disadvantages” or “the dilemma that politicians are facing”. To some extent the more divergent responses in this section resonate previous research that points towards the challenge of designing a game that matches the optimal learning level due to the heterogeneity of student groups and complexity of climate adaptation.

## 5. Discussion and Conclusions

This study set out to discuss to what extent a digital serious game on climate adaptation can support knowledge co-creation and increase the understanding of the complexity of climate adaptation. Based on the results of surveys conducted to evaluate gaming sessions with Swedish high school students, we assessed to what extent different aspects of the game, namely the game narrative, gameplay, content and didactics, bear potential to support an increased understanding of the needs and benefits of adaptation actions.

Serious games imply both opportunities and barriers—both in terms of communication, inclusivity and to some extent regarding their legitimacy when dealing with complex issues [31,32]. While this study demonstrated a positive result on the engagement and interest for climate adaptation for the participating high school students, it also raises question regarding the level of terminology, and to what extent the aspects of the gameplay, in terms of single-player or roleplay mode, as well as the complexity of the feedback system, influenced the game experience.

The participants’ responses reflected that the game generated a relatively high degree of interest to learn more about climate adaptation, and hence created an increased interest for the subject, which is expectable when contextualizing content as a socioscientific issues (cf. [12]). Similarly, participants also, to a high degree, agreed that they learned something new about climate adaptation, although the majority had rated their own prior knowledge on the subject relatively high. This high rating of pre-knowledge, can, however, be expected to reflect their perceived knowledge about climate change in general rather than climate adaptation. Although participants rated their increased knowledge on how different decisions are taken slightly lower, the majority nevertheless agreed with this statement, and several text responses speak of an ‘eye opener’ in relation to the complexity of decisions, positive

synergies and trade-offs, and the compromises that need to be made. This in turn highlights the value of designing games in which conflicting interests are placed at the center of attention.

While this study does not assess differences between different types of game settings, it shows a large potential for the roleplay setting in order to engage students in a dialogue on climate adaptation and to increase their understanding of the need to, as a basis for decision-making, assess synergies with other goals, as well as trade-offs. This is in line with earlier studies, that pointed towards the potential of scripted dialogues [51] and roleplay in particular [9,36] to increase learning outcomes. Our study further confirms the potential of serious games when introducing complex themes in the curriculum, but emphasizes the importance of informed moderators (or teachers) to ensure reflections and debriefing, as well as the value of a structured context. Hence, at least in these educational settings, knowledge co-creation strongly relies on the moderator to keep the students' focus on the content of the game.

Participants assessed the level of the texts and terminology used in the game as adequate, and to some extent even low, but also raised examples of new terms that needed to be explained. The game provided a large number of possibilities to acquaint more information, definitions and to take part of arguments in favor or against different decisions by means of in-game characters, which enable learning about climate adaptation measures and the complexity of decision making, even in single-player online mode. In the roleplay setting, participants were able to both discuss different options, but also ask the moderator or climate adaptation experts that were present in the session for further explanations. Finding the optimal terminological level is difficult given the heterogeneity of the participants' knowledge. An option to increase inclusiveness could be to provide more in-game voices with different levels of terminology to allow participants to start at their own level.

While participants did not reflect particularly on the gaming missions, the responses to the feedback after each time step and the final results of the game session showed some concern related to understanding of the outcomes and impacts of individual decisions. In the overall ranking, the majority of participants agreed that the feedback both during and related to the final results were clear, but in several of the text responses, uncertainty about the economic impacts, the role of different decisions, and to some extent the role of different scenarios was questioned. In particular, the single-player mode provides the ability to run the game several times, which allows the players to test different ways to solve the issues. One of the missions of the game is to illustrate that decisions have to be made in spite of uncertainties about when or how often extreme climatic events will occur. Since the occurrence of such events in the game is based on randomization from a range of probabilities, the number of occurring extreme events will differ between each game session. This could lead to frustration among players that aim to optimize the game. This demonstrates the trade-off between the wish to address several complexities and to disseminate clear messages about the value of measures. Balancing simplification and complexity is a common challenge for climate change games, and in line with earlier studies [6,7,20,26]. This also points to the importance of not using games as a stand-alone event but as an integrated part of a longer learning process [31,36].

The game narrative, making the player the new climate adaptation coordinator of Weatherton and presenting a small set of missions to be addressed in each time period, was partly altered in the roleplay setting, in which decisions for each mission had to be made within each interest group and subsequently voted for in the city council. The role of the narrative in supporting an increased understanding of the needs and benefits of adaptation actions was however evident in the participants' reflections regarding the complexity and dilemmas that had to be addressed in the game, as well as in terms of economic and social impacts and consequences that the city had to face. Participants reflected on insights into different perspectives, in particular given the priorities of the interest groups of the roleplay, as well as an understanding of the compromises that need to be made when adapting the city to a changing climate. While the events were based on scientific data representing the trend for climate change for the selected climate scenario superimposed by natural variability, players might nevertheless experience consequences of actions as a somewhat random feature. The role of the



moderator in explaining the fact that we cannot know to what degree we will be exposed to extreme climate events during a specified time period, as we can only know the probabilities that events will occur, not exactly what will happen, is thus important.

As the climate adaptation game has the clearly formulated purpose to assist in co-creating a common understanding of the needs and benefits of adaptation actions, and features an ‘intention-based design’ [44], we have assessed the game design as well as the participants’ responses in relation to this purpose. While the narrative engaged the players in an active role as the new climate adaptation officer of the city, or as influencers of decision in the city council, the various missions challenged the players to explore different options, inherent synergies, conflicts of interest as well as the general complexity of adaptation decision making for a time period of 80 years. The use of time steps of initially 10 years and finally one of 50 years, aims to stimulate reflections related to long-term changes of climate combined with considerations to climate variability to be included in decisions where selected adaptation actions are suitable for the relevant lifespan of a decision. Nevertheless, participants frequently commented on difficulties to handle dilemmas and complexity. In the development of the game, the balance between the desire to include complexities by including a large set of relevant aspects, needed to be balanced by finding a level where it is possible to understand linkages between actions and consequences. As indicated in this study, this is especially important when a game is played without a moderator. In the continuous development of the game, partly driven by test-sessions with students, the inclusion of additional texts that facilitated understanding of the consequences of choices was shown to be a critical component. Since all participants start with different perspectives and knowledge, one way of achieving this could be to develop a dynamic text that is adjustable (e.g., providing an option to obtain selected word definitions). There is a limit, however, when the inclusion of additional components, such as social dimension, could increase the complexity to a degree that would make it challenging to evaluate the consequences of actions. This highlights the importance of reflections and debriefing [36,37] of a gaming session, where important components that are not included in the digital game can be discussed. The feedback which was presented after each time step as well as at the end of the game aimed to support the players in reflecting on the consequences of their choices. Nevertheless, some participants commented on specific game logics that remained obscured and the lack of an overall perspective of how the city was impacted by climate change, which was to some extent enhanced by the fact that frequently many different extreme events had occurred during a time step. In terms of knowledge, competences and abilities that could be attained by playing the game, the different playing modes provided different possibilities for learning. While the game is easily accessible and is supported by didactic material and in-game explanatory texts, the learning, or self-assessment of increased knowledge, varied, and was possibly linked to the level of discussions in the roleplay groups or pairs, as well as to what extent the moderator motivated reflection and debriefing in any of the gaming sessions.

The challenges addressed by the climate adaptation game include several components that characterize “wicked problems” [10], referring to challenges that have no simple solutions, feature a lack of common understanding of the problem, high complexity, diverse perspectives and changing conditions. As such, this study presents an example of a serious game that allows the exploration of a wicked problem, where the synthesized outcome of several decisions, viewed from different perspectives, is reflected upon. This study provides some reflections related to the design of serious games to address these challenges: (i) in order to ensure that the players are not lost in the complexity, the game design needs to ensure a balanced amount of information that facilitates an understanding of choices, (ii) the option of addressing some of the complexity as part of the moderated discussion, rather than including it in the game, needs to be considered and (iii) the importance of guidelines for reflection and debriefing needs to be acknowledged, as much of the value of a gaming session is linked to debriefing and dialogue.

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