Sustainability Competencies in Serious Games

Implementing existing research into educational game development for sustainability

Larissa Lachmann

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Supervisor: Darin Wahl, LUCSUS, Lund University

Abstract

Serious Games have gained increased attention in sustainability education. I developed a Serious Game that aims to increase sustainability competencies related to water problems among university students. I applied socio-constructivist learning theory to investigate how sustainability competency can be operationalised in learning outcomes and how these can be translated into game elements. Methodologically, I followed an educational game development structure, including several rounds of playtesting and assessments. Further, translating the learning outcomes into game elements was made possible through a mix of several approaches of different strength. Results showed that sustainability competency remains vague, which requires substantial reflection on the theoretical and methodological choices. The game was received very positively from testers, both from an enjoyment and an educational perspective. Results from observations and pre- and post-testing showed learning in almost all sustainability competencies. In combination with another teaching form and more playtime, learning could be enhanced.

Keywords:

Serious Games, ESD, Sustainability competencies, water, educational game design, educational games

Word count: 11687

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Abbreviations

DP – Design Principles

ESD – Education for Sustainable Development

HE – Higher Education

ILO – Intended learning outcomes

NE Germany – Northeast Germany

RQ – Research question

SC – Sustainability competency

SG – Serious Game

List of Tables

List of Figures

1 Introduction

Sustainability education can play a central role in improving the basic conditions for a required social change (Barth, 2015). Under large-scale pressures such as climate change, one of the main challenges is to ensure access to adequate and clean water resources under changing conditions. This requires societies to fundamentally change their interactions with water resources (Caretta et al., 2022). Key research questions in sustainability science are how to support sustainable transformation and link existing knowledge to action (Clark & Harley, 2020). Transformation toward sustainable development requires that people are capable and willing to challenge the status quo (Shephard et al., 2019). Education can play a key role in creating widespread understanding, support and participation in sustainable change by promoting a joint learning process in society (Barth, 2015).

Increasing sustainability competency (SC) has become a central task of Education for Sustainable Development (ESD), but there is still a great deal of uncertainty about the concrete implementation of SCs. Among a variety of terms, ESD is the most common term to describe attempts to integrate sustainability into educational practices (Vare et al., 2022). ESD has undergone a paradigm shift from knowledge orientation to action orientation, as it became evident in recent years that conventional teaching methods are often insufficient to prepare learners for a highly volatile future (Wilhelm et al., 2019). Instead of transferring knowledge, sustainability action should be promoted by increasing competencies among students to solve the complex problems of today and the future (Cebrián et al., 2020; Vare, 2022; Wilhelm et al., 2019). However, while competencies have become a widespread term, little is known about how to operationalise SCs in the educational context (Brundiers et al., 2021; Cebrián et al., 2020; Wilhelm et al., 2019). In the higher education (HE) context, educators often have not received professional training in didactics or pedagogy; therefore, they regularly have to develop teaching units in an autodidactic manner. More knowledge on how to concretely operationalise and realise SCs is needed (Wilhelm et al., 2019).

Serious Games as a teaching strategy have gained increasing attention in the last decade for sustainability education (Ouariachi et al., 2019; Stanitsas et al., 2019). Serious Games are not solely designed to entertain, but to convey ideas and values and facilitate learning or practice skills. They aim to influence the players' thoughts and actions in a real-life context; therefore, their purpose goes beyond the gameplay itself. Through their mechanisms of play, games require constant action, which can offer a deeper learning experience and reach players on a cognitive, emotional and social level

(Ouariachi et al., 2019). Sustainability-themed Serious Games continue to gain popularity, and a rising number of games are being developed (Douglas & Brauer, 2021; Fuchs et al., 2021; Stanitsas et al., 2019). This includes various types of games, from board games to online games. The range of topics of sustainability-themed games is as broad as sustainability itself, ranging from classical sustainability themes such as water issues (de Kraker et al., 2021) or climate change (Fernández Galeote & Hamari, 2021) to sustainable development (Tsai et al., 2021) and political considerations (Raffn & Lassen, 2021).

Little is known about the integration of SCs into game design. Although many researchers have explored how to develop games for educational purposes, very few combine learning and game elements on a theoretical level, as well as on an evidence-based or empirical level (Lameras et al., 2017). This leaves little guidance on how to specifically design an educational game to foster specific learning outcomes, let alone SCs. The game format itself is often seen as sufficient to achieve the desired learning outcomes; however, simply building a sustainability-themed game not guarantee an increase in SCs. In contrast, how learning content is integrated into game elements makes a huge difference in game educational outcomes (Lozano et al., 2019). The consequences of this theoretical and empirical gap are shown in a study by Stanitas et al. (2019). They found that most of the 77 sustainability games they analysed did not cover environmental, economic, and social issues simultaneously. This prevents the holistic learning necessary to address sustainability issues. Furthermore, the concrete pedagogical approaches and learning theories underpinning the games are rarely discussed in research papers about game development.

1.1 Research Aim

In this thesis, I aim to explore how a Serious Game can be developed in a manner that fosters SCs. I did this by designing and developing a game based on the existing literature. I focussed on water issues in Northeast Germany (NE Germany), but those are just one exemplary area where sustainable change is needed. My findings are intended to be applicable to other areas of sustainability. By designing and developing the game, I intend to overcome the lack of clarity on how competence orientation in ESD can be implemented in an educational context and show potential future areas of research. Three questions that represent essential parts of the game development process guided my research. While the first one focuses on the conceptual considerations, the second one deals with the practical implications, and the third one reflects on the results of the previous questions.

RQ1: How can sustainability competencies be operationalised as learning outcomes?

RQ2: How can these learning outcomes be realised in the game features?

RQ3: How effective is the game in achieving its learning outcomes?

To answer these questions, in the background section (2) I give an overview of water issues in NE Germany as an example of a sustainability problem. In the theory section (3), I introduce the role of sustainability competencies in ESD and explain why socio-constructivist learning theory and constructive alignment are essential for operationalizing SCs in SGs. Methods (4) follow a common structure of game design: generation of student-centred learning outcomes, decisions on basic game elements, integration of learning content into the game, playtesting and, lastly, publishing. In the results section (5), the derived learning outcomes are demonstrated, as well as the results of the game and the assessment. The discussion (6) relates my findings to the RQs and the broader context of Serious Games and sustainability.

2 Background

2.1 Water issues in Germany

As mentioned above, I focussed on water issues in Northeast Germany (NE Germany), more precisely the Berlin-Brandenburg region, an area that is under threat of increased water problems due to climate change. Changes are required to ensure long-term water availability (CLiWaC, n.d.).

The 2018 drought already showed the severe effects of extreme droughts in large parts of Europe. It caused significant losses in agricultural production and led to water shortages and low river flows in many regions (Buras et al., 2020) . While Germany is not necessarily known for water shortages, recent years have shown that climate change puts pressure on water systems throughout Germany. The Berlin-Brandenburg region is especially prone to droughts due to low precipitation values and dry soils (Ihinegbu & Ogunwumi, 2021). This is also reflected in a negative long-term water balance in the region (Figure 1a). At the time of writing, the next drought is already developing (Figure 1b). Climate change is predicted to increase the severity and frequency of droughts in the future (Vicente-Serrano et al., 2020). While there is much uncertainty around the exact consequences on the water system, the changed climate will have substantial impact in the proximate future and even more severe consequences in the long term. This includes reduced overall precipitation, reduced groundwater recharge, increased risks of extreme events such as droughts and floods, and as new pressures on water infrastructure (adelphi / PRC / EURAC, 2015). Consequently, water availability, quality, and water-related ecosystems are heavily aeffected and adaption to the conditions will be crucial to avoid billions of euros in damages (adelphi / Fresh Thoughts Consulting / PIK, 2020).

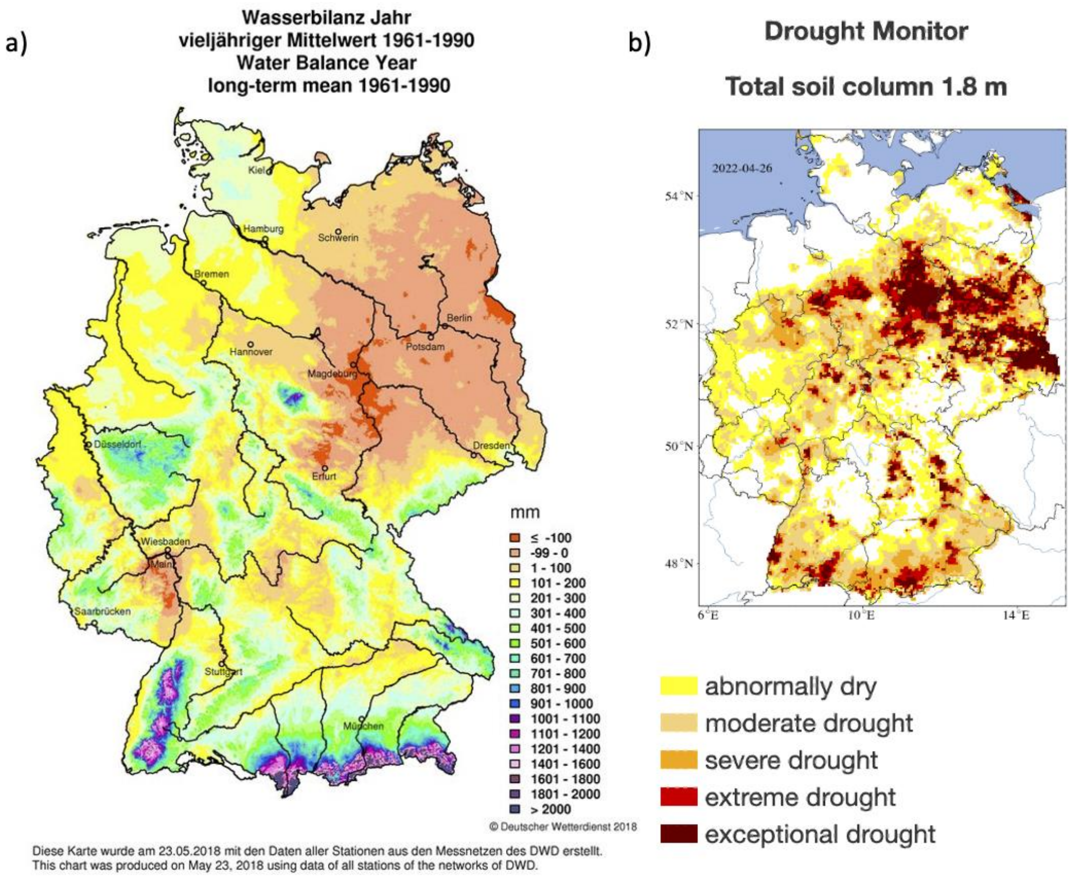

Figure 1. Dry conditions in the Berlin-Brandenburg region. a) Annual water balance long-term mean 1961-1990 showing negative balance in NE, including Berlin and surrounding area. The water balance subtracts the potential evaporation from the precipitation (DWD, 2018), b) Drought monitor of total soil column 1,8 m showing extreme and exceptional drought values in the area around Berlin. The drought monitor uses the hydrological model system mHM which models the soil moisture conditions. A drought is defined in reference to the average soil moisture between 1951 and 2015 (UFZ, 2022).

In addition to dry conditions in general, floods and water pollution also threaten the region. Three major floods occurred in Brandenburg in the last 20 years causing severe damage (LfU, n.a.). As was shown in 2021 during extreme flood events, floods can have catastrophic consequences causing high death tolls and massive damage to essential infrastructure (Fekete & Sandholz, 2021). In addition to water quantity issues, water quality also presents a major concern. According to the European Water Framework Directive, in 2015 70% of Germany's lakes have not reached 'good ecological status' despite many efforts to reduce point source pollution by wastewater. The main source of this pollution is excessive nutrient emissions from agriculture. To achieve better lake conditions, agricultural practices must be drastically improved (Rücker et al., 2019). The lack of active regulation also led to Germany being sued by the EU for unacceptably high nitrate levels in 2016 (Schumacher, 2016). Droughts can worsen the effects of nutrient surplus even more (Klages et al., 2020).

3 Theory

In the following three subsections, I elaborate on the importance of sustainability competencies (SCs) for ESD. Furthermore, I introduce socio-constructivist learning theory as a theoretical foundation for gamified learning, constructive alignment as a tool to improve teaching efforts, and introduce the implications for Serious Game (SG) development.

3.1 Importance of Sustainability Competencies for ESD

I will use ESD as a long-standing and internationally accepted term for sustainability education, though ESD as a concept has been criticised for often having an uncritical incorporation of the Sustainable Development Goals (SDGs) and their growth-paradigm (Kopnina, 2020), and often having an instrumental character, which is hard to reconcile with the frequently desired emancipatory purpose of education (Barth, 2015). In practice, however, it can include other perspectives, such as alternative economic models, rights-based approaches, or local knowledge; thus, it can encourage critical and sustainable attitudes. ESD has been established as a key factor in promoting sustainable change, but its concrete implementation is contested (Ssossé et al., 2021). ESD gained international attention during the United Nations Decade of Education for Sustainable Development (2005-2014), which was followed by many initiatives, programmes, and recommendations to bring ESD into higher education (HE) (Cebrián et al., 2020). Since then, there has been an ongoing discussion on the concrete implementation of sustainability in HE (Lozano et al., 2019).

While competence orientation is seen as a key for successful sustainability education, the lack of clarity surrounding SCs is a big obstacle for practical implementation and assessment (Mulà et al., 2022). First, there is a substantial amount of confusion about the concept of competence, as few use the concept in the same way. Second, it is also debated whether a common definition is even desirable or might even reduce the usefulness for sustainability teaching. Third, the outcome focus of competency orientation might go against more emancipatory objectives. Forth, concept-orientation omits other concepts that might be valuable for sustainability teaching (Vare, 2022). Furthermore, a fundamental problem with teaching competency is that it cannot be taught directly. Instead, pedagogic theory suggests that only the underlying dispositions can be taught (Wilhelm et al., 2019), which adds another layer of complexity as cognitive abilities and affective objectives are often conflated (Shephard, 2022). Additionally, one core challenge is the diversity in how people understand sustainability and the consequent variety of expectations of what ESD is supposed to provide. Lastly, the wide range of requirements makes measuring and comparing the outcomes of ESD a difficult endeavour (Ssossé et al., 2021).

Nevertheless, the notion of sustainability competence is increasingly gaining focus as an educational goal to prepare students for future challenges (Cebrián et al., 2020; Mulà et al., 2022; Redman et al., 2021; Wilhelm et al., 2019). Instead of abandoning the concept completely, critical application and testing can be a promising path (Vare, 2020). Among a wide variety of sustainability competence models, the lowest common denominator is that all of them include the need for an increased ability of individuals to deal with complex problems and future challenges in a transdisciplinary manner incorporating multiple perspectives (Wilhelm et al., 2019). Additionally, there is agreement that ESD is especially effective when it promotes several competencies instead of teaching them separately (Brundiers et al., 2021; Lozano et al., 2019). While there is no undisputed definition of what SCs are, there are several reference frameworks (Brundiers et al., 2021). For this thesis, I used the reference framework by Brundiers et al. (2021) to describe and conceptualise key competencies in sustainability. The idea of key competencies for sustainability goes back to an understanding of competency as a specific set of context-specific learned attributes (Vare et al., 2022). Key competencies for sustainability are defined as:

"A distinctive and multifunctional competency, which is composed of several sustainability competencies that functionally relate to each other. It facilitates achieving successful performance and a positive outcome that progresses sustainability (given what is known, valued, and aspired at a given moment in time), while working on specific sustainability challenges and opportunities in a range of contexts" (Brundiers et al., 2021, p. 17).

The framework by Brundiers et al. (2021) is a refinement of a frequently-cited framework developed by Wiek et al. (2011). They added two competencies (Implementation competency and Interpersonal competency) to the original competencies (Systems-thinking competency, Anticipatory/futures-thinking competency, Normative/values-thinking competency, Strategic-thinking competency, and Integrated problem-solving competency) and suggest a hierarchy of competencies (Figure 2). Thus, the SCs used throughout this thesis are drawn from this framework of key competencies for sustainability.

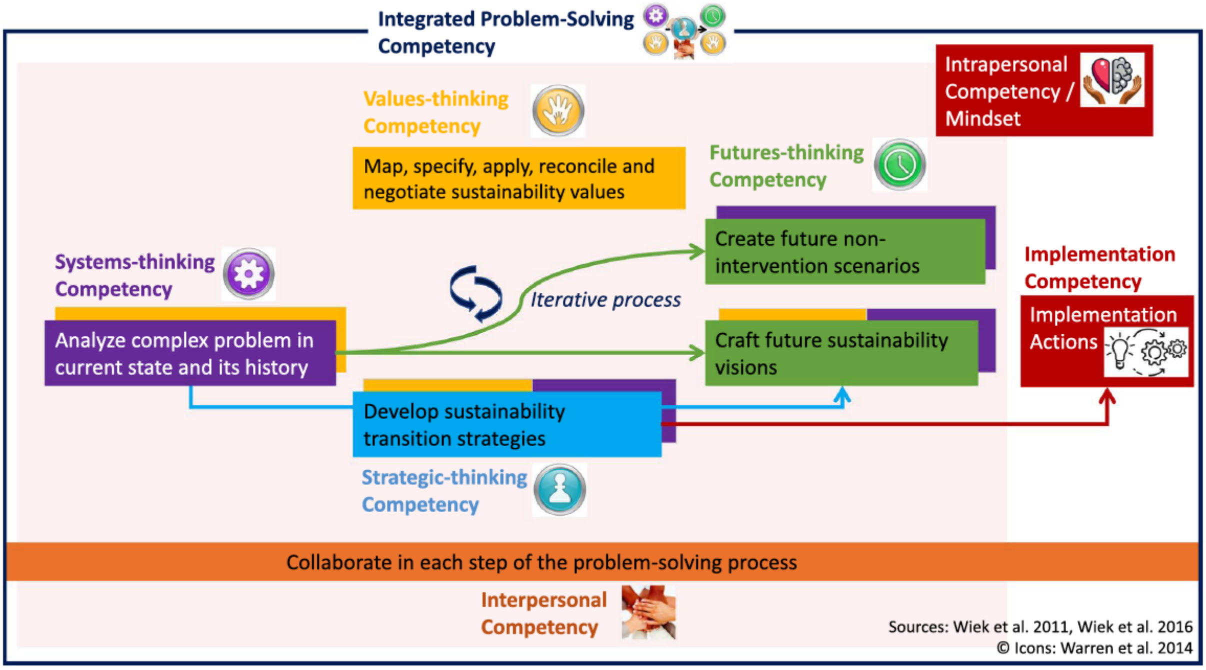

Figure 2. Key competencies in sustainability reference framework. The framework is based on Wiek et al. (2011) and was refined by Brundiers et al. (2021). Together the different competencies should amount to an integrated problem-solving competency. As is shown, the different competencies are interlinked. How the intrapersonal competency is integrated is still debated, thus it has no fixed position in the framework yet.

3.2 Socio-constructivist learning theory and constructive alignment

In the following, I will explain how socio-constructivist learning theory influenced my game development process by providing a theoretical basis for designing a meaningful learning environment and highlighting the importance of constructive alignment for Serious Games. Social constructivism as a learning theory understands learning as a social, active, situated, and playful experience. Individuals are conceptualised as autonomous systems that cannot be transformed from the outside. Instead, learning environments must be designed to support reflective and experimental learning. The whole learning process is understood as a cycle of reflection, abstraction, and active exploration of these abstractions (Barth, 2015). While there are several theories and approaches to learning in ESD, they all have in common that they conceptualise “learning as active construction, based on situated learning and constructivism” (Barth, 2015, p. 86). Additionally, teaching based on socio-constructivist theory is common in game-based sustainability teaching (Qian & Clark, 2016).

According to socio-constructivist learning theory, competence development can be supported through self-directed learning in a meaningful learning environment. For self-directed learning, it is essential to motivate learners to acquire knowledge themselves. Consequently, emotions play an important role as they can be highly motivational and further help in assessing the value of the given information and transferring knowledge into a real-world environment. Therefore, this approach acknowledges the subjectivity of reality and, in turn, requires consideration of learners' prior mindsets and how they affect their interpretation of the content presented (Barth, 2015). According to Barth (2015), the creation of a meaningful learning environment should include a great variety of presentation forms, as well as a strong focus on collaborative learning. This makes teaching in small groups suitable, as it is assumed that students learn primarily through interactions with others. Most game designs also rely on small groups.

Pedagogical methods for SC should include cognitive and affective learning, supported by active, experimental, and multimethod teaching practices (Ssossé et al., 2021). Grund and Brock (2020) also emphasise the need to consider controversial topics in ESD, including socioemotional learning approaches, to make it effective. This includes enabling learners "to understand and manage emotions, set and accomplish goals, feel and express empathy, and create and maintain good relationships with others" (p. 14). The emotional aspect is especially important due to the often highly normative nature of sustainability problems, which require people to respond in a way that reflects one's own values and norms and is empathetic to the perceptions of other people. This requires embedding sustainability issues in a meaningful and conceptualised manner that allows learners to respond emotionally (Barth, 2015).

Constructive alignment between learning outcomes, teaching methods, and assessment is essential for successful SC teaching (Wiek & Redman, 2022). Constructive Alignment recognizes on one hand that each learner constructs his own knowledge and, on the other hand, highlights the importance of aligning the assessment and methods with what is intended to be learned. Constructive alignment of the assessment with the intended learning is needed to provide useful feedback for teachers and learners. For the application, it is important to see constructive alignment as a constant challenge that requires educators to reflect on their teaching approach rather than a fixed tool (Barth, 2015). When it comes to aligning the assessment, the SC assessment is still in its infancy, but the amount of research from this field is growing and assessment strategies have diversified (Barth, 2015; Redman et al., 2021).

3.3 Constructive Alignment of Serious Games for Sustainability

A variety of effects of game-based learning makes it a potentially suitable pedagogic approach to foster various SCs in a meaningful learning environment. As stipulated by socio-constructivist learning, a learning environment using games creates active participation by the players by nature and allows them to explore social roles, form hypotheses, test ideas, and develop skills by playing (Qian & Clark, 2016). This offers a deeper learning experience and reaches players at a cognitive, emotional, and social level (Ouariachi et al., 2019). Games can also enhance problem solving skills, understanding, and the development of emotional and collaborative skills. Games also promote the collaborative construction of knowledge by providing opportunities to "actively experience, practice, interact, and reflect in a collaborative, game-based, and learner-centred setting" , games promote learning, engage, and motivate (Vlachopoulos & Makri, 2017). This aspect is also often used to enhance social learning by bringing different stakeholders together in a game format (den Haan & van der Voort, 2018). Furthermore, while not explored sufficiently, SG also has the potential for a holistic learning experience by integrating knowledge from various disciplines (Stanitsas et al., 2019). Thus, game-based learning has gained increased attention in recent years as a didactic method for sustainability education (Fuchs et al., 2021). Many games also emerged related to water issues, for example the video game *Let Us Save Venice*, which prepares citizens for extreme water-related events such as floods (Bontchev et al., 2021), and the tabletop game *Water Ark* about water resource adaption (Cheng et al., 2019).

In theory, constructive alignment in Serious Games requires constant consideration about how the game play brings the players closer to achieving the learning outcomes. According to Romero and Kalmpourtzis (2020), a game is constructively aligned to learning objectives if it includes a high degree of coherence between the learning objective and the game objective, andbetween the learning mechanics and the game mechanics. This initially requires an integration of the learning outcomes in the game content, but this alone cannot ensure that the learning mechanics, game mechanics and learning outcome will align. Thus, only a deeper reflection about the connection of game and learning mechanics enables the interconnections that create the potential for value-, systems- and strategic thinking in a game.

However, little is known about how to constructively align the gaming and learning objectives of Serious Games in practice. Serious Games have a purpose beyond entertainment; they should also transport values, ideas, facilitate learning, or train skills (Ouariachi et al., 2019). These games are very diverse in their content, mechanics and setup, ranging from online simulations of environmental disaster to political board games (Stanitsas et al., 2019). Many attempts have been made to summarize the broad range of games and link game elements and learning objectives. Among those were various frameworks (Aubert et al., 2019; Fjællingsdal & Klöckner, 2017; Wang & Huang, 2021; Westera et al., 2008), models (Arnab et al., 2015), guides (Gallego-Durán et al., 2019), principles (Laine & Lindberg, 2020), methods (Lameras et al., 2017; Nicholson, 2011; Romero & Kalmpourtzis, 2020), and quality criteria (Caserman et al., 2020) to design educational games. However, many studies about these games do not link learning theory and game development sufficiently, and it remains unclear in what learning outcomes are expected. This in turn prevents an effective game design and assessment for sustainability competency (Rodela, 2019). I intend to fill this implementation gap by designing a constructively aligned Serious Game.

4 Methods

In this chapter, I describe the various steps that influenced the game development process and helped me to constructively align the game. Game development is a multi-layered process that requires a wide range of choices to be made that can be structured in various ways. During the development of a Serious Game, the integration of educational objectives adds another layer of complexity (Romero & Kalmpourtzis, 2020). This study uses Nicholson's (2011) previously-established general game development structure for educational games, which I adapted for the context of SCs and learning (Figure 3). This included the development of suitable learning outcomes in Step 1 (4.1), their integration into a board game in Steps 2 and 3 (4.2 and 4.3), and an assessment in Step 4 (4.4) of whether the game helped to achieve the intended learning outcomes. As shown in Figure 3, each step requires its own method or approach. Throughout the process, my decisions were based mainly on existing literature and practical considerations, but also on feedback from typical players, as well as from a hydrologist and education practitioners.

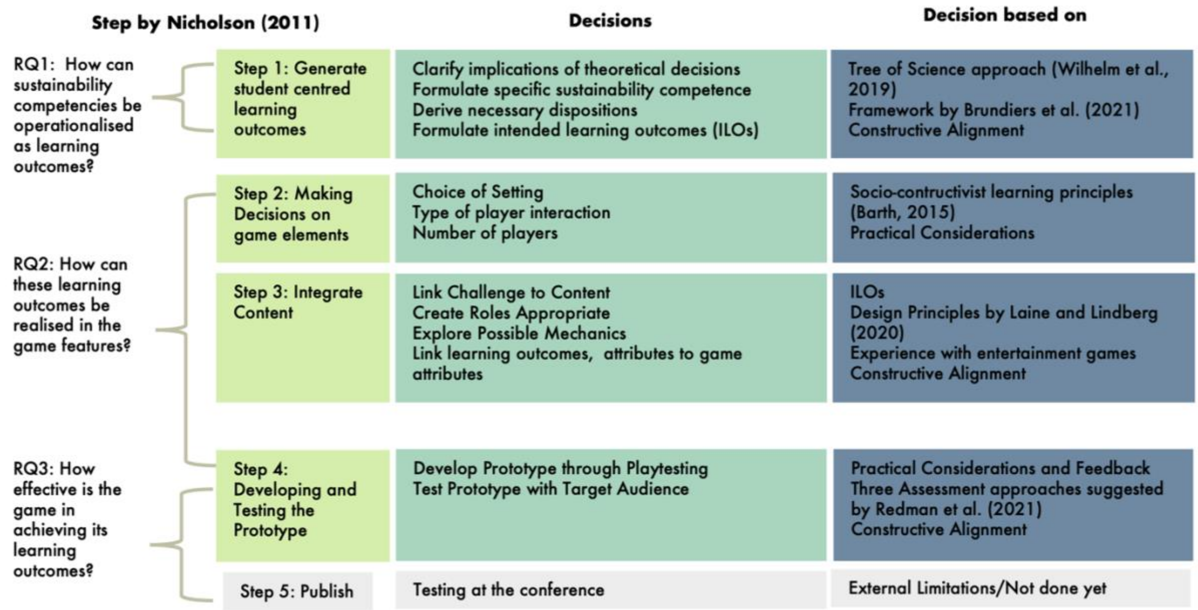

Figure 3. Steps of Game Development with Research Questions and relevant decisions. From left to right: RQs and respective Game Development Process by in five steps by Nicholson (2011, light green). Corresponding decisions for each step (medium green) and theoretical or practical considerations for each decision in darker blue. Step 5 could not be completed due to external limitations (grey).

4.1 Step 1: Generate student-centred learning outcomes

In Step 1 student-centred learning outcomes are generated based on SCs (Figure 3). A first step to practically applying constructive alignment is to formulate *intended learning outcomes* (ILOs) actively focussing on what students should be able to do rather than know (Biggs et al., 2017). I used Bloom's revised taxonomy, which is commonly used as a guide to develop ILOs. It differentiates between six learning outcomes: Remembering, Understanding, Applying, Analysis, Evaluating, and Creating (Krathwohl, 2002).

To increase coherence between my meta-theoretical and theoretical-conceptual perspectives, teaching models, and practices, as well as to embed teaching into broader considerations about learning, I used guiding questions by Wilhelm et al. (2019) (Table 1). This also helped structure the implicit and explicit characteristics of my choices regarding the design of the learning environment and resulted in a clarification of the learning theory and its relevance for educational objectives and didactic principles. Additionally, I selected the three key sustainability competencies on which the ILOs are based. In this step, I answer the first RQ: how can SCs be operationalised as learning outcomes.

Table 1. Questions suggested by Wilhelm et al. (2019) to increase the coherence between one's meta-theoretical and theoretical-conceptual perspectives, teaching models and practices.

Values and meta-theory
What is our prevailing view of human beings and understanding of education?
What are the underlying norms and values in the course contents and learning outcomes?
Theoretical-conceptual perspectives
What characterizes our understanding of ESD?
Upon what learning theories is our own understanding of teaching based?
Teaching Models
What teaching models do we apply or need to know?
What understanding of competence do we have?
What references do we make to existing models for competence for sustainable action (SD)?
What didactic principles guide our course work?
Teaching practice
What educational objectives have we formulated?
What set of competences should students develop?
What specific competences for SD have we formulated?
What didactic methods do we need to apply?

4.2 Step 2: Making Decisions on Basic Game Elements

In Step 2, I chose the basic game elements, which included setting, audience, number of players, and type of interaction between players (Figure 3). This is important to fit the game into the pedagogical context and align game elements with learners' needs (Romero & Kalmpourtzis, 2020). The game will be played by international university students in a conference setting with around 50 participants. Thus, in this case, I need to consider how the basic game elements fit into an international student conference, what kind of guidance the players might need, what kind of prior knowledge can be expected, and how balanced fun and serious elements need to be. Furthermore, I followed the key principles for designing a desirable learning environment in socio-constructivist theory as described by Barth (2015): the learning environment should be self-directed, collaborative and problem-oriented.

4.3 Step 3: Integrating the Content

In Step 3 I integrated the content into the game in order to constructively align the game and learning objectives, as well as the learning and mechanics of the game. Three main considerations affected the initial integration of content into the game: the intended learning outcomes, the design principles by Laine and Lindberg (2020), and experiences with existing board games. An overview of how the different elements were connected throughout the process ise found in Figure 4.

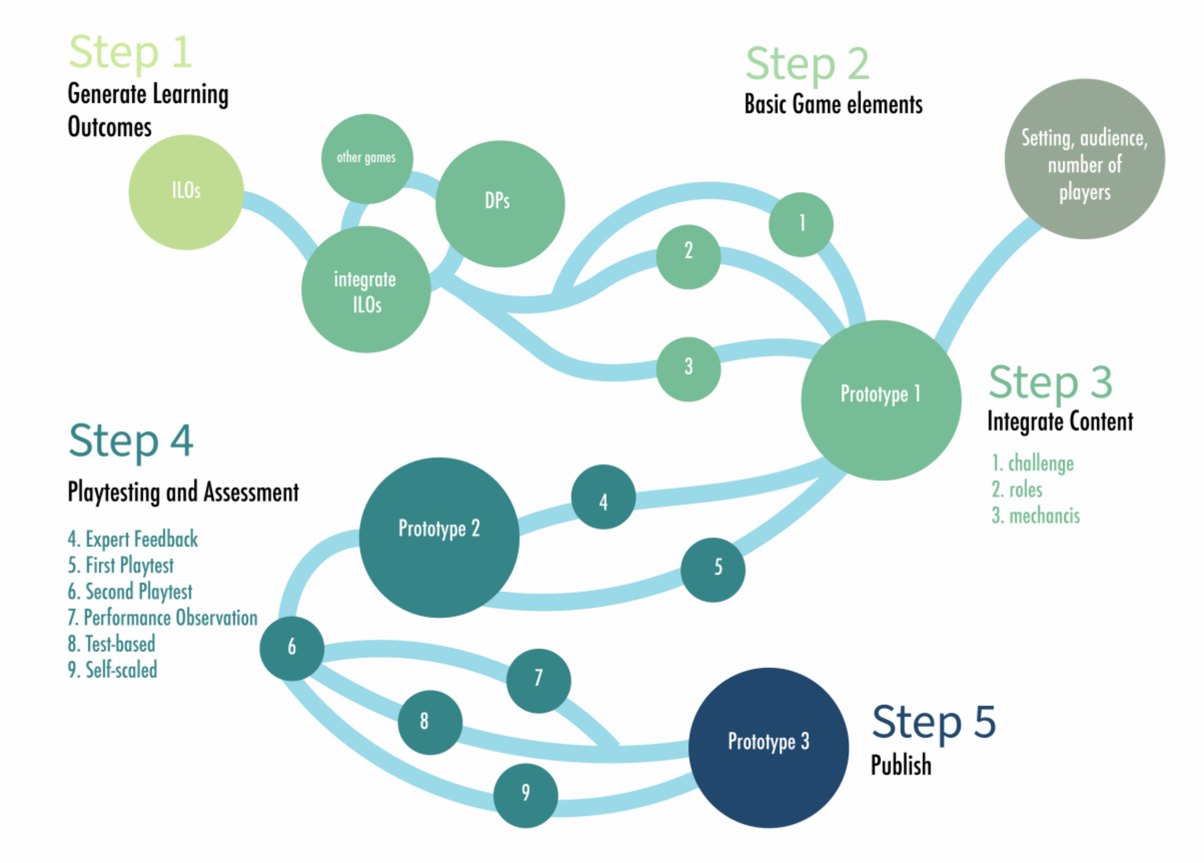

Figure 4. Overview Game Development Process. Learning Outcomes and Design Principles informed the initial content integration by affecting decisions about linking challenge and content, finding appropriate roles, and exploring possible mechanics. Afterwards, the game was discussed with experts from sustainability education, hydrology, and psychology. Further, the initial realisations in the game were tested with the target audience. Feedback from the experts and playtests was used to refine the prototype in an iterative process. The assessment of the prototype led to final adjustments before the publication in May.

First, I integrated the learning outcomes into the three aspects suggested by Nicholson (2011): *Link Challenge and Content*, create *Roles Appropriate for the Content,* and *Explore Possibilities for Mechanics*. Linking the challenge to the content means that the barriers that players face during the game must be like the ones that the game wants to teach about. The appropriate roles must be suitable to achieve the learning outcomes by requiring the players to increase the desired abilities. Furthermore, the game mechanics need to be designed to give the players feedback about their performance, so that an increased game performance aligns with an increased SC.

Second, I applied various design principles (DPs) by Laine and Lindberg (2020). Similar to the integration of the ILOs, different DPs were used to create the game content, roles, and game mechanics. This was done to make the learning experience more attractive. Laine and Lindberg (2020) developed 56 design principles to make Serious Games as motivating as possible. Their focus on motivational aspects is highly suitable to socio-constructivist learning theory, as it sees the active participation of the learner as foundational for a successful learning experience. Additionally, its design principles were found to be a practical toolkit to create an engaging educational game, since one can choose some of the clearly formulated goals without losing the flexibility required in the design process.

Third, I used inspiration from popular board games for entertainment. In addition to these conceptual considerations, the first prototype design was strongly influenced by my own experience with board games for entertainment (Figure 4). Other authors have suggested taking inspiration from existing board games (Abbott, 2019; Chappin et al., 2017; Sousa, 2021). One of the biggest advantages of this is that the game mechanics have been sufficiently tested and already convinced many players (Abbott, 2019).

4.4 Step 4: Adjusting and Testing the first Prototype

Playtesting and feedback helped to develop and assess the different prototypes (Figure 4). After developing an initial version of the game, I discussed the game with experts in the field of sustainability education and hydrology. Their feedback influenced the content, roles, and mechanics of the game. At the same time, the game was also tested with the target audience. Testing and adjusting the prototype is crucial to creating a functioning and exciting game (Nicholson, 2011). This was an iterative process of testing the game, feedback, and adjustment. Although all rounds contributed to answering the second RQ: How can these learning outcomes be realised in the game features, the second round of playtesting also helped to answer the third RQ: How effective is the game in achieving its learning outcomes?

Two rounds of playtesting were conducted to improve the prototype. The first round included three test runs, during which two to three players from the target audience played in an informal setting with the first prototype (Figure 5). Feedback was used to refine the instructions and layout, and increase useability. The second round of playtesting included five runs with three to four players from the target audience. In the third round, improvements of the games were tested to ensure smooth gameplay at the conference**.** In total, around 25 people contributed to the development of the game in different stages of development through playtesting and feedback. Sixteen of them completed the assessment sheets in the second round of playtesting. All but one of the students who completed the assessment studied a Master's degree ranging from natural sciences to social sciences and humanities. Their national backgrounds included Germany, the Netherlands, the UK, Sweden, Denmark, and Spain. They were between 21-30 years old.

Figure 5. Playtesting. During playtesting, rules and scenarios were improved together to create a functional and exciting prototype.

To test the second prototype, I used three different assessment strategies: self-perceived based, observation-based and test-based assessment (Figure 4). A combination of the three was used because traditional assessment formats are considered inadequate to measure multidimensional and performance-oriented competencies (Redman et al., 2021). The first assessment tool was a scaled self-assessment and a statement of three main learning outcomes. This kind of assessment improves students' self-awareness, is easy to administer, and can easily be integrated with other content (Redman et al., 2021). Rather than being a reflection on actual learning improvement, it is a tool to improve the player's ability to work towards these competencies. From a game development perspective, this feedback is also highly valuable to see whether players felt that the game helped them to improve their competencies. Afterwards, players were asked to describe their three main learning outcomes. For the scaled self- and the test-based (cognitive maps) assessment, the players filled out pre- and post-questionnaires (see Appendix A), which are common practice in assessing learning outcomes (den Haan & van der Voort, 2018). The pre and post-questionnaires were the same, but after playing the game the participants used a different coloured pencil to elaborate and adapt previous answers. This allowed me and them to see potential progress.

The second assessment was a performance observation, as the actual performance can be best observed during the game. As the game includes performance measures like rewards and speed, the different choices can be compared and analysed afterwards. I noted the students' game decisions, as well as occurrence of adverse events and the final performance at the end of the game. I paid special attention to how much they interacted with the fictional local population and whether their strategy changed during the game. Finally, I also paid attention to how the game was perceived. The questionnaires were complemented by observations that I made during the game, including tracking performance, die luck, occurrence of adverse events, and which scenarios they chose. Of course, the overall perception of the game and feedback was also noted.

The third assessment tool was cognitive mapping. Before the game, players were asked to draw cognitive maps around the topic of 'useable water'. After the game, they had the opportunity to adjust the maps. Cognitive maps are visual representations of individuals' (or groups') understanding of a theme. Thus, they can provide a 'snapshot' of one's knowledge structure (Jones et al., 2014). I used these to assess how the game influenced adjustments the students made to their maps after playing. Due to the great variety and complexity of visualisations, I only analysed which themes were mentioned and in which areas growth occurred.

4.5 Step 5: Publish

The last step in a successful development is the publication of the game. The thesis needed to be handed in before the game could be introduced to a wider public as the conference had to be moved to 23 May 2022. Thus, this step falls outside the scope of this study.

5 Results

This section presents the results of the four game development steps represented, along with examples from the actual game where necessary. The full details of decisions and their associated game elements are in Appendices B and C. In the results of Step 1, I introduce the intended learning outcomes (ILOs) generated and clarify the underlying assumptions that inform the formulation of the ILOs, as well as the game design (5.1). Furthermore, the results of Steps 2-4 are presented by introducing the game with its different features, as well as the justifications for each decision (5.2). This includes a general description of the game (5.2.1), detailed explanation of the integration of ILOs (5.2.2) and design principles (DPs) (5.2.3), and a description of the hydrological system (5.2.4). Lastly, the results of the three different types of game assessment are presented (5.3).

5.1 Results of Step 1 – Generated Intended Learning Outcomes and Underlying Assumptions

To make SCs operational and formulate ILOs, I selected three key competencies for sustainability from the framework by Brundiers et al. (2021): Values-thinking, systems-thinking, strategic-thinking. As the framework is hierarchically structured and interconnected, I selected the values- and systems-thinking as two basic competencies needed for strategic thinking. This allowed me to formulate ILOs actively as required by constructive alignment. I derived four to five ILOs from each selected SC (Table 2). The formulation of the ILOs was intended to be as clear as possible, focusing on the relation of the competency to the water context.

Table 2. The intended learning outcomes are formulated based on the sustainability competencies. Competency definitions on the left, intended learning outcomes on the right.

Sustainability Competency	Intended Learning Outcomes
*"**Values-thinking** competency to be able to differentiate between intrinsic and extrinsic values in the social and natural world (...); to recognize normalized oppressive structures (...); to identify and clarify one's own values (...); to explain how values are contextually, culturally, and historically reinforced (...); to critically evaluate how particular stated values align with agreed-upon sustainability values (...); and to differentiate between espoused values and practiced values (...)" (p.22)*	V1 - Understand that everyone overlooks some aspects of water issues as perceptions are influenced by existing structures V2 - Apply values-thinking by considering different values in decision making processes regarding water issues V3 - Analyse who profits/suffers from the existing water issues V4 - Evaluate how different adaptation measures could reinforce certain values or oppressive structures
*"**Systems-thinking** ability to collectively analyze complex systems across different domains (society, environment, economy, etc.) and across different scales (local to global), thereby considering cascading effects, inertia, feedback loops and other systemic features related to sustainability issues and sustainability problem-solving frameworks." (p. 16, adopted from Wiek et al. (2011))*	SY1 - Understand how a water cycle works in general, what are the major variables and how do they interact with each other SY2 - Apply your understanding of the water system to implement adaptation measures SY3 - Analyse where potential leverage points (places where a small change causes a lot of change in the system) could be SY4 - Evaluate how sensible different adaption measures are from a systems perspective
*"**Strategic-thinking** competency to be able to recognize the historical roots and embedded resilience of deliberate and unintended unsustainability and the barriers to change (...); to creatively plan innovative experiments to test strategies" (p. 22)*	ST1 - Understand which structures lead to how water issues are often handled ST2 - Apply knowledge about these structures in adaptation suggestions ST3 - Analyse what are the barriers to suggested changes in the current system ST4 - Evaluate what could be desirable and practicable adaptation strategies ST5 - Create an adaptation strategy for a rural catchment area in NE Germany

However, prior to generating the intended learning outcomes, it was necessary to determine the overall character of the game, which provides the broader contexts, structures, and values within which the game exists and that governs the rules. To accomplish this, I answered the questions posed by Wilhelm et al. (2019), which helped to clarify the underlying assumptions regarding meta-theoretical and theoretical-conceptual perspectives, teaching models, and practices and ensure their coherence (Table 1). The answers to the questions by Wilhelm et al. (2019) can be found in the following.

As described by Barth (2015), there is a fundamental tension between the instrumental and emancipatory goals of ESD. In my game, I take an emancipatory stance on education, which allows learners to follow their own interests and come to their own conclusions, but at the same time there is, of course, the instrumental goal of teaching about the urgently needed change. I tried to reconcile both by supporting a critical engagement rather than just compliance with ESD values. This is reflected in the game by not including "right" and "wrong" choices; rather, players explore the different effects of all choices and draw their own conclusions.

As sustainability themes are often contested in nature, it is essential to make the underlying values explicit. Similar to prominent objectives in sustainability science, my game tries to promote equity and encourage cooperation and participation (Clark & Harley, 2020). From a theoretical-conceptual perspective, I conceptualise ESD as an approach to prepare ourselves for a highly volatile future. Thus, I agree with Sterling (2017) that education should move away from teaching content and rather enable students to act and deal with the uncertainties. I further agree with Caniglia et al. (2021) that multiple types of knowledge are necessary for sustainable actions; thus, I intend to support knowledge pluralism, including cognitive, normative, and relational knowledge. While it was not possible in the early stages of development, in the future I intend to integrate these considerations through making the game open source. Other educators, scientists, or other users will be able to adapt it to include more diversity and embrace the idea of cooperation and participation already in the game development process.

As elaborated in the theory section, socio-constructivist learning theory guided my game development process, which is reflected in a strong focus on creating an engaging learning environment. As explained in the theory and methods sections, the didactic principles I used to do so are based on Barth's (2015) understanding of socio-constructivist learning: the learning environment should be self-directed, collaborative and problem-oriented. My educational objectives are to increase the learners' ability to understand, evaluate and analyse water-related sustainability issues. This includes teaching about non-environmental as well as about environmental aspects of sustainability problems, highlight the importance of values when it comes to solving sustainability problems, increase the ability to use values-, systems- and strategic-thinking, and see the necessity to include non-scientists, locals, and other groups affected by changes into decision-making processes. These educational objectives show strong overlaps with the objectives formulated by Brundiers et al. (2021).

5.2 Results of Step 2, 3 – The Game

One central outcome of my thesis is the development of a game prototype, which helped to answer the second RQ: How can these learning outcomes be realised in game features? The final prototype (5.2.1) and the implementation of ILOs (5.2.4) and DPs (5.2.3) are explained in the following. Furthermore, a detailed description of the hydrological details can be found in Section 5.2.4.

5.2.1 Description of the Final Prototype

In Step 2 I decided upon the basic game elements. As I have no resources to produce a computer game nor a fully developed board game, I developed a print-and-play game, which requires minimal resources. The setting and audience of the game are determined by practical limitations. The number of players is based on the didactic key principles in a socio-constructivist learning environment, namely that it should allow for a collaborative interaction; this excludes any single-player games. According to didactic findings, a group size between three and six is optimal (Bovet & Huwendiek, 2020)..

In Step 3, I integrated the intended learning outcomes (ILOs) and design principles (DPs) and my own experience with entertainment board games. In the following, I introduce the final prototype and its connection to the DPs and the different competencies values-thinking (V), systems-thinking (SY), and strategic-thinking (ST). Afterwards, I go into more detailed explanations about how they were implemented. All DPs and ILOs and their implementation can be found in Appendices B and C.

Game Set-Up: The game consists of one A3 board that illustrates the water cycle in different seasons. The details of this water cycle are described in Section 5.2.4. On the game board, the players keep track of the water flow and storages with little wooden cubes that each represent around 10 mm of water. This set-up operationalises the following DPs: familiar and comfortable controls (DP9), providing clear visual feedback (DP23), and including an interactive map with sufficient detail (DP18). Players choose between different scenarios from a scenario booklet, during which they can ask locals for help or implement adaption measures, allowing players to interact with the story (DP 52). The gamified water cycle is an essential element in increasing system understanding, apply their understanding in the implementation of adaptation measures, and analyse where leverage points might exist (SY1, SY2, SY3). Wooden cubes make consequences immediately visible and thus help to evaluate how sensible a measure is (SY4) (Figure 6).

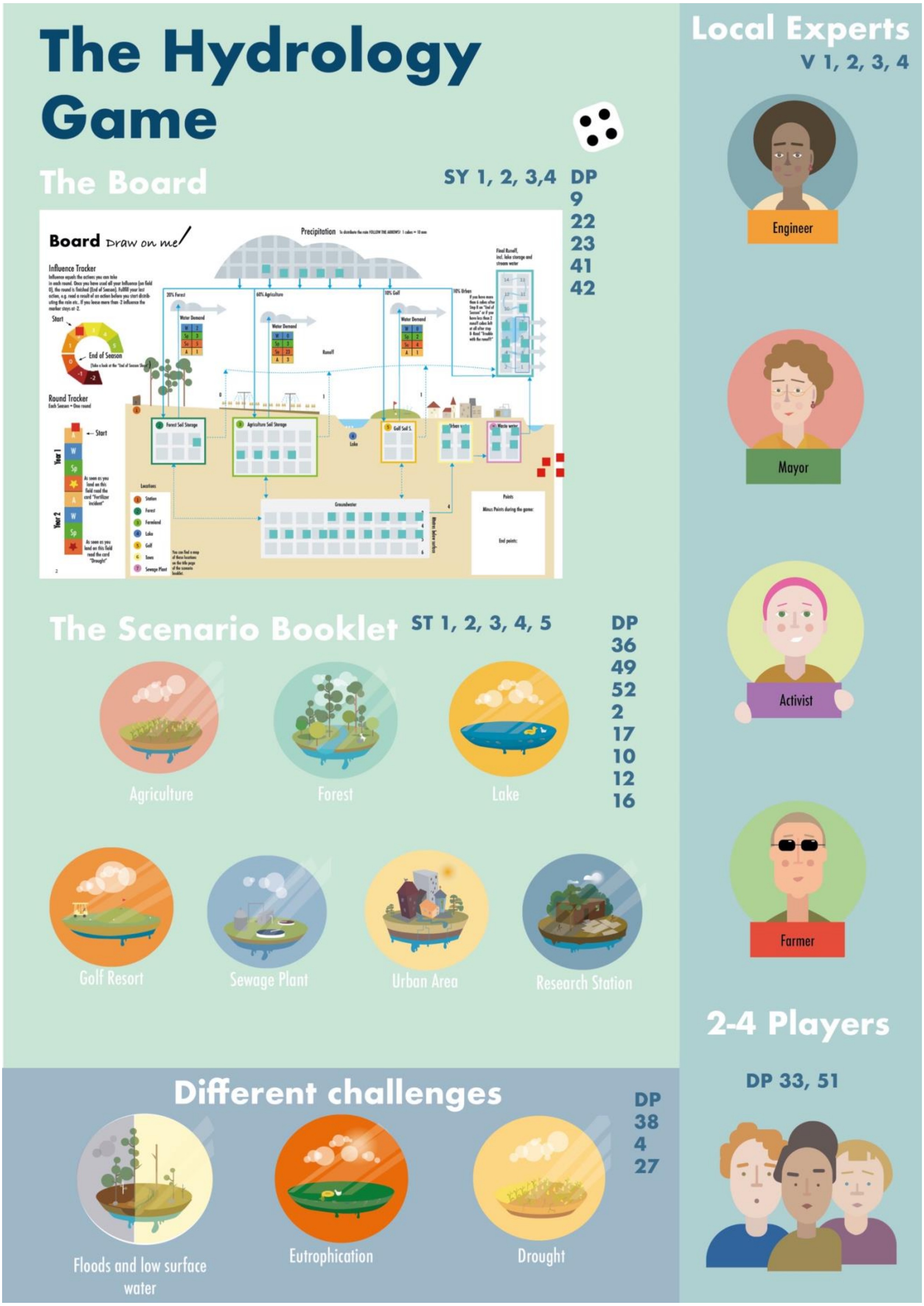

Figure 6. Game Prototype. Two to four students play together to save the fictional location of *Remnitz* to prepare for a severe drought. The game consists of a A3 board which shows the water cycle, the influence tracker, and the round tracker. In the scenario booklet the players can play different scenarios at the seven locations. In the scenarios they can ask the local experts for their opinion. Through asking they get more options. At the end of each season, they distribute water and possibly have to cope with adverse events like fertilizer incidents or floods. Each game element is either based on ILOs or DPs.

Storyline: The game is set in the fictional catchment of *Remnitz,* a rural area in Northeast Germany. Due to climate change, the region is experiencing droughts more frequently. The last drought in 2018 hit them severely and therefore the local government wants to adapt their catchment. This background story is based on existing problems in the region (DP36). The players represent a young group of scientists employed by the municipality to help the catchment. This role-play experience was chosen because for many university students, a career as a scientist is a viable option and thus relatable (DP33, DP51). Their success depends on the different adaptation measures that they manage to implement before the next drought hits. This integrates the players into a meaningful story (DP49). As many extreme events occurred in Europe in recent years, it can be expected that all players have heard of or maybe even experienced floods and droughts in their countries; thus, they can relate the game play to their past experiences (DP 38). The storyline requires players to act strategically by considering pre-existing barriers in their decision processes (ST1, ST2, ST3, ST4). Furthermore, after the game, players should be better at creating adaptation strategies (ST5).

Game play: Players can choose between 10 different scenarios at 7 locations. They play one scenario at a time in an order chosen by the players; this reduces task complexity and allows them high freedom to choose (DP2, DP17). Within the scenarios, the team must make choices about which management they want to advocate for and with whom they collaborate. They can only choose between a limited set of options, which they can increase by asking the fictional game characters (DP10, DP12, DP16). The interaction with the local population should encourage values-thinking (V1, V2, V3, V4) by introducing other values and challenging the players to analyse and revaluate the decision based on how it may affect different local groups. The game is structured into eight seasons, with one season representting one game round. Implementing adaptation measures costs the team's influence. Depending on the popularity of their implementation measure they can also gain or lose influence. When they have no influence left, the end of the season has arrived. At the end of the season, they must distribute rainwater to the different locations according to evaporation, irrigation, and other water demands (DP23, DP41, DP42). At the end of the game, a severe drought hits with no precipitation in the summer season. Depending on which functions could be maintained, they receive winning points (DP22). Furthermore, in the fourth season, a fertilizer incident also introduces water quality problems to the game, which players need to manage in addition to the water quantity problem (DP4, DP27).

Four popular board games substantially influenced my game design. Comanauts (Haethrone et al., 2019) inspired the overall setup using a scenario booklet. Similar to the game Paleo (Rustemeyer et al., 2020), each game round is structured in two phases. In the first phase, players can make choices and adjust the water cycle and in the second, the round ends and players fulfil the steps of the water cycle, such as distributing rainfall and fulfilling water demands. Rise to Nobility (Krstevski et al., 2018) uses reputation to steer the number of actions people can take in a round. I used a similar mechanism by limiting the choices that players can make in each round based on their influence. Further, the introduction of new events based on the passed time is adapted from Andor (Menzel & Kienle, 2012).

5.2.2 Detailed explanation of how to integrate ILOs

The ILOs were operationalised by integrating each ILO into the challenge and content, roles, and mechanics. A detailed table with all the learning outcomes and their integration into the game can be found in Appendix B. In the following, I explain two examples. ILO V2 'Apply values-thinking considering different values in decision making processes on water issues' was integrated by making the balance of divergent interests during problem-solving processes one of the key themes. The players must make decisions about potentially controversial topics. In the game mechanics, this is reflected in a high dependency of the players on the support of the community. If decisions are not supported, they lose time. Furthermore, the likelihood of a successful implementation increases if players asked more locals their opinion before making a choice. ILO ST3 "Analyse what are the barriers to suggested changes in the current system" was integrated by including suggestions and descriptions of existing barriers, e.g. economic dependency of the region on a certain industry. When making a decision, the players must consider these barriers; if they make decisions that do not consider the barriers, often the community will not accept the adaptation strategy (Figure 7).

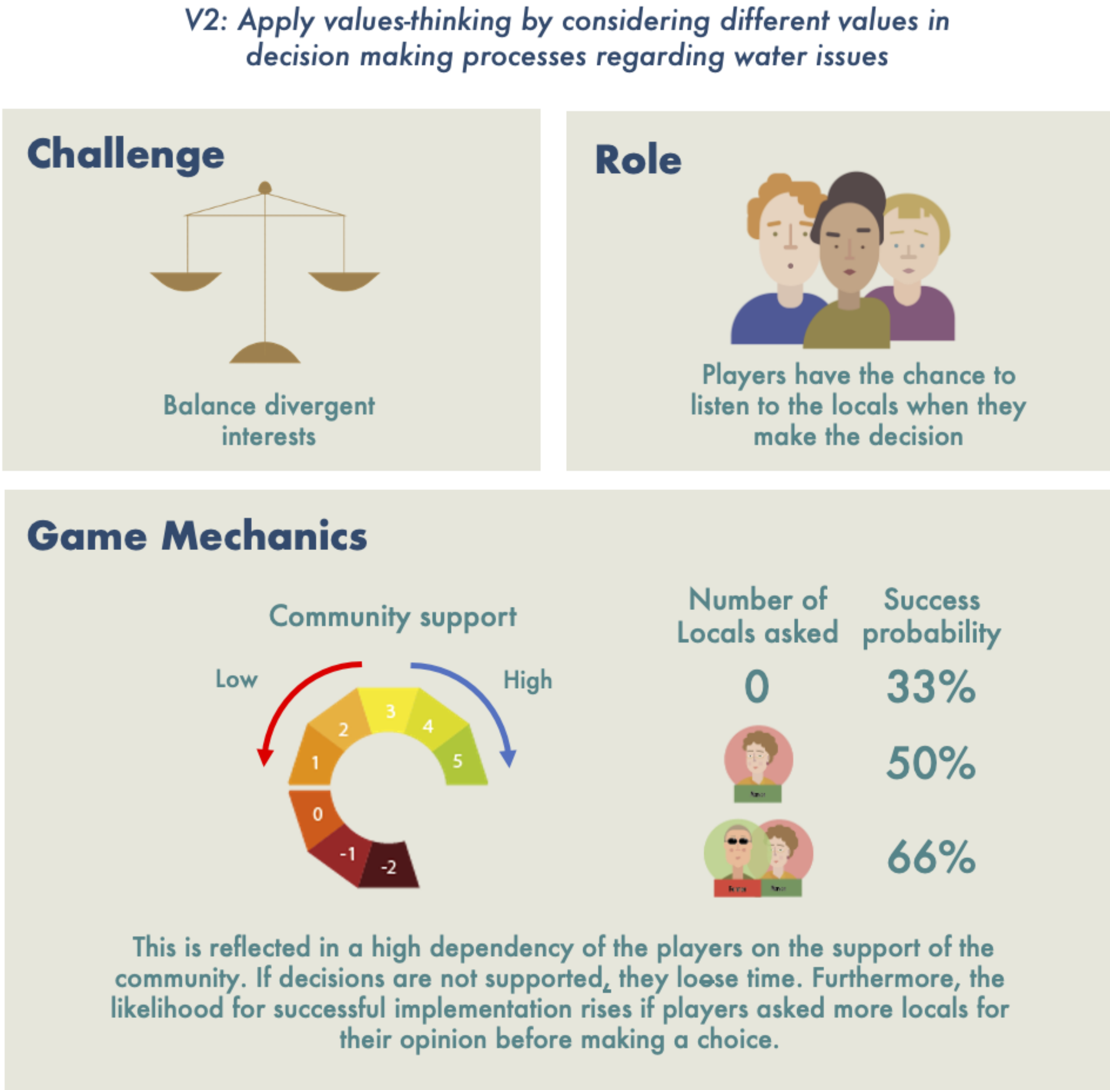

Figure 7. Detailed explanation of how ILO V2 was integrated into the content of the game. The players are challenged to balance the divergent interests and have the chance to listen to the locals during the decision-making process. This is supported by two game mechanics. On one hand they lose or gain more influence depending on the community support. On the other hand the more people they ask the more likely they are to get a successful die number.

5.2.3 Detailed explanation of how to integrate DPs

The DPs were operationalised by integrating 27 of the 56 DPs into either the challenge and content, roles, or mechanics. A detailed table with all DPs and their integration into the game can be found in the Appendix C. Some concrete examples of how the Design Principles were applied are elaborated in the following. DP 49, "Create a meaningful story that the player can relate to" (Laine & Lindberg, 2020), is implemented in the game by creating a story that describes common problems in agriculture areas such as too much fertilizer use, high water consumption by agriculture, and conflicts of the local population with national regulations. The fictional catchment in Northeast Germany is based on an existing location. This also relates to DP 36, "Relate gameplay to real-world contexts". The real-world aspect was enhanced by taking up stories that happened in newspapers and my own experience (Table 3). Additionally, a lot of effort was put into creating a realistic water cycle by creating a simplified water balance model, which will be explained in Section 5.2.4.

Table 3. Excerpt of the application of DPs of the application and their realisation in the game. Full table in Appendix C.

Integrating the Content	Design Principles by Laine and Lindberg (2020)	Realisation in the game
Link challenge and Content	Relate gameplay to real-world contexts (DP 36)	The game is based on existing water issues in the region (DP36)
Create Roles Appropriate for the Context and Content	Create a meaningful story that the player can relate to (DP 49)	Many regions in Europe have experienced increased water stress or floods; thus, most players probably can relate to the scenarios (DP 49)
Explore Possibilities for Mechanics	Favour simple challenges over complex challenges (DP 2) Create progressive goals that built up on each other (DP 27)	To simplify the task, the players play one scenario after another (DP2) Later in the game, additional challenges are introduced (DP27).

5.2.4 Creation of the water cycle and integration into the game

One key element of educating about the water cycle through game play is the integration of the water cycle itself. It is important to achieve several learning outcomes, especially those related to systems thinking, and to create the scientific foundation of the game required by Caserman et al. (2020). I chose a concrete location to inform my game water cycle, as water cycling differs substantially depending on various environmental factors. As my target group are international students from several Baltic countries, the water cycle needed to at least partially resemble an environment familiar to players, as making the game relatable contributes to the motivation (see DP 49, Table 3). The concrete location was chosen based on my prior experience working in a research group as a student, which had a study site in NE Germany. The characteristics of the catchment are based on the catchment in many ways but cannot in any way be considered an accurate representation of the catchment.

Using data only from the study site or the NE region was a good starting point to develop the catchment characteristics: the basin is a lowland basin with humid continental climate, which is quite flat (average slope 2%) and the surface waters are mainly dominated by groundwater. It is in one of the driest areas of Germany with an average precipitation of 569 mm per year and a potential evapotranspiration of 650-700 mm per year. Compared to many regions in the west or south of Germany, annual precipitation values greater than 800 mm are common (Figure 1). The primarily light sandy soils are fast draining. Around 5000 people live in the area (Smith et al., 2020). To fit the game objectives, the land use distribution was changed. The final input parameters can be found in Table 4.

Table 4. Different water parameters and sources in the game water cycle.

Parameter	**Integration in game**
Precipitation	Default seasonal precipitation height in the game is based on long-term average precipitation data of the area from the German weather service, DWD. Rain is distributed according to land use area: 60% agriculture land, 20% forest area, 10% golf course, 10% urban
Rural water demand Includes evapotranspiration from agriculture, golf resort and forestry.	Seasonal variability is included through different ET values per season. Those are based on irrigated maize and grassland values from an irrigation calculator (ALB Bayern e.V., 2022).The ET values for the forest area are based on one paper from a similar area, which studied ET for pines (Kessler et al., 1988). There is not ET from the lake or the urban area.
Runoff	To simplify the implementation runoff is mainly generated from the agriculture site and urban area at the beginning of the game. The amounts do not reflect the site exactly, but where derived from several playtests.
Urban Water demand	Urban water use was estimated based on the German average consumption including communal water use (Statista, 2018).

Many simplifications had to be made as the game is meant as an introduction for people without prior hydrological knowledge. For example, there are no groundwater flows into and out of the catchment from other catchments, and precipitation falls evenly over the whole catchment and is distributed to the different land use types according to their size. It is further assumed that water only infiltrates if precipitation exceeds evapotranspiration at the site. Surplus irrigation needs are not accounted for in the model. At least in the initial set up, all agriculture is planted with only one crop and all forestry only has one tree type. Evapotranspiration for grassland and agriculture are set to zero outside the vegetation period in winter. Urban water demand does not show any seasonal change.

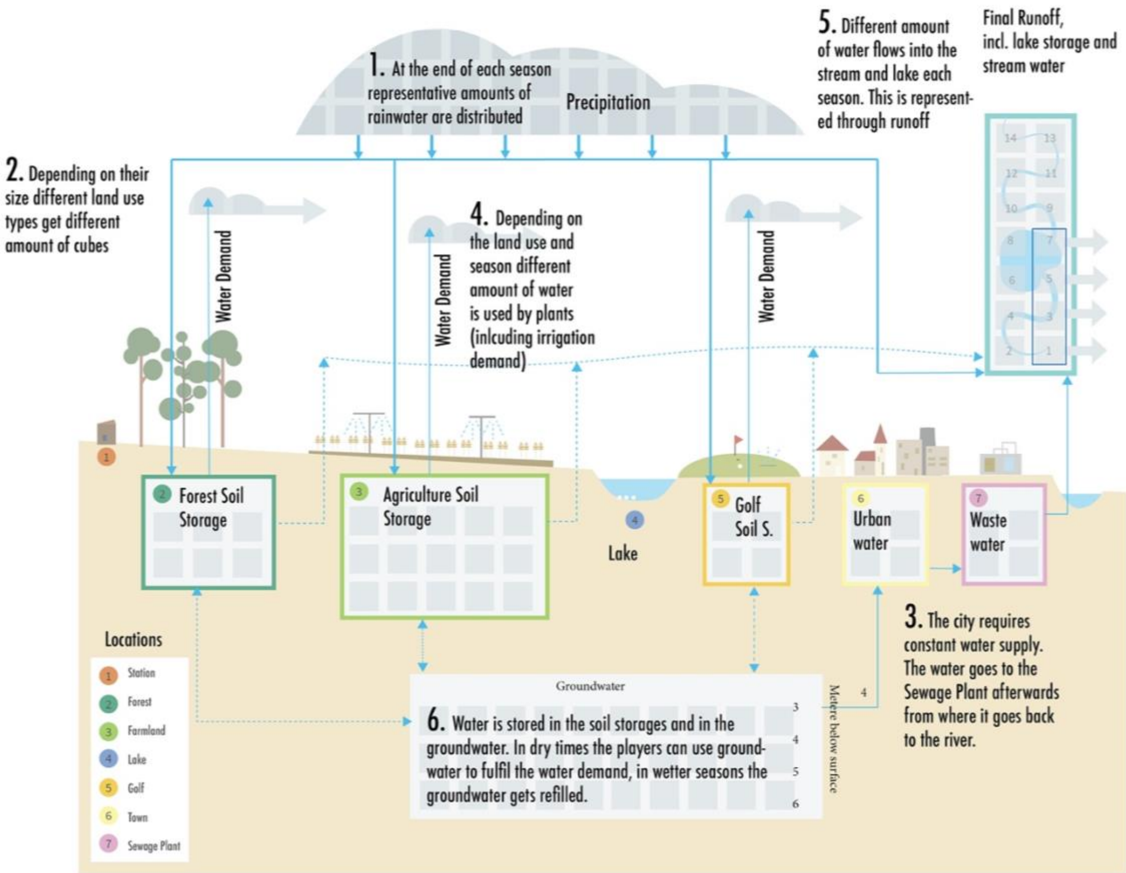

Figure 8. Detailed game water cycle. Based on an existing location in NE Germany a water cycle was developed for the fictional location of *Remnitz*. The water cycle considers: Precipitation (1), spatial distribution based on land use size (2), urban water demand (3), rural water demand, which represents evapotranspiration with irrigation (4), runoff (5) and groundwater (6).

5.3 Results of Step 4 – Playtesting and Game Assessment

Step 4 consisted of playtesting to improve and assess the first prototype. This contributed to RQs two and three: How can these learning outcomes be realised in game features? How effective is the game in achieving its learning outcomes? The first playtesting rounds resulted in many clarifications in the instructions. Additionally, the players suggested changing the probability mechanism in the scenarios. Major changes included reducing game complexity through omitting some game pieces and some possibilities to gain additional abilities. Another interesting observation was that while the groups seemed to enjoy the collaborative nature of the game, they were very curious about how the other groups performed. In addition to improving the playability of the game, the second round of playtests focused on assessing the ability of the game to achieve ILOs to allow adjustments. In the following, I will discuss the results of the three assessment forms that were conducted in the second playtesting round.

16 players completed the assessment sheets with the self-assessment and the cognitive maps individually before and after play. During the game, I observed the performance of the group. This generates three different sets of assessment results. First, the results of the self-scaled assessment observed the perceived change in ability by the players. This was complemented by three self-reported learning outcomes. Second, the results of the performance observation enabled me to see how the groups played the game and what goals they achieved. Third, the results of the test-based assessment and the cognitive maps showed how the game play changed players' understanding.

5.3.1 Results of the self-scaled assessment

The self-scaled assessment showed that perceived ability increased by 0.7 on average. In general, the highest increase in ability was reported for ST5, SY2, and V2. In particular, the lowest change was achieved in V3 (Figure 9). Both the very successful as well as less successful groups showed similar average increases in perceived abilities. In three cases, people either adjusted down their initial pre-game rating after the game or rated their own ability lower than before the game. Furthermore, the average self-rated score was compared to the final points in the game. The group that got by far the best results (46 points) also rated their own abilities before the game around a point higher on average than the players from the other groups, indicating that high prior knowledge helps to play the game and that students' perceptions of their ability were reflected in the game outcome. Informal feedback also revealed that students did not fully understand what the ILOs meant and how they should rate their ability; however, some also reported that they knew better what was meant after the gameplay.

Figure 9. Change in the perceived ability of players after the game. The self-scaled assessment allowed players to rate their own ability from very low (1) to very high (5). After the game, the players could change their ability rating. The average of that perceived change per ILO is shown above.

The self-scaled assessment also revealed that the game was found to be effective in conveying the conflictual character of water issues and their solutions. This could be seen in the self-reported main learning outcomes, as well as during the game. Another main learning outcome occurred in the self-stated learning outcomes, as well as in the game play: the importance of communication and the acceptance of the community. The game was effective in creating fun, and many people expressed the want to replay on another occasion. The aspects that were positively mentioned included worldbuilding aspects such as characters, locations, and cultural nuances. In particular, communication with local experts generated many emotions in the players.

Furthermore, next to the self-scaled assessment, the reported learning outcomes were diverse, but many themes reoccurred frequently. As shown in Figure 10, the main learning outcomes described by the players can be summarized in seven themes. Most frequently, students described the importance of water management, participation, and increased knowledge of the water cycle. Furthermore, the conflictual character of sustainability problems was mentioned a lot, as well as increased problem awareness about water issues and the connection of society and water. See Appendix D for a full table with answers.

Figure 10. Main themes in self-reported learning outcomes. To the left of each symbol, the number of occurrences is shown.

5.3.2 Results of the performance- based observation

The results from the performance observation showed that people managed to play between five and nine scenarios of the eleven available. All players were confronted with floods, overuse of fertilizer, and a drought. Four groups took two hours to understand and play the game, while the fifth took 45 minutes longer, presumably due to language barriers. The final performance differed a lot. Groups that took more risks performed worse (represented by scoring fewer points). However, after experiencing the harsh effects of choices, the groups also reconsidered their strategy. The game also showed that it can be hard to get back on track after an undesirable choice was made. Furthermore, if they were unlucky with their die throws, they often had little time to change anything before the round finished. The fact that the groups with the highest points had a lot of die luck also indicates a big dependence of die luck on game performance (Table 5). Furthermore, when players realised that their choices had strong influences on the game play, they became more cautious about their choices.

Table 5. Game Performance. Groups performed very differently which is reflected in the different number of scenarios, floods, and end points.

Group Number	**Number of Scenarios Completed**	**Floods or Contamination Events**	**Unlucky die throws (Players did not get the die number they needed.**	**Points**
1	5	3	7	5
2	9	1	3	46
3	6	2	7	4.5
4	5	2	13	16
5	7	1	9	21

At some point during play, all groups understood the mechanism that the likelihood of success is higher the more locals (fictional game characters) were asked, and that the outcome is more favourable if players follow their advice. All groups discussed conflicts among different interest groups and were very concerned about their water cycle. Conversations with the local experts led to a lot of discussion and seemingly also sympathies and dislike towards the characters. Despite disliking certain characters, groups still often asked the respective character for help. However, not all opinions were taken similarly seriously. For example, a local expert, the mayor, was introduced as a person who wants to convince other people that she does a good job. Almost all groups displayed a very strong aversion to speaking to her because they felt that she was too intrusive.

5.3.3 Results of the test-based assessment (cognitive maps)

In the cognitive maps most players only added one or two aspects after the game; thus, overall learning reflected in the cognitive maps was very limited. Before playing the game, most maps contained elements that connected “useable water” with themes of water flux/storage and infrastructure/technical solutions and landscape characteristics, as well as aspects of water quality and human water use. Less than half of the maps included value-based elements or organisational and political aspects of useable water, and only two maps included economic considerations. After the game, players primarily added to the themes that they already had drawn prior to the game, which can be seen in the number of additions in the fields, but almost no rise in overall number of themes in several maps. Among the themes that were less prominent, economic considerations came up in two more maps and political and organisational themes in one additional map. Value-based elements did not change at all, which indicates that the game either did not convey learning in this area or players did not perceive it as related to useable water (Figure 11).

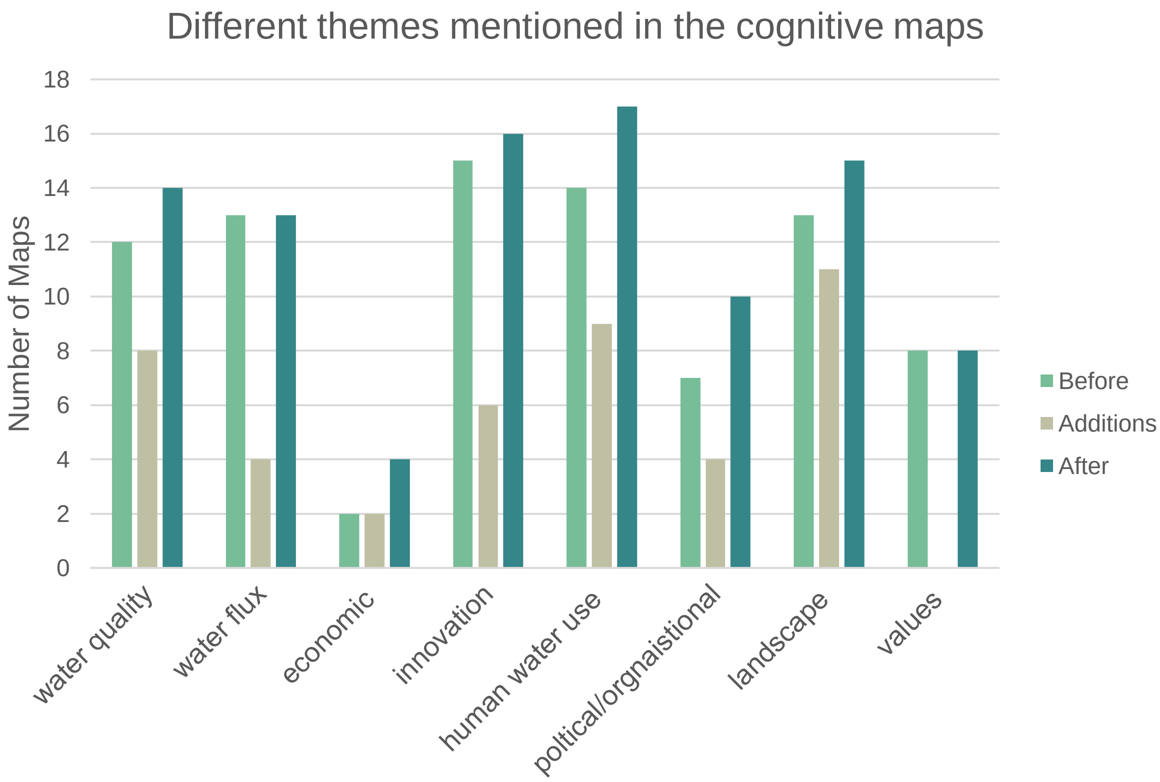

Figure 11. Analysis Cognitive Maps. Several themes could be identified in the maps. The number of themes drawn before the map (green), the number of maps that showed additions in these themes (beige) and the number of maps that showed increased number of themes after the game (blue) are differentiated. Most additions could be seen in the water quality, human water use and landscape categories. Economic and value related themes did not or barely change.

While it was difficult to compare the different cognitive maps, some interesting observations could be derived. Although many people added values and political aspects to their perceived learning outcomes, this was hardly reflected in the maps. Also, economic or value-based measures were hardly drawn or indicated and little to no change was visible after game play. Another observation was that players tended to compare and discuss their maps.

Discussion

In this thesis, I developed a Serious Game (SG) that increased sustainability competencies (SCs) among players. As shown in the results, I was able to translate three SCs (values-, systems- and strategic-thinking) into learning outcomes. Furthermore, I was able to realise the learning outcomes as game elements in a printable board game by integrating the intended learning outcomes (ILOs), Design Principles (DPs) and game mechanics from entertainment games. Finally, I assessed the game's ability to increase the three selected SCs with three assessment types. However, the concept of SC remains contested, and I would like to elaborate on the possible alternatives and limitations of my approach. Moreover, I will summarise my experience of developing the game, highlight some limitations, and compile suggestions for future applications. I will discuss the methods that I used and suggest adaptations for future use. The discussion is organized following the RQs (6.1, 6.2, 6.3), with their broader implications and learnings for ESD teaching summarised in Section 6.4.

6.1 How can sustainability competencies be operationalised as concrete learning outcomes?

The results of Step 1 show that the formulation of clear learning outcomes is a necessary first step in designing a constructively aligned educational game. Below, I explain the implications of choosing a limited set of SCs, illustrate how the vagueness of SCs can be an obstacle, and reflect on the need to embed SCs in a broader concept of learning.

To make the task of operationalising SCs more approachable, I chose three specific competencies (values-, systems-, and strategic-thinking) from a competency reference framework developed by Brundiers et al. (2021). This certainly reduced the complexity of the task for me. Conversely, Wiek and Redman (2022) strongly discourage the disintegration of the framework into separate competencies as they are all interconnected and training of all competencies is needed. While their concern is understandable, SCs are often highly theoretical and abstract and, thus, hard to operationalise into a single teaching tool. In light of their critique, combining three competencies achieved a balance between complexity and operationalisability.

The conceptual vagueness around SCs made it difficult to formulate clear ILOs, which was both a weakness and a strength of the concept (see Vare, 2022). With few examples on how to operationalise the different SCs, the formulation into concrete ILOs was challenging, which was reflected in player feedback. However, the fact that many players reported that they understood the ILOs better after the game indicates alignment between the ILOs and the game elements. In hindsight, the vagueness of SCs is more a reflection of the diversity of sustainability education, and therefore necessary or even desired.

The questions posed by Wilhelm et al. (2019) proved helpful in reflecting on one's own values, theories, and practices and making them explicit. This is crucial in any type of education, but especially in the field of sustainability science, where the contested, controversial, and complex nature of many issues requires teaching to go beyond the mere transport of knowledge. According to Sterling (2017), learners need to be prepared for a volatile future. Thus, when formulating learning outcomes, it is important to consider whether they manage to fulfil both the emancipatory and instrumental needs of ESD described by Barth (2015) and make purposive choices to align learning theory, didactic principles, ESD framework and didactic tools. Furthermore, this approach also integrated Westera's (2019) demand for the integration of learning science into game design.

Based on above, I will now consider the following implications and areas of future research. To make the theoretical SCs applicable without neglecting the theoretical need for holistic learning, as required by Wiek and Redman (2022), a solution may be to embed the game into a broader teaching module with other aspects targeting the full range of SCs. This could, for example, be a university course on sustainable water use. Furthermore, the application of SCs might become easier by considering the opinion of Wiek and Redman (2022) that, rather than using SC frameworks as a list of tasks, it is a tool to reflect on one's own approach. Creating clear and understandable ILOs might require some test runs and can be continuously improved. The deep-rooted conceptual unclarities regarding SCs require further research; in particular, the conflation of cognitive abilities and affective objectives in the term 'competency' described by Shephard (2022) represents an urgent field of clarification.

6.2 How can these learning outcomes be realised in the game features?

I used the results of Steps 2 and 3 to develop a prototype, which was refined in Step 4. This informed my understanding of how learning outcomes can be realised in game features. In the following, I interpret my results, elaborate on possible weaknesses, and summarise the implications for SG development.

My decisions about basic game elements in Step 2 were based on whether the didactic principles (self-directed, collaborative, problem-oriented) founded in learning theory worked well for this prototype, and the practical limitations turned out to be less of an obstacle than expected. The game format was very suitable to create a problem-oriented and self-directed learning environment. The findings of Caserman et al. (2020) that cooperative and competitive games increase motivation were confirmed by player feedback. At the same time, there was also a high curiosity about the performance of other groups, highlighting the importance of different forms of social interaction for enjoyment, also described by Caserman et al. (2020). Furthermore, player feedback showed that even with limited monetary resources, a visually attractive and engaging game was developed, in line with other quality criteria from Caserman et al. (2020). Lastly, it is worth noting that despite the very limited resources, the final prototype is surprisingly adaptable; it can be played with one to four players, scenarios can be added or removed, and different difficulty levels are possible.

Step 3 was an essential step to constructively align learning with gaming objectives and mechanics. Integration of the educational objective into the content of the game was done by implementing different approaches as it became clear that no single approach was suitable for all purposes. Nicholson's (2011) game development advice was very useful in structuring the process; within it, I was able to operationalise the ILOs, apply the DPs, and integrate my own experience with entertainment games. The ILOs were operationalised by considering how each ILO could be reflected in the challenges, roles, and mechanics of the game. Then, DPs by Laine and Lindberg (2020) were added to the challenges, roles, and mechanics. Breaking down the different game features into challenges, roles, and mechanics reduced development complexity and ensured that the desired learning objectives would be reflected in the game objectives and mechanics. Having played many games myself certainly eased the game development process as I was able to grasp the full implications of a game feature, which facilitated empathising with the target group.

Playtesting was essential to show the gaps in the instructions and game play; however, often playtesting receives far too little attention in educational game design literature, where playtesting is often only briefly mentioned or not mentioned at all (Catalano et al., 2014; Cheng et al., 2019; Gallego-Durán et al., 2019; Lameras et al., 2017; Romero & Kalmpourtzis, 2020; Westera, 2019) despite being a very established and essential part of all game development (Slack & Stegmaier, 2017). In hindsight, I consider playtesting to be the most important part of the entire game development process. I received feedback, tested game mechanics, implemented new ideas, and reduced extraneous content. It is important to remove extraneous content as it takes away from the learning experience (Romero & Kalmpourtzis, 2020; Westera, 2019).

Furthermore, the playtest showed how visuals, storytelling, and haptics substantially add to the game experience. Although it is important to balance entertainment and educational aspects of SGs (Caserman et al., 2020), my experience during the game development process showed that little details contributed greatly to the game experience. Unexpectedly, entire stories were often developed around small side notes that I added for detail.Also, minor aspects in the illustrations were appreciated, for example all the golf balls at the bottom of the lake. The haptic and visual experience (Caserman et al., 2020) as well as the storyline are central aspects of games (Naul & Liu, 2020); thus, it is not surprising that these also led to many reactions among the play testers.

Although the developed prototype can provide information on how to establish a connection between learning outcomes and game elements in practice, making the theoretical connection remains unclear. The game that I developed appears to be just one example of SGs. There is an immense variety of games with extremely different game features that might require very different approaches. However, theoretical links between gaming and learning are scarce and rarely supported by empirical findings (see Lameras et al., 2017). My game development approach is not suitable to close this gap as a clear link between certain game features and learning outcomes cannot be shown without more long-term evaluation.

The focus of this thesis was on the integration of SCs into SGs, which did not allow for a deeper reflection about the water issues portrayed in the game. The current prototype only includes a limited range of topics and perspectives, but water issues can be approached from various angles and implemented in multiple game styles (Aubert et al., 2019; Cheng et al., 2019; de Kraker et al., 2021; Rodela et al., 2019). More in-depth and more diverse knowledge can be included in the game design, and I hope its significance for multiple teaching purposes will increase.

I see the implications for future SG development as follows: Instead of creating a framework to incorporate this whole variety of educational games, I would argue that it is more important to develop the game from different perspectives, drawing from a wide range of sources and experiences. Given the immense workload that comes with developing a game, I would suggest cooperation among game designers, illustrators, and educators. If resources for this are not available, 'modding' existing games, e.g. Abbott (2019) and Sousa (2021), could be a more feasible option. If one wants to develop a cooperative game without excluding the motivational effects of competition, more competitive elements are desired: different groups could compete against each other and compare their performance afterwards. Finally, playtesting should become an essential part of every guide to game design.

6.3 How effective was the game in achieving the learning outcomes?

I used three types of assessment to answer the third RQ: How effective is the game in achieving its learning outcomes? The assessment showed promising results in all three types of assessment, indicating positive effects of serious gaming. Furthermore, I will elaborate on the limitations of the assessment, its implications for future application and possible areas for future research.

In the self-scaled assessment, students rated their perceived ability higher on average after the game. However, not all ILOs showed similar learning effects. The fact that several students reported after the game that they understood better what the ILOs meant indicates that the game seems to reflect the ILOs well. Understanding the ILOs can be interpreted as a learning outcome in itself. Additionally, many of the self-reported learning outcomes reflect aspects of the ILOs.

Performance-based observation revealed that all groups understood at some point that asking the locals for advice leads to more favourable outcomes in the end. This is also reflected in the self-reported learning outcomes. The group that rated their ability significantly higher prior to the game also got the best results, indicating that a high ability is connected to good performance. Performance-based observation also raises some doubts as to whether the rich game world might distract from the ILOs by creating a cognitive overload. However, the relationship between game performance, learning outcome, and die luck remains relatively unclear. What is certain is that bad die-luck reduced the possibility of groups to enact more scenarios, possibly this also reduced the learning.

The cognitive maps showed relatively little change; most players only added one or two aspects, seemingly independent of prior map complexity. The game appeared to increase players' knowledge about water quality, human water use, and relevant landscape characteristics. However, economic, value-based, or political themes did not appear to be reflected in the game or did not appear relevant for cognitive maps around 'useable water'.

However, interpreting the results of the assessment proved to be very difficult, involving many uncertainties. Particularly, the cognitive maps turned out to be very hard to analyse, as predicted by Redman et al. (2021),. First, the students played different scenarios, which made it difficult to compare their learning results. Additionally, the social aspect of knowledge creation was not well reflected in the self-rated assessment and the cognitive maps, as each player answered individually. Furthermore, performance observation might have been more insightful if people played the game a second time. Several reasons might have influenced the limited change in the cognitive maps. First, the fact that players were adding to their previous map rather than making a new one could have limited their ability to restructure their understanding of how useable water is connected. Second, playing the game once might not lead to significant changes. Third, the instructions might have been unclear. Lastly, after two hours of gameplay, the motivation and concentration of the players may have been much lower, reducing desire to work on their map.

This highlights the need for future research into adequate assessments of SGs (see Redman et al., 2021). Resulting from the initiative of the players to compare their cognitive maps, I suggest that in addition to having an individual map, a group cognitive map could have greatly increased learning. Furthermore, providing clearer guidance on how to make a cognitive map could have created more comparable results, which could have been more easily interpreted and quantified. In a classroom setting, I would strongly suggest practicing cognitive mapping with students beforehand. As pointed out by Redman et al. (2021), a lot of research needs to be done to find adequate assessment methods.

6.4 Broader implications and learnings for ESD teaching

This study builds on the idea that learning is a key aspect of enabling change for sustainability. My game showed that there is potential for sustainability-oriented Serious Games to be an important part of ESD by creating opportunities for students to actively experience the consequences of climate change on water resources, how they can be managed differently, and that the support of the local population is essential to implementing successful changes. Although this game evolved around water issues in NE Germany, small adaptations could certainly create scenarios for other locations. Furthermore, the game development steps that I used to create the game and implement sustainability competencies could be applied to a broad range of sustainability problems.

7 Conclusion

In this thesis, I created a Serious Game to investigate how Serious Games can be developed to foster sustainability competencies. While there is a lot of literature surrounding sustainability competencies and Serious Games, they are seldom combined. Thus, information on the practical implementation is lacking. By applying existing literature and common game development steps, this thesis could identify several crucial elements for the design and development of Serious Games for Sustainability.

I found that the first step to operationalise sustainability competencies into learning outcomes is to clarify what concrete sustainability competencies should be fostered in the context of the game. This requires a deeper reflection of one's understanding of sustainability, competency, and learning itself. Furthermore, the intended learning outcomes should be formulated as clearly and actively as possible, meaning that they rather describe what a student should do than what a student should know.

Subsequently, I found the intended learning outcomes can be realised in a game through a process of constructive alignment. In this context, the motivational and functional aspects of the game should not be underestimated. This thesis underlines the crucial role of playtesting for game designing, which is in line with previous findings but often not reflected in the literature on educational games. Finally, the ability of the game to teach sustainability competencies was evaluated. Testing required a multidimensional assessment strategy that must align with the intended learning outcomes formulated. Throughout the process, I constantly sought to achieve a constructive alignment between learning, gaming, and assessment. Nicholson's (2011) game development structure and the design principles of Laine and Lindberg (2020) provided practical tools to guide that process.

This thesis contributes to the structure of the Nicholson (2011) game development, the constructive alignment of the intended learning outcomes and the features of the game, and the application of the design principles of Laine and Lindberg (2020) by adding information on the practical application of sustainability competencies. Furthermore, different assessment strategies were applied and evaluated. The thesis also highlights existing gaps in sustainability competencies in ESD, showing conceptual ambiguities around sustainability competencies that need clarification. Regarding the development of Serious Games, the thesis underlines the lack of clear connections between learning and gaming mechanics and the need for more empirical research. It also confirms that more research is needed on assessment strategies.

Despite these limitations, Serious Games have a lot of potential to engage students in active sustainability education. The versatile nature of games opens many possibilities to implement sustainability competency teaching. Hopefully, the developed game can function as an inspirational example for all those interested in developing their own games for sustainability.

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Appendix

Appendix A

Assessment Sheets 1-4

As you will notice, these questions do not have right or wrong answers and are highly subjective. Thus, please just answer according to your perception and not according to possibly perceived "desired" answers.
You will get the possibility to fill in changed perceptions and answers after the game with a differently colored pencil.

This form has two purposes
1) To encourage a learning process towards the three competencies: values-thinking, systems-thinking and strategic-thinking.
2) To help me evaluate and improve my game.

Values-thinking competence Rate your own ability to:	Very Low	Low	Medium	High	Very High
Understand how your own perception is influenced by existing structures, norms and values (V1)	1	2	3	4	5
Apply values-thinking by making decisions regarding water issues that do consider existing oppressive structures or injustice (V2)	1	2	3	4	5
Analyse how decisions regarding water management can be influenced by existing societal structures and thus can also reinforce existing injustices (V3)	1	2	3	4	5
Evaluate how different adaptation measures could reinforce certain values or oppressive structures (V4)	1	2	3	4	5
Systems-thinking competence Rate your own ability to:	Very Low	Low	Medium	High	Very High
Understand how a water cycle works in general, what are the major variables and how do they interact with each other (SY1)	1	2	3	4	5
Apply your understanding of the water system to implement adaptation measures (SY 2)	1	2	3	4	5
Analyse where potential leverage points (places where a small change causes a lot of change in the system) could be (SY3)	1	2	3	4	5

Evaluate how sensible different adaption measures are from a systems perspective (SY4)	1	2	3	4	5
Strategic-thinking competence Rate your own ability to:	Very Low	Low	Medium	High	Very High
Understand different adaption measures for different aspects of the water management (ST1)	1	2	3	4	5
Apply values-thinking and systems-thinking in the decision processes (ST2)	1	2	3	4	5
Analyse the results of the decisions based on systems-thinking and value thinking (ST3)	1	2	3	4	5
Evaluate what would be a desirable alternative founded in systems-thinking and values-thinking (ST4)	1	2	3	4	5

Enrichen this drawing by

1) Make a list with the different variables that you consider important in regards to useable water
2) Draw them
3) Draw the relations among those
4) Add little explanations how they are related
5) Highlight points that you consider as leverage points (places where a small change causes a lot of change in the system) by circling them twice

Guidelines
The water system is NOT limited to the water cycle. The task is not to draw a perfect water system, in fact, it would be impossible to do that in a short time. So don't despair if it get's messy or confusing.

State your three main learning outcomes:

Appendix B

Table linking ILOs to Game Content

Intended Learning Outcome	**Link Challenge and Content**	**Create Appropriate roles**	**Possible Mechanics**
Values-thinking competency			
Understand that everyone overlooks some aspects of water issues as perceptions are influenced by existing structures (V1)	Different opinions by locals (fictional game characters)	Ask as many locals as possible	Only by asking all the possible experts they can get to a solution that is desirable. Sometimes no option is disireable for everyone. Further, the likelihood for a successful implementation rises if players asked more locals for their opinion.
Apply values-thinking by considering different values in decision making processes regarding water issues (V2)	Balance divergent interests for solving water issues to on one hand increase the catchment's drought resilience, but also to gain the support for these measures form the locals.	Players should listen to the locals when they make the decision	How successful the choice was is very dependent on the support of the community. If they don't support it the players loose time.
Analyse who profits/suffers from the existing water issues (V3)	Environmental degradation, economic dependency and distribution issues become a problem	Discuss what can be done about these problems	The problem description at the beginning shows a conflict and some locals already predict the consequences for different groups.
Evaluate how different adaptation measures could reinforce certain values or oppressive structures (V4)	Adaption measures can reinforce the problems	Choose adaptation measures that do not reinforce the problems	The game rewards decisions based on how "harmful" they are. They can learn to be very considerate about their choices.
Systems-thinking competency			

Understand how a water cycle works in general, what are the major variables and how do they interact with each other (SY1)	The main challenge in the game evolves around how the different components interact with each other	Understand the water cycle by imitating the water cycle	The board symbolizes the water cycle. Each round the players can internalize how the components are interrelated by moving the cubes.
Apply your understanding of the water system to implement adaptation measures (SY 2)	Players need to implement adaption measures	The players can choose between different adaption measures	Allows for different choices
Analyze where potential leverage points (places where a small change causes a lot of change in the system) could be (SY3)	Not all adaption measures are equally important	Players should decide what to prioritize	The game gives hints on what to do next if e.g. a flood occurs
Evaluate how sensible different adaption measures are from a systems perspective (SY4)	Not all adaptation measures are equally sensible	Players should choose an option which makes the catchment most adapted	The game gives immediate feedback on the effect of the measures on the system
Strategic-thinking competency			
Understand which structures lead to how water issues are often handled (ST1)	Long-established structures lead to the current situation	Players need to identify these structures	The locals and the booklet describe which structures lead to the current situation
Apply knowledge about these structures in adaptation suggestions (ST2)	Some of the possible choices cannot be made because of too much resistance of the local population or monetary limits	Players must try to work around the barriers	The game offers possibilities to work around many of the obstacles Most of the time choices that include more opinion are the most favourable
Analyze what are the barriers to suggested changes in the current system (ST3)	Long-established structures resist change	Players must identify the barriers	Adaption strategies without consideration of barriers do not work out Less options are given if the locals are not asked

Evaluate what could be desirable and practicable adaptation strategies (ST4)	Identify a promising strategy	Players can reflect on their prior choices	Adaption strategies with high participation increase chances for success
Create an adaptation strategy for a rural catchment area in NE-Germany (ST5)	Apply the game learning onto other contents	Players need to evaluate the learnings from the game	A variety of solutions are introduced

Appendix C

Integration of DPs in Game Content

Integrating the Content	Design Principles by Laine and Lindberg (2020)	Realisation in the game
Link challenge and Content	Create clear, meaningful, and achievable goals (DP25) Provide an epic meaning (DP26) Raise curiosity by interesting and unpredictable challenges (DP4) Provide cognitive challenges (DP29) Offer past, present, and future perspectives (DP35) Relate gameplay to real-world contexts (DP 36) Create thought-provoking scenarios (DP 54)	Save the location from drought (DP25) Embedded in the broader context of climate change (DP26) Additional to the drought a fertilizer incident, floods and periods of low flows might occur). Further, after bad choices in some scenarios it becomes more difficult to fulfil the goals. (DP4) The scenarios in combination with the water cycle provide a lot of information that needs to be understood and analysed by the players (DP29) Most scenarios include some explanation how it has been, what the current problem is and offer various future scenarios (DP35) The game is based on existing water issues in the region (DP36) The scenarios include controversial decisions, which do not have optimal outcomes. Players must debate with each other, what they consider the best outcome (DP54)
Create Roles Appropriate for the Context and Content	Use a profile/avatar that player can own and relate to (DP33) Relate to past experiences (DP38) Create a meaningful story that the player can relate to (DP49) Offer role-play experience (DP51)	Many regions in Europe will experience increased water stress in the future, thus most players probably can relate to the scenario. Futhermore, the extreme events in recent years like floods or droughts should make it easy for players to relate the game to their past experiences (DP 38, 49)

		Further, the players are playing as a young group of scientists, which might be a perspective for some students (DP 33, 51)
Explore Possibilities for Mechanics	Create possibilities for players to interact with the Story (DP52) Favour simple challenges over complex challenges (DP2) Create progressive goals that built up on each other (DP27) Choose an appropriate transparency level for learning content (DP31) Use familiar, safe, and comfortable controls (DP9) Provide an interactive game map of sufficient detail (DP18) Favor simple interaction (DP10) Freedom of choice and control in gameplay (DP 12) Freedom of exploration and experimentation (DP16) Provide multiple paths/options and dynamic ordering of events (DP17) Provide instructions and /or tutorials (DP21) Provide immediate, positive, and useful feedback (DP 22) Provide clear feedback via different channels (DP23) Make some resources scarce (DP41) Introduce the possibility of losing resources (DP42) Provide means for social communication and interaction (DP43) Provide opportunities for collaboration (DP 45)	The players can interact with the story in the scenarios (DP52) To simplify the task the players play one scenario after another (DP2) Later in the game extra challenges are introduced (DP27). While the players can understand the game mechanism over time it is not too evident so that the game fun is not destroyed (DP31) The game-set up as a board game with water cubes plus a scenario booklet with a chance element (die) reflects many popular games and should be familiar to some of the players (DP9) The water cycle with the different game locations also functions as an interactive map (DP 18). In the scenarios they can only choose between a limited set of options, which they can increase through asking the fictional game characters (DP 10, 12, 16) They can play the scenarios in any order, after the intro scenario (DP17) The game is primiarly explained through an introductory scenario (DP21) The players can change how the water flows and see immediate feedback at the end of every round (DP22). The feedback is provided through different elements: changes in the water flow, more or less influence/time (DP23). Water is scarce and can become even less (DP41, DP 42) In the scenarios they can ask the local population and they are constantly asked to communicate with each other as they paly as a team (DP43, DP 45)

Appendix D

Self-reported Learning Outcomes

Person	Answers	Themes
1.1	Consciousness of both ecological and societal factors of the water system, Groundwater is not an infinite resource Difficult to both meet the needs/wants of society and make sustainable decisions	Connection of society and water Problem awareness Conflictual character of sustainability problems
1.2	Helped me to understand the importance of forests Visualized the high stance of agriculture in the water cycle (contamination, runoff, groundwater) Showcased the water cycle's sensitivity very well -> long lasting consequences from "one" mistake	Knowledge about the water cycle Importance of water management
1.3	Better understand the idea of water sharing in a community There is no solution that pleases everyone Too much water is as bad as too little	Importance of water management Conflictual character of sustainability problems Problem awareness
2.1	How each and everyone's water use influences the whole region, ground water How much the water cycle changes with the seasons, how the seasons affect each other Finding the best solution is quite difficult -> not for everyone the best, compromise is sometimes the best but not always	Connection of society and water Knowledge about the water cycle Conflictual character of sustainability problems
2.2	Monocultures (pine forest) use a lot of groundwater and don't keep water -> diversity is very important also for the water cycles Droughts are a problem but might be overcome when you take the right measures Include people from different backgrounds to everything you do. That makes people happy and brings the best outcome.	Knowledge about the water cycle Importance of water management Participation
2.3	Communication is very useful in implementing measures It is important to have everyone on the same side (especially farmers) A drought is a catastrophic event	Participation Problem awareness

2.4	Being aware of the value of water – where the system can be improved Including many participant in measures to get the best possible outcome -> communication is important Which measures are not successful	Importance of water management Participation
3.1	Barriers to implementation of certain WRM strategies (e.g. economic political) Seemingly small decisions can have large resulting impacts (e.g. large runoff: fertilizer use causing dangerous algae bloom) The importance of preparatory measures before adverse events	Conflictual character of sustainability problems Importance of water management
3.2	People from outside need to understand the contextual factors and not just run ahead with action Algea bloom is a big problem (fertilizer use) People's opinions and wishes/preferences have more influence than what science is good or bad	Participation Problem awareness Conflictual character of sustainability problems
3.3	The water cycle for water usage is not simply the natural water usage That making sustainable choices is a constant battle of weighing pros and cons. Each action will have repercussions That water systems are complex and one "positive" change in one area might negatively impact another	Connection society and water Conflictual character of sus. Problems Knowledge about the water cycle
4.1	- understand the importance of transdisciplinary approaches more in decision-making - have a better understanding of the interrelations in the water cycle - better understanding how different measures can have positive/negative consequences for stakeholders	Participation Knowledge about the water cycle Importance of water management
4.2	I'd say better understanding of the different elements of the water system/cycle, realise 'in practice' that we need to include different stakeholders' opinions, and learning about different adaptation approaches to floods/droughts	Knowledge about the water cycle Participation Importance of water management
4.3	I understood the water cycle/system better and understood how society and natural processes are connected regarding hydrology I understood better how different measures affect different actors/stakeholders differently I understood the importance of taking all actors/stakeholders into account when implementing new	Knowledge about the water cycle Connection society and water cycle Participation

	measures. Measures that are good for one actor might be disadvantageous for another	
5.1	Agriculture as the main factor in the water cycle Possibility of using water better in urban areas Discrepancy between demand and precipitation depended on season	Connection society and water Importance of water management Knowledge about the water cycle
5.2	Complexity of water use Analyses of important leverage points for whole process Importance of political figures	Connection society and water Knowledge about the water cycle Importance of politicians
5.3	Water cycle Effects of drought Adaptation strategies Role of groundwater Awareness to find compromises/consider multiple interests	Knowledge about the water cycle Importance of water management Participation