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ORIGINAL ARTICLE

How a Digital Educational Game can Promote Learning about Sustainability

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ABSTRACT

Education for Sustainable Development (ESD) has become an essential issue for schools facing major challenges such as bridging the knowledge-action-gap. Interactive simulations could help to focus on action-oriented learning. As part of a design-based research (DBR) process, we investigated the learning potential of game elements within a digital educational game for ESD we are currently developing. The final game aims to convey specific aspects of ESD ranging from sustainable land use to personal power consumption. Seven groups of 2–3 secondary school students (9th and 10th grade, n = 18) played the educational game in an early prototype phase. Following the DBR approach, students were shown screenshots of specific game situations in subsequent group interviews to reveal their conceptions and conceptual developments regarding sustainability. To analyze the causes of possible learning processes, we used the retrospective query on the learning process and qualitative content analysis. The results indicate that the observed learning processes can be primarily traced back to feedback mechanisms and the visualization of processes that would be too complex and long-termed to be experienced by students in real-life. This is how a simulation game, which makes complex interrelations tangible, can contribute to ESD. The possibility to make decisions and act (digitally) within the game allowed students to experience immediate feedback and self-efficacy. Therefore, the easily accessible visualizations and the immediate feedback are essential elements for the final game. It appears however necessary to embed the game in well-structured reflective processes. The study also contributes to adaptive game-based learning as a growing branch of research in which game elements are adopted and adapted for learning based on learner characteristics and the thematic context.

KEY WORDS: Design-based research; education for sustainable development; game-based learning; gamification; sustainability

INTRODUCTION

Challenges in Education for Sustainable Development (ESD)

The rise of awareness toward global problems such as the decline of biological diversity, climate change, or poverty has led to the proclamation of the United Nations decade of ESD from 2005 to 2014 and the definition of the 17 sustainability development goals (SDGs). Since then, "sustainability" has become an anchoring basic principle in national education systems. Educational institutions can and should thus consistently foster the development of sustainability competencies (Cebrián et al., 2021), whereby ESD can be seen as an extension of classic environmental education. However, the complexity and the multiple perspectives of sustainability (e.g., ecological, social, economic, cultural) remain a major challenge for classroom teaching, especially because sustainability competencies are difficult to access (Scharenberg et al., 2021). Several studies found that the influence of environmental education in schools on environmental action is only slight (e.g. Otto and Pensini, 2017). On the other hand, some studies on extracurricular environmental education in national parks show some positive effects on attitudes, knowledge, and behavior among learners (e.g. Baierl et al., 2021). We know that concrete and achievable goals motivate action. However, the goals of ESD are often on an abstract level and the link between behavior and its consequences is far afield and therefore barely experienceable. Furthermore, knowledge alone does not principally generate corresponding behavior, which is influenced by various aspects such as self-efficacy or outcome expectancy (Ajzen, 2002; 2012; Collado and Evans, 2019). Thus, ESD as well as related learning processes need to overcome the "Knowledge-Action-Gap" (Barth et al., 2012; Otto et al., 2019). Since environmentally responsible behavior can most likely be initiated through action-oriented learning (in a sense of "experiential learning" according to Kolb, 2014), the focus on action and experience should be given priority at school (Bornemann et al., 2020; Caniglia et al., 2021).

Digital Games for Learning

Although the use of digital technologies in learning is often ascribed a major role in public discussion, Hattie's new meta-study, based on 130,000 individual studies, shows only minor effects that can be directly attributed to digital media (Hattie, 2023). His study bemoans that technology is often only used as a substitute. However, some empirical studies have shown

how digital media can be effective in teaching (Hamilton et al., 2016). Especially, the benefit of digital educational games and game-based learning has been highlighted in formal and informal learning (Crookall, 2010; Hallinger and Wang, 2020; Kalogiannakis et al., 2021; Zeng et al., 2020). Initial experiences with programs that integrate digital learning games into regular school lessons confirm this assumption, which appears particularly interesting for complex and multi-layered topics such as "sustainability" (Azeiteiro et al., 2015). Other studies examined the influence of specific digital games on sustainability-related learning (Bontchev et al., 2022; Wang et al., 2021) or systematically reviewed games depicting climate change (Fernández Galeote and Hamari, 2021). In general, digital simulation games can turn students into actively experiencing individuals and thus they could be fruitful tools for ESD (Janakiraman et al., 2021; Katsaliaki and Mustafee, 2015; Liarakou et al., 2012). On the other hand, it is still difficult to draw reliable general conclusions about the effectiveness of serious games because of the varied nature of the different studies and because of their specific limitations (Girard et al., 2013), although there has been a considerable increase in the number of studies on game-based learning in the past 10 years (Ekin et al., 2023).

Gaming in the Light of Constructivist Learning

Our understanding of learning is based on (i) moderate constructivism (Fosnot, 2013) and (ii) a revised conceptual change approach (Chi, 2008; Duit and Treagust, 2003), that considers a situated perspective (Novak, 2002).

i. Students are seen as learners who actively construct knowledge through their experiences and interactions with the environment. Accordingly, they are not passive recipients of information but are actively engaged in the learning process, constructing meaning based on their prior knowledge and experiences. The learning process cannot be controlled completely by external factors, but it can be initiated by thoughtfully designed learning environments. Serious games showed the potential to foster constructivist learning in many ways (Krath et al., 2021). According to Jong et al. (2010), "computer games' intrinsic educational traits favor [...] constructivist learning" (p. 207) because motivational, cognitive, and sociocultural perspectives are met during gaming. Especially, the acquisition of knowledge is not solely based on conditioning and reinforcement, but rather it is a result of cognitive and sociocultural interactions within a stimulating and genuine learning environment. To become skilled at complex games, gamers must dedicate numerous hours of focused attention, sometimes even exceeding dozens of hours. These games often involve generative and open-ended tasks that do not have pre-defined gaming strategies. Gamers who play complex games cannot be passive, as active engagement is necessary for success. At the same time, this cognitive activation is a central element of constructivist learning (Antonacci and Modaress, 2008). Li et al. (2013) propose a design framework emphasizing constructionism as the foundation, which prioritizes the principles of construction as the ultimate objective. The framework also incorporates the concepts of low-threshold-high-ceiling and computer simulation to develop game-like learning systems.

ii. The students' conceptions derived from everyday experiences can be beneficial or obstructive for learning. Thus, we understand conceptual changes as reconstructions of conceptions (Kattmann, 2008), where conceptions can be further developed, changed, or newly formed. Such learning processes could be initiated by simulation games (Polin, 2018). A body of evidence highlights the potential of digital games to foster conceptual change (Xiao and Jiang, 2020; Koops and Hoevenaar, 2013; Chen, 2020; Van der Linden and van Joolingen, 2019; Gauthier and Jenkinson, 2017). Common themes are the need for adequate structures and supportive prompts and feedback finding a balance of challenge and flow to reach the zone of proximate development (Pasqualotto et al., 2023).

Research Questions

Game-based learning through simulation games seems to be a promising approach to make complex interrelations within sustainability tangible and thus they could bridge the "Knowledge-Action-Gap" in ESD. Our project aims to combine individual action, feedback, and experience with the multiple perspectives of sustainability in a digital educational simulation game. The final game is intended to be integrated into school lessons (formal context) and it engages players within the topic of sustainability in leisure time (informal context). For this purpose, we aim to identify specific game elements that are promising to convey relevant content for ESD by analyzing their potential to promote learning. As visualization and feedback mechanisms are considered to improve learning and are also very common elements in game design (Dickey, 2005; Ritterfeld et al., 2009; Shute, 2008), we focused in this study on game elements that mainly utilize clear visualization and immediate feedback.

To be able to design learning processes effectively, it is important to know the initial student conceptions. Based on this, those game elements should be found that best induce or promote the desired learning processes. Therefore, the research questions of this study which is dedicated to the game design process are: (1) Which conceptions regarding sustainability issues addressed by our game do the students have? (2) Which specific game elements can induce or promote learning processes on sustainability? We hypothesized that students are mainly influenced by the visualized effects of their game actions and by the immediate feedback within the game.

MATERIALS AND METHODS

This study is based on design-based research (DBR; McKenney and Reeves, 2018; Scott et al., 2020). We used qualitative interviews (Mayring and Fenzl, 2014) to examine learning

processes initiated or promoted by specific gameplay situations which are to be implemented in a digital educational game about sustainability. As part of DBR, game elements are optimized collaboratively with teachers and students in recurring, iterative sub-steps until they can achieve the best possible learning effects (Groß et al., 2020).

Game Concept and Development

The digital educational game about sustainability we are currently developing can be assigned to the rich genre of construction and management simulations. While most building strategy games require continuous growth, the particular aim of our game is to keep the three main ESD-indicators (economic, ecological, and social perspectives) in balance while developing a sustainable island. These three perspectives, which clearly structure and link selected SDGs (Rockström and Sukhdev, 2016) also serve as the main factors for successful gameplay. The player slips into the role of a mayor who governs a small town with surrounding environment on an island. Various dilemma decisions that the player is frequently confronted with should lead to a reflective contemplation with the topic. This game is collaboratively designed with an established game developer (upjers GmbH, Germany) and five regional secondary schools.

The game is aimed at secondary school students and is intended to be integrated into regular school lessons and into informal home learning and leisure activities. In addition to an open-end setting in which the player will start from scratch to develop an island, the final game will include different scenarios with pre-built islands. These will already have certain buildings and resources to confront the player with specific situations, such as shortage of fossil energy, emphasizing particular aspects of sustainability. The currently planned scenarios will cover the topics "sustainable nutrition and agriculture," "regional products and global trade," "energy demand and climate crisis" as well as "raw materials, recycling, and circular economy."

In this study, we tested some selected game elements, for example, the visualization of additional land use in meat production (more plant farms to supply life stock farms) or in regenerative energy sources (more wind and solar power plants), to determine whether they can promote conceptual development about sustainability. To provide immediate feedback, the effects of the players' decisions and actions during gameplay on the three main indicators were additionally visualized by red (negative influence) and green (positive influence) icons. These icons emerged from unused land, buildings, or certain actions such as selling or harvesting items and dynamically floated then toward one of the three indicators. Specifically, the framework for visualization and feedback included the following elements that were tested: (1) Status bars indicating ecological, social, and economic scores, (2) arrow icons below the status bars indicating trends, (3) icons emerging from actions or decisions made during gameplay floating towards the corresponding status bars, (4) counter icon indicating remaining unused land, (5) visualization of land needed for differently sized buildings and production chains (Table 1).

Research Methodology

To achieve validity and reliability in this qualitative interview study, we implemented the following methodological strategies (according to Denzin and Lincoln, 2017; Mayring and Fenzl, 2014; Seidman, 2006): First, ensuring validity involves using rigorous sampling techniques to select participants who can provide rich and diverse perspectives on the research topic. In addition, we used an appropriate interview guideline, which contains, for example, open questions, that enhances the validity by allowing participants to express their experiences and views authentically. To establish reliability, our interview guideline comprises different questions on the same topic to double-check the answers, and we implemented a systematic coding process (Mayring, 2014) to analyze the qualitative data, ensuring replicability and consistency.

For this study, seven groups of 2–3 volunteer students from two different secondary schools (9th and 10th grade, 15–18 years old; nine females, nine males) were invited to online (through Zoom) guided group interviews (according to Komorek and Duit, 2004). The sampling procedure was carried out according to the applicable quality criteria of qualitative research methods (Denzin and Lincoln, 2017). The samples were selected at random. For this purpose, students from two partner schools were asked to participate. The participants for the interviews were then randomly selected from the student volunteers, taking into account the best possible variation in terms of age, gender, and school performance. Each group interview lasted for approximately 60 min. All personalized data were made anonymous. Before the interview, students were allowed to

Table 1: Examples of designing game experiences that are relevant to sustainability decision-making

Serial number	A) Select an important variable with a high impact on sustainability	B) Choose (one of) the most relevant consequences resulting from decision-making during gameplay	C) Call the attention of the player to these consequences through prominent game elements
1	Meat production	Land use by agriculture	Visualization of land use
2	Electric power generation	Land use by power plants	Visualization of land use
3	Land use	Loss of nature	Counter icon indicating unused land
4	Combustion of fossil fuels	CO2 emissions and climate change	Icons moving to the key indicators
5	Economic growth	Enough decent work in industry	Icons moving to the key indicators

The table describes the design process from left to right with the steps A, B, C

familiarize themselves with the game and its mechanisms by playing an early prototype. During the interviews, the groups were then presented game-related graphics and screenshots. To reveal students' conceptions and conceptual developments, the interview guideline integrates two methodological approaches: First, problem-oriented, open, and half-open questions to collect current conceptions and secondly the retrospective query on the learning process (Paul et al., 2016). When structuring student conceptions into different levels of complexity, we focused on the concept level (Michelsen et al., 2022). According to the principle of saturation, interviews were carried out until no more fundamentally new concept could be identified. Thus, a generalization can be made on a conceptual level, not on a quantitative statistical level such as a frequency distribution of specific concepts in the population. We wanted to know whether and how student conceptions at the conceptual level are influenced by specific game elements and prompts. Hence, a qualitative approach was most appropriate.

The conceptions found primarily served as indicators to evaluate whether the intended game elements are suitable to induce learning processes on specific ESD aspects. Therefore, the interview guideline was structured in three parts: (1) General questions about the gameplay, (2) general questions about the participant's conceptions of sustainability, and (3) conceptual developments using game-related graphics and screenshots as prompts. The game-related prompts during the interviews reduced the complexity of a topic such as livestock farming and meat production to one essential aspect, here, namely, the influence of trophic levels on land use. However, the simulations in the final game will also consider more detailed aspects of agriculture, such as type of livestock or crop.

The prompts were designed as tasks in which the students had to evaluate or compare different screenshots from the game. The idea behind these prompts was to remind students of certain gameplay situations and analyze their effectiveness to induce discussions and conceptional developments on sustainability. Since the game basically has a linear plot pattern, there are typical situations that are clearly linked with concrete decisions on sustainability issues. In addition, the screenshots from the game were selected independently by two different researchers. To improve validity, only these screenshots were used as prompts that were selected by both researchers. Within the first prompt, students were asked to sort various foods from the game with respect to sustainability during the production process (Figure 1a). In addition, we presented screenshots comparing the land use for producing the same amount of fruits and vegetables versus meat in the game (Figure 1b and c). A similar prompt design was used, when students were asked to rank the diverse power plants in the game according to the most sustainable energy sources or when sorting overview map screenshots of different islands (e.g. heavy industry, small handcraft business) for sustainable land use. The presentation of these prompts led to partly intense discussions within the student groups, during which the students revealed conceptions on sustainable food, energy production, and land use. They argued based on their respective background knowledge and integrated experiences from the game. Utilizing the retrospective query technique, students were asked to name whether and which game element actually triggered conceptual developments. The interviews were analyzed using qualitative content analyses (Mayring and Fenzl, 2014). To improve validity and reliability, the interrelationship between questions and answers was validated by two different researchers as suggested by Seidman (2006). By comparing retrospectively and currently named concepts, conclusions about the learning process could be derived and possible causes be discussed. This research was approved by the State Ministry of Education and Culture and our institution's research ethics committee.

RESULTS

Students' Conceptions

To obtain an idea whether and how the game elements from the early prototype and from the prompts used in the interviews influence learning, we firstly addressed the conceptions students named in the context of the game. Our interviews revealed a wide range of players' concepts about sustainability. A total of 21 different concepts were found, which were assigned to four categories (Table 2). These four categories, determined on the basis of the data, are: Land use, food production, energy sources, and sustainability in general. For the latter, we found three different concepts, six concepts were assigned to the category "food production," four concepts to the category "land use," and the category "energy sources" yielded eight different concepts. The concepts mentioned most frequently were number 1, 4, 10, and 14 (bold in Table 2). The necessary balance between ecology, economy, and social issues is regularly described referring to the three main game indicators (Table 2, concept no. 1). Many students were aware of animals (particularly cows) emitting methane and therefore named livestock farming as a source of carbon dioxide and methane (Table 2, concept no. 4). Pointing out the multi-step production process that requires several grain farms to produce meat in the game, the students cited livestock farming to need additional land (Table 2, concept no. 10). During the discussion, many students emphasized the extremely long formation process of oil from organic materials (Table 2, concept no. 14), making it a limited resource (Table 2, concept no. 15).

Students' Conceptual Developments

One set of prompts during the group interviews addressed sustainable nutrition (Figure 1). It particularly focused on land use in the context of meat production compared to fruit or vegetable production. The following statement on meat production represents a typical interview situation (original transcript excerpt, retrospective query on the learning process):

Interviewer: "What did you know about sustainability before and has your conception on sustainability changed?"

Ben: "(...) I associated sustainability with nature and environmental awareness (...) and I didn't consider all

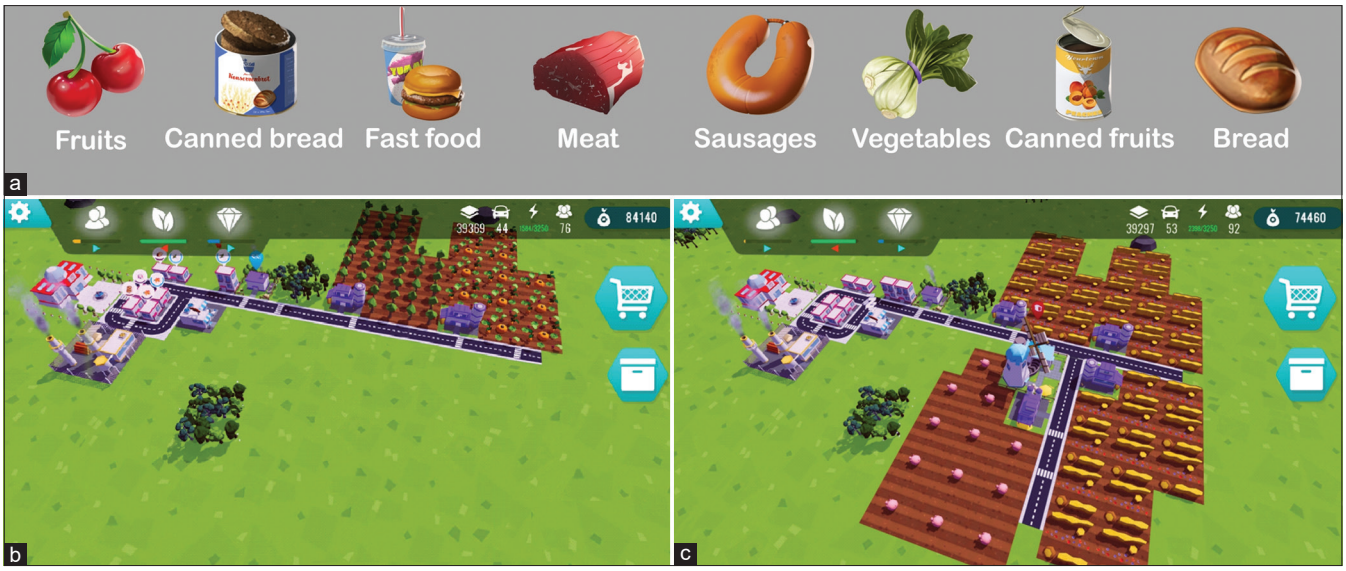

Figure 1: Group interview prompts on sustainable food production. (a) Students were asked to sort food items from the prototype game with respect to sustainable production. (b and c) Screenshots from the game illustrating the land needed to produce the same amount of vegetables and fruits (b) and meat (c). In the upper left corner, the continuously visible three main gameplay indicators allow the players to receive immediate feedback on how their decisions influence the social, ecological or economical perspective of sustainability. The blue and red arrows underneath these indicators symbolize the trend for the respective perspective

Table 2: The derived concepts about sustainability and related issues mentioned in the seven group interviews (18 participants)

Category	Serial number	Derived concepts	Incidence
Sustainability (in general)	1	Sustainability means the balance of ecology, economy, and social aspects	6
	2	Sustainability is synonymous with environmental protection	2
	3	Economy and environment protection are opposing driving forces	2
Food production	4	Livestock farming increases CO_2 and methane emission	7
	5	Livestock farming needs additional energy	3
	6	Livestock farming is ethically questionable	2
	7	Packed products are less sustainable	4
	8	Regional products are more sustainable	3
	9	Transportation reduces sustainability	5
Land use	10	Livestock farming needs much more additional land	6
	11	Renewable energy powerplants need more land	5
	12	Unused natural land is needed for intact ecosystems	5
	13	Nature reserves are better than unused land	5
Energy sources	14	Oil originates from organic material over extremely long periods of time	6
	15	Oil is a limited resource	5
	16	Solar energy is directly accessible	2
	17	Wood burning causes CO_2 emission	4
	18	Trees bind CO_2 and emit O_2	4
	19	Nuclear waste is difficult to dispose of	4
	20	Nuclear powerplants may result in catastrophic damages to the environment	2
	21	Oil production may result in catastrophic damage to the environment	2

The four categories were determined subsequently based on the data and the prompts presented during the interviews

> *the three perspectives (of sustainability). (...) I was not aware, before this visualization, that meat production needs that much more land and energy. I will rethink this and probably reduce my meat consumption."*

For Ben, sustainability was restricted to the ecological perspective, but while playing the game he realized that also economic and social aspects have to be considered. Even though Ben was aware that meat consumption is discussed as less sustainable than eating fruits or vegetables, the visual comparison of the land use made him realize that this is indeed true due to the increased energy and land use. This also suggests an attitudinal development. Ben's change of mind represents

two learning processes: First, sustainability became a multi-perspective topic with ecological, social, and economic aspects being considered. Second, he realized that meat production is an "add-on" process to vegetable production, thereby consuming more land and energy.

The continuous presence of the three main game indicators representing the economic, ecological, and social perspective of ESD let the students immediately perceive the consequences of their actions in the game. This allowed them to realize the often hidden interconnectedness of these three parameters, which in turn enabled the conceptual development that the three perspectives of ESD should be kept in an equilibrium, as exemplarily illustrated by the following retrospective interview situation (original transcript excerpt):

> *Interviewer: "What did you know about sustainability before and has your conception on sustainability changed?"*
> *Jan: "(...) in any case I realized that sustainability needs all three of these pillars together [referring to the economic, ecological and social perspective], and that one should not focus on just one aspect but rather make sure that everything stays in harmony and balance.".*

Named Reasons for Conceptual Developments

Since sustainability is a prominent topic, students often already had rather detailed and accurate conceptions on sustainability. Four students reported no new insights during the group interview after playing the game. Nonetheless, conceptual developments occurred in all four categories mentioned above. In some cases, participants even named the cause-effect relation mediating their learning processes. However, the game-related prompts themself often just revealed individual students' conceptions and the following discussion among the students actually promoted the conceptual development. This was the case, for example, when the students were discussing different energy sources: Students were aware that combined heat and power plants emit carbon dioxide, which is a major greenhouse gas. During discussion, students stated that using wood as a renewable energy source is a carbon dioxide neutral process (Figure 2b).

When sorting food items as a prompt (Figure 1a), students argued that regional production, transport routes, and packaging affect sustainability (concepts 7–9). After additionally showing how much farmland is needed for meat production compared to fruits and vegetables (Figure 1b and c), several students realized that meat production has higher sustainability-related costs for energy consumption and land use (concepts 5, 10). Some students derived from this the general idea that the number of manufacturing steps needed for food production negatively correlates with sustainability. As the reason for this conceptual development (Figure 2a), the participants named the visualization of farmland required in the game.

When assessing game screenshots showing different land use (unused land, moderate and heavy industry, and conservation area), students argued either that only unused land or, even better, conservation areas can preserve natural ecosystems (concepts 12, 13). In this way, sustainability was often equated with environmental protection. Thereby, most students did not consider ecology as the limiting factor of sustainability in the sense of a strong sustainability but rather ignored economic and social consequences. By adding the three main game indicators to the screenshots (ecology, economy, and society), this conception changed as students became aware that sustainability equally includes the three different perspectives of ecology, economy, and social issues, and one sometimes has to weigh between these perspectives (Figure 2c). According to the participating students, this conceptual development resulted from the effects of their own actions on the three sustainability indicators in the game, especially by the emerging icons that floated toward one of the three indicators. Through the discussion process, the students in three group interviews took a step further and recognized that basically all everyday decisions should be evaluated in terms of sustainability using the multi-perspective approach of ecological, economic, and social consequences.

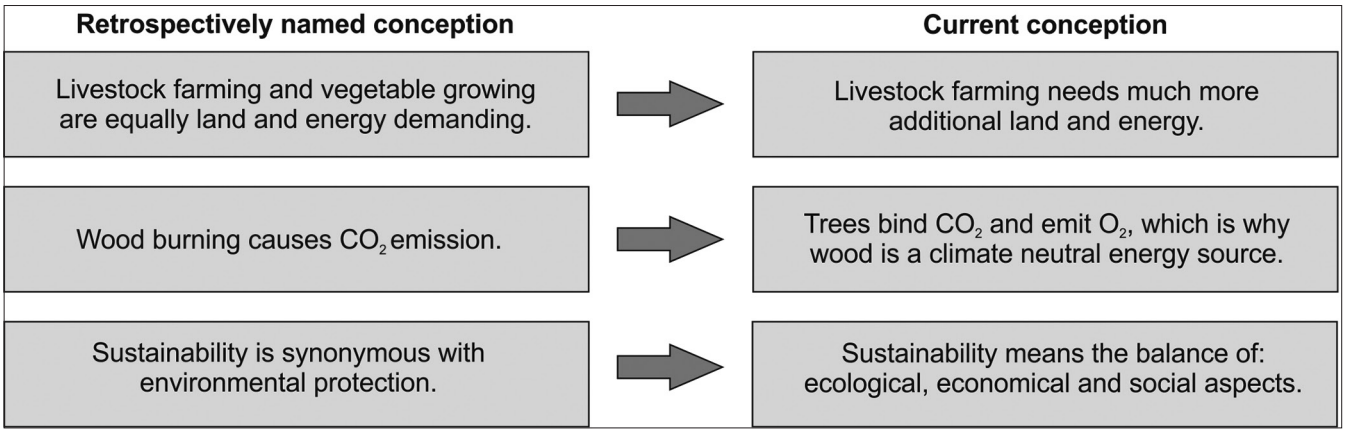

Figure 2: Exemplary conceptual developments in response to the game experience and the following reflection process (each example represents another category according to Table 2: (a) food production, (b) energy sources, (c) sustainability in general). On the left is the retrospectively named conception, on the right is the current conception

DISCUSSION

During the group interviews, screenshots of specific game situations derived from the prototype game were presented to the students. These prompts were intended to activate and resemble the students' decisions made during the free-play phase of the prototype game. Hence, which conceptions regarding sustainability issues addressed by our game do the students have and how are they to be assessed in terms of their adequacy? Table 2 gives an overview of the concepts found. These concepts derived from the interviews suggest students' differentiated approaches toward sustainability. None of the concepts found is technically completely wrong, while some of them are questionable, strongly simplified, and worth discussion or depend on a very specific perspective (e.g., concepts 2, 8, 13, 15). For example, whether regional or imported products are more sustainable (8) does not only depend on transportation (9) but also on local production and storage conditions. Regardless, we detected several conceptual developments (Figure 2), all of which reflect appropriate learning processes or a more sophisticated understanding of sustainability. Some of them were not induced by the educational game itself, but rather during phases of reflection when the students discussed the game-related prompts. This is in line with other studies which suggest that reflection phases are highly conducive to learning (Crookall, 2014; Moon, 2013; Petranek et al., 1992; Schneider and Schaal, 2018). Accordingly, so that educational games can develop their full potential, for example, to relate emerging concepts to real-world problems, preparatory and reflective follow-up lessons are required, also to embed the games as a core element of teaching and learning at school (Crookall, 2010; Fjællingsdal and Klöckner, 2019).

Our prompts during the interviews considerably reduced the complexity of a topic to reveal the effects of single-game elements of the prototype. This also showed that reduced complexity could lead to oversimplified knowledge, as students concluded that meat production in general is less sustainable. However, according to recent research in agricultural science, a more nuanced approach is needed to particularly account for the socio-ecological perspective (Dumont et al., 2018; 2019; 2020). Some games or tools that focus on agroecology cover this aspect extensively (Jouan et al., 2020; Ryschawy et al., 2019).

Utilizing the retrospective query technique during the interviews, we addressed our second research question: Which specific game elements can induce or promote learning processes on sustainability? Besides reflection, we thus identified a second reason for conceptual developments that explicitly depend on game design elements. Many students named the concrete visualization during the game experience as a cause. In some cases, conceptual developments could be pinpointed to the visualization of complex processes that are not easily accessible in real life, for example, for meat production that forced the player to build several grain farms to supply one single livestock farm with animal feed (Figure 1b, c; Table 1). Thus, the visualized land use within the game can have a relevant impact for learning complex interrelations. In the area of resource management such as land use, digital games and simulations can therefore make a valuable contribution if designed properly (Barreteau et al., 2007; Lindner and Neubert, 2015). In addition, within the complex topic of sustainability, digital games seem to be more effective than non-digital games (Ho et al., 2022).

The main screen of the game permanently showed the three action-sensitive sustainability indicators ecology, economy, and society. With emerging icons that dynamically floated toward the affected indicator, the players received direct and immediate feedback on the taken actions. These indicators turned out to be essential to shift the typically environment protection-based view toward a multi-perspective view on sustainability. Accordingly, the participants mentioned direct feedback as the reason for developing the conception that sustainability must balance ecological, economic, and social aspects (Figure 2c). Direct feedback is known to be a typical game design element by which entertainment games can encourage meaningful learning (Qian and Clark, 2016). In addition, it was shown that reward-based game mechanics such as badges and trophies can significantly increase sustainability knowledge (Whittaker et al., 2021). In another context, points and competitive elements such as leaderboard ranks also increased motivation for learning, although not all learners appreciated competition with classmates (Sánchez-Martín et al., 2017). Even very simple quiz elements can engage students in learning complex issues, for example, transcription and translation of protein biosynthesis in biology courses (Jones et al., 2019). However, gamification and game-based learning do not consistently achieve the expected outcomes in students' learning. Adaptive gamification is therefore a growing research stream that enhances traditional "one-size-fits-all" or unfocused gamification approaches by adopting and adapting the diverse game elements based on characteristics of users and thematic context (Zourmpakis et al., 2023).

The direct feedback also gave the players the possibility to experience self-efficacy in the game and learn specific correlations between their digital action and its outcome in terms of sustainability. The player learns through doing and the game is a designed experience (Squire, 2006) which empowers for future decision-making (Czauderna and Budke, 2020). This represents the action-oriented learning with a focus on experience required in ESD. As self-efficacy is supposed to be crucial for changing behavior in real-live situations (Ajzen, 2002; 2012; Bandura, 2010), the digital interactive experience in the game could be a basis to induce behavioral changes in students' everyday lives. Hence, educational games may play an important role in promoting ESD in classroom teaching by linking knowledge and action in combination with immediate feedback, as has also been suggested in the previous studies (Knol and De Vries, 2011; Paul et al., 2020). In addition, emotions and affective components are considered to have a

huge impact on behavior (Dolan, 2002). When designing an ESD game, it therefore seems obvious to focus on the game flow, affective approaches, and personal attitudes as well as on action even if only experienced in a virtual setting (Schneider and Schaal, 2018).

CONCLUSION

We conclude that specific game elements or reflection on them might initiate learning processes on difficult aspects of sustainability by (1) realizing complex interrelations through visualized digital interactive experiences and (2) balancing multiple perspectives through direct and immediate feedback. However, such an educational game should be integrated into classroom teaching or comparable settings to provide opportunities for further reflection with teachers or experts and to monitor whether students have drawn appropriate conclusions. Further research on the final game is needed to determine the impact of the game and its elements addressed here.

INSTITUTIONAL REVIEW BOARD STATEMENT

This research was approved by the Bavarian State Ministry of Education and Culture (Approval Code: IV.7-BO4106.2020/10/8; Approval Date: May 15, 2020) and our institutions' research ethics committee.

INFORMED CONSENT STATEMENT

Informed consent was obtained from all subjects involved in the study.

DATA AVAILABILITY STATEMENT

Data available on request due to restrictions, for example, privacy or ethical. The data presented in this study are available on request from the corresponding author.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of the data; in the writing of the manuscript; nor in the decision to publish the results.

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