Games to Collaboratively Explore Environmental Complexity

Designing the Virtual River Game

Robert-Jan den Haan

**GAMES TO COLLABORATIVELY EXPLORE
ENVIRONMENTAL COMPLEXITY:
DESIGNING THE VIRTUAL RIVER GAME**

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GAMES TO COLLABORATIVELY EXPLORE ENVIRONMENTAL COMPLEXITY: DESIGNING THE VIRTUAL RIVER GAME

PhD Thesis

By Robert-Jan den Haan at the Faculty of Engineering Technology (ET), University of Twente, Enschede, the Netherlands.

Enschede, September 2020

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Preface

It was not until a few months before completing my Industrial Design Engineering master that I even considered pursuing a PhD. Perhaps that was because my dad completed his about nine months before I was born. Given my stubbornness (disclaimer: this statement may never be used against me and if confronted I will deny its existence), I may have had some determination to not follow his path. Perhaps this thesis is therefore proof that I am more like my dad than I dare to admit. Perhaps it is also proof that I inherited some of my mom's perseverance and dedication.

The journey of this PhD project started rather unexpectedly. Following random events that led me to join a remote response team around the Haiyan typhoon that decimated the Philippines, I was invited to a Creative Industry conference in Amsterdam. After his talk, I approached Edward Faber from T-Xchange and he gave me the tip to contact professor Hulscher if I was interested in pursuing a PhD in serious gaming (thank you for that tip). I sent an e-mail to Suzanne that same evening, not knowing that Mascha was also involved in the project. That is, in a nutshell, how this journey started.

What a journey it turned out to be. And what amazing people I have worked with or met along the way. Many people deserve thanks for their help in completing the journey (and I sincerely hope I am not forgetting anyone).

To all my RiverCare colleagues, thank you for all the insightful meetings, discussions and barbecues. It is an amazing feat that, at the time of writing, almost all of the researchers have successfully defended their theses or will do so in the near future. To Koen, Juliette, Laura, Pepijn and Valesca, my RiverCare colleagues at the University of Twente, thank you for the fact that your doors were always open for me. Koen and Juliette, this certainly applies to you if we consider frequency. Koen, you have a natural ability to very quickly separate the core of a problem from its side issues. Thank you for all the interesting and useful discussions that helped organize my thoughts and for your enthusiasm and help in the development of the Virtual River Game. The advantage of postponing the defense is that I can now congratulate you and Marieke with the birth of Annika. Juliette, we were in the "project G journey" together and your positive attitude really made it a team effort. We both went through ups and downs in the project and it was good to know we could always fall back on each other. I am really happy for you and Yared that Eliana joined your lives and I wish the three of you all the happiness in the world.

Thanks also to NWO and the industrial partners for making RiverCare possible. Thanks especially to David, Fedor, Florian, Hansje, Hermjan, Johan, Pascal, Rina, Roula and Thomas for providing valuable feedback on the project during the multiple user committee meetings.

To all my DPM department colleagues, thanks for always making me feel at home. To my (former) Human Centered Design colleagues, Anika, Anouk, Arie Paul, Cristina, Deger, Frederick, Jelle, Julia, Julieta, Mascha and Renan, thanks for all the inspiration that you provided me along the way. It is great to know that I am staying in the HCD group now that this journey has come to an end. Thanks to Anouk, Katja, Hans, Johannes, Julieta, Leopoldo, Monique, Patrick, Pieter, Renan, Rick and Steven – i.e. my roommates in N211 and W258 over the years (some for only a short time, some longer, one prolonged even after leaving the university) – for the nice and welcome atmosphere. We all had our ups and downs in our PhD/PDEng projects and, at least for me, it was great to be able to share success stories, vent frustrations and exchange advice. Thanks also to Adriaan, Chanmi, Gisela, Ilknur, Jorge, Marlise, Nick, Roberto, Wienik and Willem for the fun and interesting talks, both at the university and elsewhere. To Norbert, Joop, Peter, Simon, Theo, Thomas, Henk, Dennis, Kai and Esther, thank you for your help and advice in manufacturing the Virtual River Game prototype (I still owe you a cake). To Inge, Inge and Annemarie, thank you for being the heartbeat of DPM, you keep us all going. It is invaluable to know that I can always walk into the secretary to ask any question. To Clareyne, Theo, Tox and Vera, thank you for the fun in all the Optimus board meetings and in organizing its activities. It is great to see that Optimus is still going strong.

Also thanks to my colleagues at the WEM department. Formally I was only part of the department for three months, but I was a regular lurker in the WEM corridors in the last few years (and I have some bad news if you were hoping that is now coming to an end). Denie and Ralph, thank you for all your work on both getting RiverCare off the ground and making it a success. Jord, thank you for the experience (and pleasure) of setting up a complete minor course together from scratch.

Ryan, thank you for all the help to build the game prototype. Your practical look on how to (mass) produce parts of the prototype likely saved countless hours of work. Your flexibility to spend time on this project when it was needed most was also greatly appreciated (even while you were faced with the uncertainties of Brexit). Also thanks for the in-depth political discussions we had as well as for your podcast recommendations (please provide new ones, I have ran out of Freakonomics episodes).

Many thanks to all my co-authors, Jan, Juliette, Jelle, Fedor, Koen, Marc, Menno, Anouk, Mascha and Suzanne: you helped shape the thesis that you now hold in your hands. Fedor, working together with you has been (note: not past tense) very inspiring and you have taught me so much. Your optimism, looking at problems as solvable puzzles rather than insurmountable obstacles, greatly helped the success of this project.

Koen and Anouk, thank you for being my paranymphs. Given that you are both co-authors of Chapter 5, it reassures me that either of you can take over the defense if necessary (but no pressure).

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To my family, Dini, Bep, Loes, Kees, Danielle, Gertjan, Michel, Lizette, Patrique, Sjoerd, Nynke, Noortje and Pim, thank you for always making me feel welcome. I am also very thankful to now find family in Marianne, Hans, Bas, Sandra, Matthijs and Josephine. Klaas and Saskia, thank you for being the loving parents that you are, for all the lessons that you gave me that helped completing this journey, and for all the support you have given me during my entire life. Words cannot express the gratitude that I have for all the things you have done for me.

Monique, the fact that I was working on this journey in room N211 is, literally, the reason we met. Special thanks to many people mentioned above for ensuring that Monique became part of my life (please also apologize to Monique for bringing this PhD into her life). Monique, thank you for looking after me when I needed it most. I am a very lucky man to have you by my side. I could not wish for a nicer, sweeter and caring partner to explore the future together. We now have our house (although it is still under construction). We now have our tree (although it needs to grow a bit more before it will give us apples). The only thing missing then is our animal (it seems doubtful that China will grant us a panda).

Summary

Environmental management concerns the management of land and natural resources in a way that creates and maintains prosperous social, economic and ecological systems. Environmental management therefore typically has to deal with multiple sources of complexity and uncertainty to reach robust, informed and well-considered decisions based on all the knowledge available. To combat complexity and uncertainty, active experimentation and continuous evaluation are advocated. Serious games are receiving increased attention in environmental management as a method both to facilitate stakeholder participation and to stimulate social learning.

Yet, the research, design and implementation of serious games is still largely driven by technical aspects, fueled by expectations rooted in advances in computational power and in the entertainment gaming industry. Less attention has been given to research the extent to which the design of serious games can cater to the needs and desires of stakeholders. The aim of this thesis is therefore to explore how a human centered design of serious games contributes to foster exploring complexity, facilitating stakeholder participation and stimulating social learning in environmental management. Human centered design can be viewed as a design philosophy that considers the will and needs of a product's prospective users as the starting point of the design process. The first contribution of this thesis is therefore exploring how human centered design can contribute to developing a serious game that meets the actual needs and desires of stakeholders. To pursue the aim, a human centered design process is applied to the design of the Virtual River Game, a serious game on Dutch river management, as a case study.

S As a starting point to design the Virtual River Game, we researched the actual needs and desires of river management stakeholders based on interviews ([Chapter 2](#)). We developed an interview method that integrates Sense-making and Cultural Theory. Following the human centered design philosophy, the method facilitates river management stakeholders to structurally reflect on a self-introduced, challenging situation and subsequently imagine how they would like to address this situation. Based on these interviews, we identified three challenges that stakeholders face in Dutch river management: (1) the distribution between the contribution of spatial measures and dike reinforcement to reach flood safety norms, (2) the inclusion of secondary objectives next to reaching flood safety norms, and (3) sustaining the integrated river management approach in the maintenance of floodplains. By analyzing the stakeholders' perspectives on these challenges, we gained an initial understanding of the actual needs and desires of stakeholders. Subsequently, this understanding evolved by developing prototypes and evaluating these with stakeholders ([Chapter 4](#)). Without applying the human centered design approach, we would likely not have realized or fully understood that several stakeholders view hydrodynamic models, models used in river management decision-making, as black boxes.

To fulfill this identified need, we developed a tangible user interface, linking a physical game board to digital models ([Chapter 4](#)). The game board is a hexagonal grid where each grid tile contains pieces that represent the tile's elevation and land use. The grid tiles combined represent a typical, but fictional, stretch of a Dutch river. Players apply river management interventions by changing pieces on the game board. The changes are subsequently turned digital as input to a hydrodynamic and other environmental models and the output of the hydrodynamic model is visualized on the game board. This way, players see the effects of interventions (the model's output) on the location where they applied them (the model's input). The interface enables players to collaboratively work with the models in the game, regardless of background or expertise ([Chapter 5](#)). Furthermore, by using a physical game board, the interface eases the players' cognitive load to process information and stimulates players to use visible actions that make their views on both the problems and their solutions explicit to each other. Applying human centered design therefore led to the development of the novel interface design that links a physical game board to environmental models in order to make models used in practice both accessible and transparent, the second contribution of this thesis.

We analyzed the state-of-the-art in evaluating social learning outcomes of serious games to collaboratively explore complexity ([Chapter 3](#)). The review shows that there is a lack of systematic evaluation approaches to assess cognitive, normative and relational learning outcomes, the operationalization of social learning, of such

serious games. Three evaluation strategies to assess each type of learning outcome are identified: (1) measuring participants' knowledge before and after playing a game (measured learning), (2) participants self-reporting on learning after playing a game (self-reporting learning), and (3) observing learning by participants during a game (observed learning). Based on the review, all three strategies are suitable for assessing cognitive learning outcomes. For normative learning outcomes, the use of the measured and self-reported learning evaluation strategies are suitable. For assessing relational learning outcomes, the self-reported and observed learning strategies are applicable. The review further provides an overview of methods applicable to each evaluation strategy to assess each type of social learning outcome. In the context of this thesis, the evaluation strategies and identified methods were used in two ways. First, to develop an evaluation approach to assess the social learning outcomes of the Virtual River Game. Second, to use as design guidelines that sets a design objective towards social learning that we aimed to attain and assess.

After developing a final prototype of the Virtual River Game, we applied the game in five sessions with both domain experts (river management professionals) and non-experts (non-professionals and laymen) to evaluate how and to what extent the game stimulates social learning using the developed evaluation strategy ([Chapter 5](#)). Through self-reporting, both domain experts and non-experts stated that they gained insights by playing the game, albeit to a different extent. Non-experts mostly agreed or strongly agreed with statements that they gained insights in relation to topics such as the functioning of the river system, the trade-offs between interventions, the use of hydrodynamic models, and the views and perspectives of other players. In their comments, non-experts emphasized insights that are exclusively associated with cognitive learning. Experts rated the statements in a more mixed way, with some statements rated positively but some statements, such as on the use of hydrodynamic models, neutrally to negatively. In their comments, experts emphasized insights related to both cognitive and relational learning. A contributing factor to stimulate social learning in the sessions was the ability for players to experiment with river management interventions. In particular, the interface design enables players to design interventions in the game – experimenting with the location, shape, direction and size of interventions – over selecting predefined intervention options. As the third contribution of this thesis, adding this type of experimentation using tangible game pieces to serious games is valuable as it enables players to collaboratively explore and learn how interventions can be implemented effectively. As the fourth contribution of this thesis, although serious games are tailor-made, the platform developed for the Virtual River Game may be used to more easily transfer the game to other physical, political and cultural settings. Moreover, the tangible, hybrid

S interface may be used as a platform to develop new serious games with a spatial component in application areas such as water management, land use management and urban planning.

In conclusion, applying a human centered design approach, explicitly researching the actual needs and wishes of stakeholders, can enrich the design of a serious game and lead to novel game designs that provide meaning and value to stakeholders. Supported by the results of this thesis, we strongly believe in the value of serious games to collaboratively explore complexity in environmental management. As we show in this thesis, serious games can provide a simplified yet accurate representation of reality where stakeholders can engage in a shared exploration of environmental complexity. Moreover, we show how human centered design can contribute to designing serious games that cater to the actual needs and wishes of stakeholders. As a result, the four main contributions of this thesis are (1) applying a human centered design process to the design of serious games, (2) developing a novel interface design that uses a physical game board linked to environmental models to make the models accessible and transparent, (3) adding the ability to experiment with the design of interventions as a game mechanic over selecting predefined interventions, and (4) creating a hybrid, tangible interface as a platform to customize existing or develop new serious games with a spatial component. There is work to be done to further explore to use and potential of serious games and we provide recommendations for both research in general and towards the outcomes of this thesis specifically. We hope that this thesis encourages and inspires both design researchers and game designers to continue exploring how the design of serious games to collaboratively explore complexity in environmental management can add meaning and value to stakeholders.

Chapter 1

Introduction

1.1 Environmental management

We, as a species, place enormous strain on our planet and face unprecedented environmental challenges as a result. We place strain on our planet by using natural resources and land for social benefit and economic activities such as to produce hydropower in the Nile river basin and to create agricultural land through deforestation of the Amazon rainforest. We face environmental challenges such as climate change and global warming and see their effects through devastating forest fires in Australia and the melting ice mass in the Arctics. It is undeniable that human actions and decisions are major contributing factors to the environmental challenges we face today (IPCC, 2014). Environmental management therefore refers to the management of human activity and its impacts on the environment, both now and in the future. As Folke et al. (2002, p. 8) state, environmental management concerns the management of land and natural resources in a way that creates and maintains prosperous social, economic and ecological systems. Environmental management may therefore be defined as *“the actual decisions and actions concerning policy and practice regarding how resources and the environment are appraised, protected, allocated, developed, used, rehabilitated, remediated and restored, monitored and evaluated”* (Mitchell, 2002, p. 8). As a result, environmental management is concerned with the process of decision-making in relation to objectives on using natural resources, improving the quality of the environment or limiting its degradation, and avoiding humanitarian as well as environmental disasters. Environmental management calls for an interdisciplinary approach and requires dealing with complexity to reach robust, informed and well-considered decisions based on all the knowledge available.

1.1.1 Complexity in environmental management

From a systems perspective, environmental management addresses the management of complex adaptive systems as the behavior of environmental systems is more than the sum of the behavior of its elements (Norberg and Cumming, 2008). Complexity in environmental systems therefore relates to the fact that all the elements of a system combined function as a whole, while the interaction of these elements is dynamic, non-linear and self-organizing (Cilliers, 1998). Moreover, as environmental management is concerned with social-ecological systems (Berkes et al., 2000; Colding and Barthel, 2019), this interaction is not limited to physical interaction within an environmental system, but also includes the social interaction between the stakeholders and institutions that manage or affect the system. Consequently, environmental management typically deals with multiple sources of complexity (Hommes, 2008). First, interventions in environmental systems have effects on a

1 range of spatial scales, from local to global, that transcend boundaries such as country borders (Boyd et al., 2008; Cheruvelil et al., 2008; Gurnell et al., 2016; Pelosi et al., 2010; Vinke-de Kruijf et al., 2013; Vreugdenhil et al., 2010). For example, constructing a hydropower dam has ecological, hydraulic and social effects throughout a river basin. Second, interventions in environmental systems have effects on different temporal scales, from short- to long-term (Cash et al., 2006; Groffman et al., 2006; Grumbine, 1994; Mardle and Pascoe, 2002; Zevenbergen et al., 2008). Deciding to reduce or cease the extraction of natural gas may reduce CO₂ emissions in the long-term, but may require an initial increase of emissions in order to construct infrastructure for alternative energy sources. Third, environmental systems concern inherent uncertainties, meaning that we are not able to fully anticipate the effects of interventions (Berends et al., 2019; Berends et al., 2018; Brugnach et al., 2007; Polasky et al., 2011; Warmink et al., 2017). We use tools such as computer models and climate change scenarios to take decisions based on the best available knowledge, but the real impacts and effects of interventions only become apparent well after their implementation. Fourth, environmental systems cover a range of stakeholders and agencies, meaning that interventions are planned in policy arenas guided by different objectives, perspectives and skewed decision-making power (Brugnach et al., 2011; Fliervoet et al., 2017; Gregory et al., 2012; Huang et al., 2011; Mendoza and Martins, 2006; Verbrugge et al., 2017). Although environmental management requires an integral approach, sectoral responsibilities and interests as well as more positive or negative future outlooks all affect how stakeholders view both problems and their solutions. In this thesis, we view complexity to therefore include both the techno-physical complexity of the environmental system itself as well as the socio-political complexity of managing the system.

To combat complexity and uncertainty, scholars have advocated active experimentation and continuous evaluation in the form of adaptive management (Allen et al., 2011; Armitage et al., 2007; Armitage et al., 2008; Berkes, 2009; Lee, 1999; Pahl-Wostl et al., 2007b; Rodela, 2011; Tompkins and Adger, 2004). Adaptive management accepts both complexity and uncertainty in environmental management while acknowledging the need to act. Adaptive management therefore emphasizes monitoring carefully defined system indicators and responding to changes in the system. Central in these approaches is the need for stakeholder participation and learning to include additional forms of knowledge, to improve the shared understanding of environmental systems, and to build trust and the ability to collaborate between stakeholders (Crona and Parker, 2012; Cundill et al., 2012; Fabricius and Cundill, 2014; Huitema et al., 2009; Lockwood, 2000; Pahl-Wostl et al., 2007a; Pahl-Wostl et al., 2008; Stringer et al., 2006).

1.1.2 Stakeholder participation and social learning

Adaptive management calls for stakeholder participation to increase the knowledge about environmental systems in the form of learning through management (Allen et al., 2011; Lee, 1999; Tompkins and Adger, 2004). Moreover, stakeholder participation is advocated to include the stakeholders' different values, perspectives and tacit knowledge in environmental decision-making in order to increase the quality and acceptability of decisions (Ananda and Herath, 2003; Cundill and Rodela, 2012; Gregory and Wellman, 2001; Reed, 2008; Ruiz-Frau et al., 2011; Voinov and Bousquet, 2010; Voinov et al., 2016). Therefore, through active participation, stakeholders learn about the environmental system, about the effects of interventions, and about the views and perspectives of other stakeholders (Armitage et al., 2008; Muro and Jeffrey, 2008; Pahl-Wostl et al., 2007a; Reed et al., 2010; Rodela, 2011). Such learning processes are generally referred to as social learning. Although scholars debate its definition, social learning can be referred to as a change in understanding through interaction in collaborative and participatory processes that go beyond the individual (see e.g. Cundill and Rodela, 2012; Muro and Jeffrey, 2008; Reed et al., 2010; Rodela, 2011). Social learning requires deliberative interactions and building relationships between stakeholders with the ultimate aim to lead to collective action (Cundill and Rodela, 2012; Keen et al., 2005; Mostert et al., 2008; Pahl-Wostl et al., 2008). Social learning therefore contributes to informed and robust decision-making by establishing a shared understanding of both environmental issues as well as the positions and perspectives of all stakeholders. Combined, stakeholder participation and social learning are seen as essential to pursue cross-disciplinary objectives in environmental management (Berkes, 2009; Mostert et al., 2008; Pahl-Wostl, 2007; Reed, 2008). One method that is receiving increased attention to facilitate participation and social learning in environmental management is the use of serious games (Aubert et al., 2018; Barreteau et al., 2007; Edwards et al., 2019; Flood et al., 2018; Marini et al., 2018; Medema et al., 2016; Savic et al., 2016).

1.2 Serious games to explore complexity

Serious games are generally referred to as games with a primary purpose other than mere entertainment (Michael and Chen, 2005; Susi et al., 2007). The origin of the term serious game, in line with how it is used today, can be traced back to Clark Abt's book titled *Serious Games* (Abt, 1970). Abt defined games to be serious games as "*in the sense that these games have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement. This does not mean that serious games are not, or should not be, entertaining*" (Abt, 1970, p. 9). Yet, the term serious games did not become popular until in early 2000s, when

1 Sawyer (2002), inspired by developments in the entertainment gaming industry, published the white paper titled *Serious Games: Improving Public Policy through Game-based Learning and Simulation*. Although not limited to digital games, serious games have since then increasingly been associated with computer or computer supported games (Michael and Chen, 2005; Susi et al., 2007; Zyda, 2005). While the term serious game has only recently become popular, there is a long history of using games for “serious” purposes (Wilkinson, 2016). In the military, games have been used for centuries for the purpose of training, analyzing tactics and preparing missions (Smith, 2010). In business management, games have been used since the 1930s for managers to experiment with playing the role of top executives as well as simulating existing or exploring conceptual business operations (Faria et al., 2009). In healthcare, games have been used to prepare future professional for patient interaction and empathy as well as for critical and emergency situations since the late 1970s (Nehring and Lashley, 2009).

In environmental management, serious games were adopted to address shortcomings of models and simulations. In particular, models and simulations were initially successfully introduced to analyze well-structured problems such as found in business management and operational planning (DeLeon, 1994; Miser, 1985). However, the rigid and mathematical models and simulations at the time performed poorly when applied on heavily disputed, ill-structured – or ‘wicked’ (Rittel and Webber, 1973) – problems such as found in social policies, urban planning, and environmental management (Brewer, 1986; DeLeon, 1994; Wenzler, 1993). Gaming proved to be an effective way to communicate the dynamics of the system and its model, but also to include other types of data, insights and tacit knowledge (Geurts et al., 2007; Mayer, 2009; Parson, 1997). Such serious games initially became used in urban planning to explore complex issues around land use, community development, public participation, ecology and natural resources in the 1970s (Geurts et al., 2007; Mayer, 2009; Taylor, 1971). Later, serious games started to be used in environmental management under the term policy exercises: scenario-based, preparatory activities for effective participation in official decision processes (Brewer, 1986, 2007; Toth, 1988a, b). The use of games was again seen as a method to overcome weaknesses of other science-based policy support. In particular, models and simulations fulfilled the need to communicate scientific knowledge on global environmental change, but failed to capture its politics (Mayer, 2009; Runhaar and van Nieuwaal, 2010). Games were used to open up the black box of quantitative models and enable policy makers to use these models in decision-making (Mayer, 2009; te Brömmelstroet and Bertolini, 2008; Vennix and Geurts, 1987). Moreover, games were seen as an effective method in policy exercises as games enabled policy makers to experi-

ment without decisions or outcomes becoming official (Brewer, 1986, 2007; Toth, 1988a, b).

In this thesis, we focus on serious games in order to collaboratively explore complexity in environmental management. Over the years, various other terms for such *serious games* have been used, such as *simulation games*, *policy games* and *policy exercises* (Duke and Geurts, 2004; Geurts et al., 2007; Mayer, 2009). For the purpose of this thesis and in line with common practice in literature, we consider the terms serious games, simulation games, policy games and other terms to be synonymously. Moreover, we often use the word game to refer to serious game or equivalent. In the next subsections, we discuss the design and definition as well as the strengths and weaknesses of serious games to collaboratively explore complexity in environmental management.

1.2.1 Design and definition

Serious games to collaboratively explore complexity aim at providing a simplified representations of reality (Duke and Geurts, 2004; Harteveld, 2011; Rodela et al., 2019; Savic et al., 2016). To include the reality of the environmental system, these games are generally developed as interaction layers to computer models and simulations (Bekebrede, 2010; Craven et al., 2017; Crookall et al., 1987; Geurts et al., 2007; Learmonth et al., 2011; Mayer, 2009; Rodela et al., 2019; Valkering et al., 2013; van Hardeveld et al., 2019). To interact with models and simulations, this type of serious games uses a graphical user interface (Craven et al., 2017; Jean et al., 2018; van Pelt et al., 2015), tabletop surface (Antle et al., 2011), game board (Cleland et al., 2012; Keijser et al., 2018; Meya and Eisenack, 2018), or a combination of these (Magnuszewski et al., 2018; Stefanska et al., 2011). The games allow players to perform actions, which influences the underlying models and simulations, and includes feedback mechanisms for players to inspect the actions' effects.

Next to the technical complexity of the environmental system, serious games generally include the social and political aspects of environmental management by including roles, (competing) objectives and interaction rules (de Caluwé et al., 2012; Geurts et al., 2007; Mayer, 2009). In-game roles and objectives are designed based on real-world stakeholders and reflect these stakeholders' responsibilities, priorities and resources (Magnuszewski et al., 2018; Vasconcelos et al., 2009; Villamor and Badmos, 2016). Interaction rules provide structure to the game, but also reflect stakeholders' real-world abilities, asymmetrical access to information and power dynamics (Bekebrede et al., 2018; Mayer et al., 2013; Souchère et al., 2010).

To bring these points together, serious games to collaboratively explore complexity may be defined as "*experi(m)ent(i)al, rule-based, interactive environ-*

ments, where players learn by taking actions and by experiencing their effects through feedback mechanisms that are deliberately built into and around the game” (Mayer, 2009, p. 825). Such serious games can facilitate stakeholders in their communication, can more easily incorporate diverse perspectives, can integrate scientific and tacit knowledge, can stimulate experimentation and creativity, can provide the ability to collaboratively test management strategies in a scenario, and enable to experience the problem from another perspective by taking on roles (Bekebrede, 2010; Brewer, 2007; Duke, 1974; Duke and Geurts, 2004; Geurts et al., 2007; Gilbert et al., 2002; Haug et al., 2011; Mayer, 2009; Medema et al., 2016; Parson, 1997). By doing so, serious games in environmental management aim to, for example, raise awareness about environmental risks or problems (Antle et al., 2011; Becu et al., 2017; Craven et al., 2017; Douven et al., 2014; Rebolledo-Mendez et al., 2009), to explore and communicate the complexity of an environmental problem (Ayadi et al., 2014; Bekebrede et al., 2018; Cleland et al., 2012; Page et al., 2016; Zhou et al., 2013), to facilitate public participation around environmental problems (Barnaud et al., 2007; Ducrot et al., 2015; Magnuszewski et al., 2018; Salvini et al., 2016; Speelman et al., 2014), and to support decision-making in addressing environmental problems (Hertzog et al., 2014; Hill et al., 2014; Keijser et al., 2018; Lankford and Watson, 2007; Onencan et al., 2016). In the next two sections, we discuss the strengths and weaknesses of using games to these ends.

1.2.2 Strengths

There are some clear strengths of using serious games to collaboratively explore complexity. First, serious games integrate the complexity of the environmental system with the complexity of the multi-stakeholder setting (Bekebrede, 2010; Duke and Geurts, 2004; Geurts et al., 2007; Mayer, 2009; Zhou, 2014). Based on underlying models and simulations, serious games to collaboratively explore complexity enable stakeholders to explore the problem, possible interventions, and the effects of such interventions – the physical-technical complexity. In addition, stakeholders are able to experience the strategic interactions between stakeholders – the socio-political complexity – by explicitly including roles, objectives, and interaction rules in the game.

Second, serious games enable stakeholders to explore the policy problem in a safe experimentation environment (Bekebrede, 2010; de Caluwé et al., 2012; Duke and Geurts, 2004; Geurts et al., 2007; Mayer, 2009). Games take stakeholders out of their ordinary lives and into an environment that is bound in time and space (Juul, 2011). As Duke (1974) argued, playing a game in a collaborative context starts discussions

about the game's topic, relations and outcome. However, discussions and decisions in games are only valid within these boundary conditions; they have no implications outside of the game. Therefore, as stakeholders take on roles in the game, they may take positions they might not defend in reality (de Caluwé et al., 2012; Geurts et al., 2007). Moreover, stakeholders are more inclined to experiment and be creative with solutions that may be much more sensitive in reality (Duke and Geurts, 2004; Geurts et al., 2007; Mayer, 2009).

Third, serious games can merge gaming mechanics with models and simulations (Bots and van Daalen, 2007; Mayer, 2009; Voinov et al., 2016). Serious games may be seen as an interaction layer to models and simulations, enabling stakeholders to directly interact with environmental models without the need for support from experts. By playing serious games, stakeholders may therefore increase the understanding of the models that describe environmental systems by making the models interactive and easier to use (Bekebrede, 2010; Mayer, 2009; Vennix and Geurts, 1987; Voinov et al., 2016).

Fourth, serious games enable learning about challenges in environmental management (Crookall and Thorngate, 2009; Hofstede et al., 2010; Marini et al., 2018; Mayer, 2009; Medema et al., 2016). In fact, games play into the nature of humans, who *"enjoy exploring, discovering and learning. They do not like just to be told about something; they learn most readily from concrete instances and information strong in imagery"* (Duke and Geurts, 2004, p. 35). By experimenting in a game, stakeholders learn what intervention options they have available to address an environmental problem and what the effects of interventions are. In this learning-by-doing, stakeholders therefore learn about the complexity of the system. In addition, stakeholders also engage with others in a joint problem investigation, thereby learning about how other stakeholders view both the problem and its solution (Bots and van Daalen, 2007; Geurts et al., 2007).

1.2.3 Weaknesses

Although the use of serious games to collaboratively explore complexity has the above listed strengths, serious games also have their weaknesses. First, serious games are generally tailor made to specific environmental systems with unique policy situations and cultural contexts (Ampatzidou et al., 2018; Bots and van Daalen, 2007; de Caluwé et al., 2012; Duke and Geurts, 2004; Geurts et al., 2007; Toth, 1988b). As a result, researching and developing such serious games is time consuming. Moreover, these games generally cannot be easily transferred to other situations or locations even though these seem similar. The game has to, for example, be linked to

another model (which may not be of the same quality), the roles and rules need to be adapted to the new policy situation, or the high-tech solution may not fit the location's cultural context.

Second, serious games are designed with learning objectives relevant to reality, but learning still needs to be transferred to reality (Chin et al., 2009; Crookall and Thorngate, 2009; Geurts et al., 2007; Hofstede et al., 2010; Mayer, 2009; Mayer et al., 2014). Although there is ample evidence that games support learning about environmental problems (Aubert et al., 2018; Crookall and Thorngate, 2009; Flood et al., 2018; Marini et al., 2018; Medema et al., 2016), it has not yet been systematically validated that lessons learned through games are transferred to the real world and used in addressing environmental problems (Chin et al., 2009; Mayer, 2009; Mayer et al., 2014).

Third, as a follow-up to the previous point, research on the scientific validity of using serious games is met with some suspicion (Chin et al., 2009; Hofstede et al., 2010; Mayer, 2009). As games can have many different forms and are applied in various contexts, no common methodology to assess the effectiveness of serious games currently exists (Mayer, 2014). In addition, data to assess the effectiveness of serious games needs to be gathered in an uncontrolled setting; stakeholders may have prior relationships, stakeholders may have positive or negative attitudes towards games in general and the use of serious games in particular, and facilitators have to guide the sessions while continuously making decisions on the spot (Chin et al., 2009; de Caluwé et al., 2012; Hofstede et al., 2010; Mayer et al., 2014). To quote Hofstede et al. (2010, p. 825): *“Proving that simulation games work reminds us of high school math in which one had to build a complicated argument to prove that two triangles had the same shape when one glance at the figure sufficed to confirm that they did. The effectiveness of simulation games is evident to those who work with them (players and facilitators).”* Combining this and the previous point, more systematic evaluation approaches are needed to assess the effectiveness of serious games and increase the acceptance of research on the application of serious games.

1.3 Designing serious games

Designers have some resources available to them to design games in general (Salen et al., 2004; Schell, 2008) and serious games specifically (Harteveld, 2011; Ritterfeld et al., 2009). There are also resources available to design serious games in the context of environmental management. Bots and van Daalen (2007) for example provide a conceptual framework for designing serious games to support policy-making in managing natural resources. Rodela et al. (2019) conceptualize the different uses of serious games in natural resources and environmental management. Marini et al.

(2018) provide recommendations for the design of serious games to support long-term cooperation between stakeholders in water management. Mayer et al. (2016) construct four frames to describe the utility of games for society, business and politics. All these resources are useful to consider trade-offs in the game design such as balancing meaning, reality and play in the game to reach the game's intended purpose (Harteveld, 2011). However, the resources frame serious games as an object to reach the game's defined purpose. The resources do not help designers to determine the game's purpose, nor if and how that purpose fulfills the stakeholders actual needs and desires.

1.3.1 *Human centered design*

In design, it is nowadays widely recognized that people who potentially use the product should be involved in the design process in order to develop products that meet real needs and wishes. User involvement in design is generally advocated under the umbrella of human centered design. Human centered design is a broad concept that can perhaps better be described as a philosophy to design products that considers the will and needs of those that use them as the starting point of the design process. Specifically, it places the meaning a product should offer to people as a central design activity next to a product's purpose (Krippendorff, 2004). People are involved at specific moments or actively throughout the design process (Sanders, 2002; Sanders and Stappers, 2008). All human centered design methods and techniques therefore center around designers communicating, interacting and empathizing with prospective users of the product in order to obtain an understanding of their needs, desires and experiences (Giacomin, 2014; Norman and Verganti, 2014; Steen, 2011). Interviews, focus groups, card sorting and ethnography are for example used to elicit people's needs and wishes (Arhippainen and Tähti, 2003; Hanington, 2010; Muller, 2001; Rauth et al., 2010; Sperschneider and Bagger, 2003; Stewart and Shamdasani, 2014). Scenarios and personas are developed to capture current and future use situations of the product (Anggreeni, 2010; Carroll, 1995; Pruitt and Grudin, 2003; Tideman, 2008; van der Bijl-Brouwer, 2012). Co-design workshops, design games and roleplaying are used to include users in the design process (Garde, 2013; Thalen, 2013; van Amstel, 2015). Prototypes, from early concepts to functional products, are developed iteratively and presented to users in order to evaluate these throughout the design process (Kuijjer and De Jong, 2011; Lloyd and Dykes, 2011). From a designer's perspective, the methods and techniques acknowledge the use related expertise of prospective users, empower prospective users to explore and define potential futures, and enable both designers and prospective users to experience the consequences of design decisions. In this thesis, we propose to research the needs and

desires of environmental management stakeholders and to make their needs and desires the starting point of a serious game's design process by applying a human centered design process.

1.4 Research objective

The aim of this thesis is to explore how a human centered design of serious games contributes to foster exploring complexity, facilitating stakeholder participation and stimulating social learning in environmental management. Therefore, the thesis' focus is on researching and designing serious games to meet actual stakeholder needs and desires by applying a human centered design approach. To investigate the main aim and accompanying research questions, the design and evaluation of the Virtual River Game, a serious game on Dutch river management, serves as a case study. In this thesis, we use *serious games to collaboratively explore complexity* to refer to the aim.

The contributions of this thesis to the existing literature are threefold. First, the thesis covers a wider view on serious games development by explicitly researching the stakeholder needs and desires as part of the game design process. Second, we explore and present novel research methods, design concepts and game mechanics that may contribute to boosting strengths and overcoming weaknesses of serious games in general. Third, the Virtual River Game, and particularly its evaluation, adds further evidence of the strengths of using serious games to collaboratively explore complexity in environmental management.

1.4.1 Research context

The design and evaluation of the Virtual River Game serves as a case study to pursue the aim of this thesis. We developed the game in the context of a changed management paradigm in Dutch river management. Before the paradigm shift, ensuring flood safety around rivers focused solely on constructing hydraulic structures such as dikes. Following two near-flood events in 1993 and 1995, the new management paradigm that was implemented focuses on increasing the resilience of the river system by creating space for water (Rijke et al., 2012; Warner et al., 2012; Zevenbergen et al., 2015). So called spatial measures were implemented, such as constructing side channels, lowering floodplains and relocating dikes (Berends et al., 2019; Straatsma et al., 2019; Van Denderen et al., 2019; van Stokkom et al., 2005). Similar to the old management paradigm, the measures' primary objective was to increase flood safety. As a secondary objective, the measures aimed to improve the spatial quality of the river areas, which can be summarized as its ecological value as well as its cultural meaning

and aesthetics (Fliervoet et al., 2013b; Klijn et al., 2013; Nillesen and Kok, 2015; Schut et al., 2010). These new type of measures and inclusion of secondary objectives has added to the Dutch river management complexity.

1.4.2 *RiverCare*

The Virtual River Game case study was executed as part of the RiverCare research program funded by NWO (Hulscher, 2014). The RiverCare research program was initiated in response to the spatial measures implemented in the new Dutch river management paradigm. Specifically, research projects within the RiverCare program aimed to research topics that include the effects of newly applied management measures, new governance strategies and valorization as well as communication of knowledge. For example, the management measure to construct longitudinal training dams was researched for the effects on morphology (de Ruijscher et al., 2018) and ecology (Collas et al., 2018). Morphological effects were also studied for main river channels (Chavarrías et al., 2019), side channels (Van Denderen et al., 2019), bank erosion (Duró et al., 2018) and regional river systems (Candel et al., 2018; Geertsema et al., 2018). Other research focused on quantifying uncertainty of intervention measures (Berends et al., 2018) floodplain vegetation patterns and monitoring (Harezlak et al., 2020; van Iersel et al., 2018), and ecosystem services (Koopman et al., 2018; Pfau et al., 2019). On governance, research was conducted on the collaborative management of floodplains (Fliervoet et al., 2017), public participation (Verbrugge and van Den Born, 2018) and public procurement strategies (Bout et al., 2019). Research on the valorization of knowledge developed in RiverCare focused on the development of a decision support tool to optimize river management (Straatsma and Kleinhans, 2018) and researching the export potential of generated knowledge. Lastly, research focused on the communication of research results in the form of developing a knowledge base and storylines (Cortes Arevalo et al., 2019) as well as designing a serious game, of which this thesis is a result. Developing the Virtual River Game as part of the RiverCare research program enabled us to benefit from the knowledge and expertise available within the program on topics such as hydrodynamics, ecology and governance.

1.4.3 *Serious games in river management*

A handful of serious games exist that enable stakeholders to collaboratively explore complexity in river management. Many of these games focus on managing water resources, such as for irrigation and hydropower (Burton, 1994; Douven et al., 2014; Hertzog et al., 2014; Lankford and Watson, 2007; Onencan et al., 2016; Onencan and van de Walle, 2018; Rajabu, 2007). A few river management games explicitly include

flood risk management. Below, we briefly discuss these games as these are relevant in the context of this thesis.

[Valkering et al. \(2013\)](#) developed the Sustainable Delta Game where players are tasked with developing collective strategies to limit the probability of both floods and droughts from occurring in a fictional stretch of a Dutch river. Every game round, players use cards to apply policy interventions and receive feedback in a graphical user interface that includes a virtual game world. As a higher level goal, players learn about the complex interactions between river management, climate change and changes in society. The game provides feedback to players through an integrated assessment meta model that describes cause-effect relations based on hydrological and impact models. [Van der Wal et al. \(2016\)](#) showed that playing the game in twelve sessions lead to convergence of the players' perspectives. They further concluded that model feedback in the game was an important contributing factor for converging perspectives. [Lawrence and Haasnoot \(2017\)](#) adapted the game for application in New Zealand and used it to introduce players to the use of adaptive pathways as a way to deal with climate change uncertainties. [Van Pelt et al. \(2015\)](#) also applied the Sustainable Delta Game in sessions and showed that the game was effective to communicate about climate change uncertainties.

[Stefanska et al. \(2011\)](#) created the Floodplain Management Game where players play the roles of farmers, local authorities or water boards in a stretch of a river and are tasked to manage their own objectives, such as profit, biodiversity and control of water flow. By playing the game, players explore both technical problem-solving such as problem identification and analysis as well as relational issues such as understanding mutual relationships and recognizing the other players' positions and interests. The game uses a printed game board as an abstract representation of a stretch of a river where players manage the land use of parcels in the river's floodplains. Player actions are processed manually by an operator and the actions' effects are subsequently calculated by a simplified system dynamics model of the Tisza river basin in Central Europe. [Stefanska et al. \(2011\)](#) showed that the game is a useful tool for players to experience the challenge of creating river management policy by uniting technical problem-solving with understanding mutual relationships. [Magnuszewski et al. \(2018\)](#) expanded the Floodplain Management Game to the Lords of the Valley game to further include and explore social aspects of floodplain management.

[Carson et al. \(2018\)](#) and [Bathke et al. \(2019\)](#) developed versions of the Multi Hazard Tournament – expanding on the Invitational Drought Tournament ([Hill et al., 2014](#)) – where players develop proactive management strategies to address possible droughts, floods and water quality issues in a river basin. The game presents a map of a fictional river basin on a graphical user interface where players can further

find information such as their budget, forecasted climate conditions and predefined adaptation options. Players select adaptation options and receive feedback on environmental, social and economic factors based on a system dynamics model describing the main characteristics of the Cedar River basin in Iowa, the United States. By playing the game, players gain understanding of complex water resources systems, the trade-offs of adaptation choices and of the other players' positions. [Carson et al. \(2018\)](#) and [Bathke et al. \(2019\)](#) showed that playing the game enabled players to learn about water quality as well as flood and drought mitigation options, about each other's perspectives and about potential opportunities for future partnerships.

[Craven et al. \(2017\)](#) developed the SimBasin game where players select projects to manage indicators related to flooding, agriculture, hydropower and ecology in a river basin. In a series of turns, players choose to implement projects such as hydropower construction, ecological restorations or flood protection that affect the future of the basin. Players receive feedback on their choices in the game's graphical user interface based on a simplified water resources model of the Magdalena-Cauca river basin in Colombia. The game aims to stimulate social learning and in particular for players to gain a shared understanding and sense of urgency around the river's management. They showed that the game provided an attractive and open discussion space and was therefore successful to bring stakeholders and scientists to the same table.

In this thesis, we took inspiration from these games to design the Virtual River Game and expand on these and other environmental management games by exploring how a human centered design approach benefits a serious game's design.

1.4.4 *Research gap*

The games listed above illustrate the interest in using serious games to explore complexity, facilitate participation and stimulate social learning in environmental management. The recent interest to develop and apply serious games has largely been driven by advances in computational power and in the entertainment gaming industry ([Aubert et al., 2018](#); [Bekebrede, 2010](#); [Mayer, 2009](#)). Recent studies advocate for making the stakeholders, the policy context, and the (social) processes of the problem at hand the driving force of a serious game's design rather than technical aspects ([Aubert et al., 2019](#); [Rodela et al., 2019](#)). Human centered design fits this approach, but has not been applied before on serious games to collaboratively explore environmental complexity. In this thesis, we therefore explore how applying a human centered design, taking the stakeholders and their needs and desires as the starting point of the design process, may enrich the design of serious games to collaboratively explore complexity.

1.5 Research questions

The aim of this thesis is to explore how a human centered design of serious games contributes to foster exploring complexity, facilitating stakeholder participation, and stimulating social learning in environmental management. We investigate the aim through the Virtual River Game case study. By applying a human centered design approach, the following research questions are addressed:

- RQ1. What are the challenges, needs and stakeholder perspectives needed to collaboratively explore river management complexity?
- RQ2. How can social learning through serious games be evaluated and how can the evaluation approach be used to distill game design guidelines for collaboratively exploring complexity?
- RQ3. How can the intended serious game be designed to meet the identified stakeholder needs and intended social learning outcomes?
- RQ4. How and to what extent does the Virtual River Game enable stakeholders to collaboratively explore river management complexity and stimulate social learning?

Figure 1.1 An overview of the research approach.

1.6 Methodology

Below, the methodology of the research is briefly discussed for each research question and placed in the context of the Virtual River Game case study.

- RQ1. To investigate the aim of the thesis, the needs and desires of stakeholders are considered as the prominent driver for design of the Virtual River Game. We elicited the initial stakeholder needs and desires by interviewing several stakeholders in Dutch river management. Through interviews, designers can obtain an in-depth understanding of the stakeholders' needs, desires and experiences. To enhance this process, we developed an interview method to uncover the challenges in Dutch river management as perceived by the stakeholders, as well as their perspectives on these challenges. We used these challenges and perspectives to derive stakeholder needs and desires.
- RQ2. Based on the stakeholder needs and desires elicited in RQ1, we were able to formulate social learning objectives for the Virtual River Game. To evaluate to what extent the game is effective to stimulate social learning, we aimed to develop an evaluation approach for the game. To do so, we conducted a systematic literature review to analyze the state-of-the-art in the evaluation of serious games aimed to stimulate social learning around sustainability issues. We created an overview of assessment methods in relation to a typology on social learning that defines three types of social learning: cognitive, normative and relational.
- RQ3. We explored how the Virtual River Game can be designed to meet the needs and desires elicited in RQ1 and the learning objectives in RQ2. Following a human centered design approach, we developed non-functional and playable low-fi prototypes to allow stakeholders to participate in the design process and experience the consequences of design choices. We used the input and feedback of stakeholders both to gain further understanding of the stakeholder needs and desires as well as to determine refinements and new directions for the game's design. Moreover, to facilitate participation and social learning, it is important that all stakeholders are able to identify and work with the models and simulations included in the game. We therefore focused on (1) how the Virtual River Game can serve the needs of both domain experts and non-experts in this respect, and (2) how these two groups can be facilitated to collaboratively explore river management complexity.

RQ4. We developed the Virtual River Game specifically to meet the stakeholders' needs and desires. Based on these, we formulated specific learning objectives for the game. Using the overview created in RQ2, we subsequently developed an evaluation approach to assess the learning objectives. We applied the Virtual River Game in five sessions and used the evaluation approach to determine how and to what extent the game leads to social learning outcomes.

1.7 Thesis outline

The structure of this thesis is as shown by [Figure 1.1](#). [Chapter 2](#) is concerned with the investigation of current management challenges in Dutch river management, including the perspectives of stakeholders on these challenges, answering RQ1. In [Chapter 3](#), we analyze the state-of-the-art of how social learning outcomes of serious games aimed to enable stakeholders to collaboratively explore sustainable management strategies are evaluated. [Chapter 3](#) therefore answers the first part of RQ2 and provides a framework to answer RQ4. [Chapter 4](#) concerns how prototyping efforts led to designing a physical game board as an interface to digital models for the Virtual River Game and discusses the interface's impact on the game being an effective boundary object. [Chapter 5](#) subsequently describes the Virtual River Game final prototype and discusses the game's social learning outcomes as well as how its design contributes to stimulating social learning. [Chapter 4](#) and [5](#) combined answer RQ3, while [Chapter 5](#) also answers the second part of RQ2 and RQ4.

Combined, the chapters describe the research around and the design of the Virtual River Game as a case study. As discussed, the case study is used to pursue the aim of this thesis: to explore how the serious games' design contributes to foster exploring complexity, facilitating stakeholder participation and stimulating social learning in environmental management. In [Chapter 6](#), we discuss the four main contributions of the research, reflect on the research approach and discuss the research's limitations. The four main contributions of this thesis are: (1) applying a human centered design process to the design of serious games; (2) developing a novel interface design that uses a physical game board linked to environmental models to make the models accessible and transparent; (3) adding the ability to experiment with the design of interventions as a game mechanic over selecting predefined interventions; and (4) creating a hybrid, tangible interface as a platform to customize existing or develop new serious games with a spatial component. In the final chapter, [Chapter 7](#), we provide conclusions to both the overall aim and the research questions before ending with recommendations in regard to future research and possible next steps with the thesis' outcomes.

Chapter 2

Understanding stakeholder perspectives regarding challenges for integrated river basin management

A decorative background consisting of a pattern of blue hexagons of varying sizes, arranged in a honeycomb-like structure. The hexagons are light blue with white borders, and they are scattered across the page, primarily concentrated in the middle and bottom sections.

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This chapter has two adaptations from the published version to be consistent with the thesis: (1) the chapter is adapted from U.K. English to U.S. English; and (2) the chapter uses the term "stakeholder" over "actor".

Abstract

Integrated river basin management increases technical as well as management and governance complexity. As more stakeholders are involved from different backgrounds, it becomes increasingly important to understand how stakeholders frame issues in integrated river basin management. To better understand this process, the following research questions are addressed: (1) what are the current complex challenges perceived by river basin management stakeholders; (2) what are their resolution strategies to address these challenges; and (3) what are their underlying perspectives towards these challenges? Semi-structured interviews were conducted with Dutch river basin management stakeholders following Sense-making methodology. Cultural Theory was used to analyze how respondents construct perspectives. Three shared challenges were identified following the introduction of new sources of uncertainty: (1) creating flexibility in a controlled river system; (2) sustaining the integrated approach in the maintenance of floodplains; and (3) formulating future river basin management policies to adapt to climate change. The analysis showed how stakeholders use different rationalities in constructing these perspectives. As an implication, it is important for all stakeholders to recognize and acknowledge these perspectives in integrated river basin management decision-making. New tools, such as serious gaming environments, are needed to facilitate exchanging and understanding stakeholders' perspectives.

2.1 Introduction

Integrative management approaches are increasingly common in river basin management (Fliervoet et al., 2013b; Mitchell, 1990, 2005; Pahl-Wostl et al., 2008; Rijke et al., 2012; Watson, 2004). Such approaches, commonly referenced to as integrated river basin management, in general acknowledge the interrelationships between water – both quality and quantity – and other variables such as land use. Therefore, integrated river basin management requires a holistic or systems approach to address issues (Mitchell, 1990, 2005; Rijke et al., 2012; Watson, 2004). Two interpretations of a holistic or systems approach exist. First is the comprehensive interpretation, which addresses a system at its largest scale – e.g. river basin – and includes all possible variables and their relationships. Second is the integrative interpretation, which takes a more focused approach by selecting the key variables and their relationships that determine the most variability in the system. As Watson (2004) explains, more recent forms of integrated river basin management use the integrative interpretation to avoid conceptual, analytical and managerial challenges posed by the comprehensive interpretation. The integrative interpretation is defined by Rijke et al. (2012, p. 371) as an approach that *"aligns multiple objectives in a river basin across different spatial scales and temporal dimensions"*.

In The Netherlands, integrated river basin management is found in the "Room for the River program" (RftR) and the "Delta Program" (DP). In these programs, flood risk management targets have been combined with objectives on for example nature restoration, recreation and agriculture (Klijn et al., 2013; Rijke et al., 2012; van Herk et al., 2012). Moreover, these programs have shifted Dutch river basin management from protecting against water with dikes to accommodating water with spatial measures such as side-channels and dike relocations, placing more emphasis on spatial development (Wiering and Arts, 2006; Wolsink, 2006). Such integrated river basin management approaches are not limited to the Netherlands and can be observed in many developed countries (see Warner et al., 2012).

Consequently, integrative approaches introduce stakeholders from non-water related disciplines to river basin management. As a result, decision-making in integrated river basin management has become much more multidisciplinary, collaborative and complex (Dewulf et al., 2015; Margerum and Robinson, 2015; Pahl-Wostl, 2006). Previous studies have shown a need for understanding how stakeholders frame issues in such decision-making settings (Curtis et al., 2002; Gray, 2004; Mostert et al., 2008). Following Goffman (1974), stakeholders frame issues in order to organize their own understanding of the issue and to subsequently guide future action. If stakeholders do not recognize and acknowledge other stakeholders framing issues differently, it becomes difficult to reach a shared solution (Gray, 2004; Mostert et al.,

2008; Thompson, 1997). The importance is therefore to recognize the existence of conflicting frames, develop an understanding of these frames and develop responses that takes all relevant frames into account.

This paper contributes to obtaining a better understanding of how issues in integrated river basin management are framed differently by involved stakeholders as a preparatory step for the development of a serious game. To gain this understanding, three research questions are addressed in this paper: (1) what are current complex challenges perceived by river basin management stakeholders; (2) what are river basin management stakeholders' envisioned resolution strategies to address these; and (3) what are river basin management stakeholders' underlying perspectives towards these challenges? To investigate the research questions, semi-structured interviews were conducted with river basin and floodplain management stakeholders. To explore the first and second research question, Dervin's Sense-making methodology was applied. Thereby, the interviews were set up and conducted following a user-centered, constructivist approach with a focus on both challenges and proposed resolution strategies from the respondents' point of view. To explore the third research question, the perspectives that respondents expressed towards these challenges were analyzed using Cultural Theory.

2.2 Theoretical framework

2.2.1 Sense-making methodology

Dervin's Sense-making is a generalizable methodology for studying how individual stakeholders construct meaning – or in effect frame – their surroundings (Dervin, 2003). First, it assumes the stakeholder is an expert in his or her world while acknowledging that there is other expertise which may be useful. Second, it assumes that the stakeholder is a theorist in his or her world and therefore has hunches, hypotheses and generalizations about how things are connected and how power flows (Dervin, 1999). As a user-centered approach, Sense-making focuses on identifying what individual stakeholders "really" think, feel, want [and] dream" (Dervin, 1998). In relation to natural resources management, Romanello (2003) executed Sense-making interviews and asked natural and social scientists to describe specific discussions over climate issues in which disagreement occurred. This application of Sense-making focuses on analyzing how individual stakeholders think, feel and question certain situations. Sense-making methodology was applied similarly in this study, informing the interview approach, one of the three different ways to apply Sense-making as a method (Dervin, 1999). Moreover, Sense-making was used to allow a respondent to put forward, construct and frame challenges as well as resolution strategies based on his or her own world.

In the interviewing method, Sense-making attends to constructivist assumptions by paying ‘empirical attention’ to the world of the respondents rather than the world of the researcher (Dervin, 2003). The respondent is seen as facing a gap arising out of a situation that prevents him or her from reaching a desired outcome. The gap needs to be bridged in order to reach this outcome (Dervin and Foreman-Wernet, 2012; Naumer et al., 2008). This way, Sense-making interviews incorporate a deliberate design that invites respondents to bridge gaps by drawing their own connections *"between past and present, present and future; relationships and impacts of power; the very value of formal information or lack of it"* (Dervin, 1999).

2.2.2 Cultural theory and perspectives

Cultural Theory (CT), as described by Thompson et al. (1990), explains how *ways of life* – social structures – maintain themselves – or fail to do so – following social-cultural viability. A main assumption behind the theory is that specific cultural profiles can be linked to individual perceptions. CT is based on two social dimensions coined by Douglas (1970): (1) whether an individual’s behavior is influenced by external rules (grid); and (2) whether an individual feels strongly about belonging to a group (group). Following these social dimensions as a 2x2 matrix, CT distinguishes four ways of life often referred to as rationalities: hierarchist, egalitarian, individualist and fatalist. Each rationality has its own ideal (stereotypical) world view, which are summarized in Table 2.1.

According to CT, these four world views act as *lenses* through which individuals observe the world as well as drive action. The theory therefore recognizes that individuals and social groups act differently under similar circumstances following differences in their underlying beliefs and values. Thompson et al. (1990) extended the grid-group based approach to the environmental domain, adding views on nature, resources and attitude towards risk to each rationality. Subsequently, CT has been applied in public policy studies in order to understand how both individuals and groups both interpret and address environmental challenges such as climate change (Verweij et al., 2006), environmental problems related to car use (Steg and Sievers, 2000) and renewable energy (West et al., 2010).

CT has also been extended to Dutch water and river basin management (Hoekstra, 1998; Middelkoop et al., 2004; Offermans, 2012; Valkering et al., 2009; Van Asselt et al., 2001). In this extension, most scholars focused on hierarchism, egalitarianism and individualism – the active rationalities – as fatalism – the passive rationality – withdraws itself from policy-making (asking: *"why bother?"*). Building on their work, the lenses of CT’s three active rationalities in relation to Dutch river basin management are summarized in Table 2.2.

Table 2.1 Overview of the world views of the Cultural Theory rationalities.

Cultural Theory rationality	World view
Hierarchist	<ul style="list-style-type: none"> Pursues a structured world with strong governmental responsibilities, laws and regulations Believes in strong structures where rules are followed and authorities obeyed Looks to establish stability in and controllability of the world
Egalitarian	<ul style="list-style-type: none"> Pursues a collective world wherein humans live in equality with each other and in harmony with nature Believes in strong communities with moral and ethical principles Looks to establish trust, cooperation and consensus
Individualist	<ul style="list-style-type: none"> Pursues a highly technological world based on innovations, opportunities and economic growth Believes in freedom, efficiency and self-determination Looks to establish a free market and take risks that offer rewards
Fatalist	<ul style="list-style-type: none"> Pursues a world where people are not occupied in worrying about the future Believes in the unpredictability of the world and the lack of possibility to change anything for the better Does not look to establish anything, instead asks 'why bother?'

As for the application of CT to Dutch water and river basin management, [Hoekstra \(1998\)](#) applied CT to develop perspectives on water based on the lenses of each way of life and subsequently derived future scenarios from these perspectives. Somewhat similar, [Middelkoop et al. \(2004\)](#) used CT to develop integrated scenarios for water and river basin management based on perspectives. In this approach, a perspective is a consistent and coherent description of: (1) how the world functions (world view); and (2) how policy should be carried out (management style).

[Offermans \(2012\)](#) developed the Perspective Method to analyze the role of perspectives and perspective change in river basin management. In this method, perspectives are derived by measuring positions – one for each active rationality – for a set of beliefs. For example, on the belief of water system organization, the hierarchist's position is control and regulation, the egalitarian's position is natural development and resilience and the individualist's position is opportunism and innovative technologies. Contrary to [Middelkoop et al. \(2004\)](#), perspectives in the approach of [Offermans \(2012\)](#) are therefore not stereotypical; they can be heterogeneous by

Table 2.2 Lenses of CT's three active rationalities in relation to Dutch river basin management.

Cultural Theory rationality	Views on river basin management
Hierarchist	<ul style="list-style-type: none"> • Stands for government regulation and control of both water and nature • Pursues sustainable river basin management based on win-win solutions • Flood safety is the top priority while leaving some room for economic and natural development • Decision-making should be based on expert set norms
Egalitarian	<ul style="list-style-type: none"> • Puts emphasis on the restoration of nature and ecology • Pursues sustainable river basin management where water and natural processes guide management strategies • Flood safety should be based on natural resilience • Decision-making should be based on participatory processes and participants in these processes should have an (more) equal voice
Individualist	<ul style="list-style-type: none"> • Stands for the free market and the use of the river for economic good • Pursues river basin management seeking innovative projects in pursuit of economic opportunities • Flood safety should be based on adaptation and innovation, viewing water as an opportunity • Decision-making should be based on the functioning of the free market and privatization

consisting of positions from multiple rationalities. The operationalized "Perspective Method" – a set of 15 beliefs and according positions – was used in combination with a serious game to measure participants' perspectives and perspective change in game sessions (Valkering et al., 2013). In this study, CT was applied similarly to Offermans (2012); using a set of beliefs to analyze the perspectives that river basin management stakeholders take towards challenges. Appendix 2.A provides an overview of beliefs and the respective positions that each rationality takes.

2.3 Integrated river basin management in the Netherlands

Following near-flood events of the Rhine and Meuse rivers in both 1993 and 1995, Room for the River (RftR) was developed as new national policy with a double objective of increasing flood safety through spatial measures and improving the spatial

quality of the riverine area by incorporating multiple objectives on other river functions (Klijn et al., 2013; Rijke et al., 2012; van Herk et al., 2012). Consequently, stakeholders from disciplines such as spatial planning, ecology and business have been introduced to Dutch river basin management, increasing its complexity (van Herk et al., 2012; Wiering and Arts, 2006; Wolsink, 2006). Through RftR's integrative approach, many floodplain areas have been developed as nature or cultural landscapes areas. As a result, the Dutch rivers and floodplains have been transformed from the former single function of agriculture into multifunctional riverine landscapes (Fliervoet and van den Born, 2017; Pahl-Wostl, 2006). 39 projects have been executed under the RftR program, most of which are either completed or nearly completed at the time of writing. RftR projects are therefore transitioning to their respective maintenance phases (Fliervoet and van den Born, 2017).

The Delta Program (DP) on the other hand is setting out the medium to long-term strategy (2050-2100 outlook) of Dutch water management in response to climate change (Deltacommissaris, 2011). In the context of its river component, DP is using RftR as an example for both collaborative and integrative strategies (Rijke et al., 2012). Similar to RftR, DP seeks to combine increasing flood safety with spatial quality. However, for DP spatial quality is not a secondary objective in itself and therefore not fully funded by the government. Rather, it seeks to combine flood safety measures with spatial development that other stakeholders – i.e. provincial governments, municipalities or NGOs – would like to see and contribute to financially. A second major difference between RftR and DP's river component is that where RftR only looked at spatial riverine measures, DP combines spatial measures with dike reinforcements. At the time of writing, the first short-term projects are being implemented which focuses on dike reinforcements and the long-term strategy is in its plan-making phase.

2.4 Method

To answer the research questions, interviews with a variety of river basin management stakeholders were conducted using a semi-structured protocol. Using the Sense-making interview method allowed respondents to focus on self-identified challenging situations and to construct their own views. To subsequently analyze these views, Cultural Theory was used to analyze these views and generate perspectives. The interviews were set up and executed in four phases:

1. Background questions related to respondents' work activities, their own visions on flood safety management, nature management and floodplain management as well as current trends they are observing in river basin management.

2. Contextual questions related to a challenging situation – identified by the respondents themselves – such as goals they had, other stakeholders they worked with and actions they took.
3. Specific questions related to the identified challenging situation such as what struggles they have or had, what concerned them and what questions they would like to see answered.
4. Envisioning questions related to resolution strategies to the identified challenging situation such as what would be their preferred outcome, what would help them achieve it and what would they do if given a magic wand.

2.4.1 *Selection of respondents*

Respondents were invited to participate using Table 1 from [Fliervoet and van den Born \(2017\)](#) on different river basin and floodplain management organizations as a starting point. Next, respondents were invited based on the criteria that they (1) have more than five years of experience in river and floodplain management; and (2) have a position with decision-making power in their organizations. The first criterion ensured that respondents have ample experience with the RftR policy and its integrative approaches. The second criterion ensured that respondents are involved in decision-making, both within their respective organizations and between organizations.

In total, 15 interviews were conducted, in each case by one interviewer; the first author of this paper. [Table 2.3](#) provides an overview of the interview respondents, the different organizations they represent and a categorization of their function.

One interview was conducted with two representatives of the same nature development organization (interview #2). The interviews were conducted face-to-face at the offices of the respondents. Thirteen respondents were male, three were female, which is representative for the gender division in the field. The interviews were executed between the 15th of July, 2016 and the 18th of November, 2016, lasted between 47 and 124 minutes, with an average of 80 minutes per interview, and were recorded for transcription and coding.

2.4.2 *Data analysis*

The interviews were analyzed in two steps. The first step concerned deductive coding following [Miles and Huberman \(1994\)](#). The first author acted as first coder and the second author as second coder. The first coder developed a coding scheme in iterations, which resulted in 12 themes and 66 categories below these themes. This scheme was subsequently used by both the first and second coder to code the interviews. Afterwards, memos were created to structure and analyze the information within themes and categories, structure links between categories as well as struc-

Table 2.3 Interview respondents and their organizations.

Interview #	Organization	Organization's focus in river basin management	Role in organization	Categorized Function	Experience in current function (years)
1	Agricultural Nature Association Rivierenland	Agriculture in combination with some nature management	Board member & farmer in a floodplain	Local agricultural manager	30
2	ARK Foundation Nature development organization	Nature management	1. Project leader & river team member 2. Project leader (retired)	Regional nature managers (2)	11 & 24
3	Municipality of Deventer	Local government	Environment & maintenance manager	Local governmental manager	5
4	Dutch Delta Program Rivers	Flood safety management (long-term planning)	Program coordinator Delta Program Rhine river	Regional governmental manager	2 *
5	Geldersch landscape and castles foundation	Nature management & cultural heritage	Region manager for the west region of the province of Gelderland	Regional nature manager	15
6	Ministry of Infrastructure and Environment	National government, policy-making towards flood safety	Senior policy advisor	National governmental manager	12
7	Ministry of Economic Affairs	National government, policy-making towards nature management	Manager river nature ambition	National governmental manager	13
8	Municipality of Nijmegen	Local government	Contract manager & maintenance advisor	Local governmental manager	7

Interview #	Organization	Organization's focus in river basin management	Role in organization	Categorized Function	Experience in current function (years)
9	Provincial Government of Gelderland	Regional government, setting up and stimulating nature development goals	Program leader region development	Regional governmental manager	21
10	Rijkswaterstaat, Dutch Public Works Authority	Flood safety management & managing the rivers' navigability	Senior advisor flood safety	National water manager	28
11	Rijkswaterstaat, Dutch Public Works Authority	Flood safety management & managing the rivers' navigability	Senior advisor Room for the River	National water manager	17
12	Rijkswaterstaat, Dutch Public Works Authority	Flood safety management & managing the rivers' navigability	Senior advisor water management	Regional water manager	7-8
13	Rijkswaterstaat, Dutch Public Works Authority	Flood safety management & managing the rivers' navigability	Senior advisor Room for the River	Regional water manager	9
14	Staatsbosbeheer, Dutch State Forestry Agency	Nature management	River ecology manager	National nature manager	9-10
15	Water board Rivierenland	Flood safety management (responsible for the dikes)	Flood safety specialist	Regional water manager	10

** Held previous positions that relate to river basin management at other organizations listed in this table.*

ture the respondents' answers and opinions. This way, current river basin management challenges were identified and respondents' envisioned resolution strategies analyzed, answering the first and second research questions.

To answer the third research question, the identified challenges were considered as a situation in which the respondents acted. Cultural Theory (CT) was subsequently used to understand how respondents view as well as address these situations based on how respondents' opinions, expressions of belief and proposed resolution strategies reflected CT's rationalities. As explained by [Hartmann \(2011, p. 41\)](#), the same respondent may act according to hierarchist rationality in one situation, but follow the individualist rationality in another. The analysis therefore does not assign one or multiple rationalities to a respondent, but analyzes how they act in regard to these situations. In the presented results, these views of respondents are presented as generalized perspectives. As such, these do not necessarily reflect CT's stereotypical rationalities; the perspectives can be non-stereotypical and reflect multiple rationalities. This approach was taken as the study analyses the reality of the identified challenges and in reality, both individuals and organizations do not follow CT's stereotypes, but rather follow beliefs of multiple rationalities ([Billgren and Holmén, 2008](#); [Thompson et al., 1990](#); [Verweij et al., 2006](#)). It was assumed that underlying beliefs and values at the individual level are equally found at the organizational level. The analysis approach taken resembles the operationalized Perspective Method of [Offermans \(2012\)](#), extending her 15 beliefs to a larger set of 53 relevant beliefs and positions of the three CT's active ways of life in relation to Dutch river basin management based on [Hartmann \(2011\)](#); [Hoekstra \(1998\)](#); [Middelkoop et al. \(2004\)](#); [Offermans \(2012\)](#); [Thompson et al. \(1990\)](#); [Valkering et al. \(2011\)](#); and [Van Asselt et al. \(2001\)](#). The overview of these beliefs and positions can be found in [Appendix 2.A](#). This overview was used as a coding scheme for the memos related to each identified challenge in the first analysis step to construct respondents' perspectives.

2.5 Identified challenges and diverging perspectives

Three challenges were identified in the interview analysis: (1) the challenge of creating flexibility in a controlled river system; (2) the challenge of sustaining the integrated approach in the maintenance of floodplains; and (3) the challenge of future river basin management policies to adapt to climate change. Below, each challenge is presented, combined with respondents' resolution strategies as well as generalized perspectives.

2.5.1 *The challenge of creating flexibility in a controlled river system*

The rivers in the Netherlands are considered a controlled system; the rivers are canalized and the hinterland is protected from extreme river discharges by floodplains and dikes. In Room for the River (RftR), the primary objective focused on creating space for water as a flood safety strategy and the secondary objective of developing

spatial quality put more emphasis on the rivers' floodplains by applying spatial measures as well as focusing on nature restoration. Here, respondents displayed diverging perspectives on how to manage the floodplains and specifically floodplains allocated to nature restoration. As multiple respondents explained, the main idea for these newly created nature areas is to let natural dynamics run their course up to a certain extent. But how do respondents approach management of these areas in an otherwise controlled river system?

The control perspective

In the control perspective, in particular water managers placed emphasis on creating clear boundaries on the extent of allowed natural dynamics in the nature areas. These respondents explained how allowing natural dynamics would cause vegetation to grow and hydraulic resistance of the floodplains to increase, limiting their discharge capacity. Therefore, respondents pointed out the necessity to keep vegetation in the floodplains under control. As one water manager explained: *"You do not want unwanted developments in the wrong locations. [...] How do you maximize natural dynamics on one hand and limit it for flood safety on the other?"*

As an example management solution to keep floodplain vegetation in control, respondents explained that the Public Works authority developed the so-called vegetation layer. This layer is a flood safety management instrument combining maps and rules, specifying what type of vegetation is allowed at which location in the floodplains. Basically, it establishes a norm for floodplain vegetation which may not be exceeded. As one water manager explained: *"The vegetation layer says how we, as the Public Works authority, allow vegetation to be in the floodplains."*

For the most part, respondents displayed the hierarchist rationality towards managing the floodplains in this perspective, showing a partial domination of nature, controllability as the desired system property and viewing the floodplains as controllable lands. The development of the vegetation layer is a response to safeguard the controllability of the system following the hierarchist rationality through institutionalizing as the risk-handling style and establishing thresholds that may not be exceeded.

The flexibility perspective

Where water managers in the control perspective emphasized the need for controllability of natural dynamics, nature managers and some governmental managers focused on allowing natural dynamics in the floodplains to run their course. Here, respondents explained how nature managers approach the floodplains radically different from water managers: *"Flood safety bases itself on the fixation of the*

current situation and the permitting of change. [Our] management is focused on system development that follows natural processes." These respondents expressed that it is more important to plan ahead and make sustainable developments possible. Although they acknowledged that water discharge is the main function of the floodplains and that thus flood safety is leading and agree that nature in the floodplains requires regulation, they called for more integrative approaches rather than manage flood safety and nature separately. In doing so, their call followed the egalitarian rationality, although also acknowledging elements associated with the hierarchist rationality.

In pursuit of more integrative approaches, respondents called for more flexibility to manage the floodplains and especially the newly created nature areas, expressing critique towards the vegetation layer. Some pointed out that it is quite static and conserving, determining the type of vegetation on each square meter and that such square meter fixation is not compatible with nature management's focus on floodplain development. Respondents also explained that compensation for vegetation management is similarly specified to every square meter based on costs for cutting, pruning and grazing for different vegetation types. Multiple respondents stated that this funding system is inflexible and counterproductive, not fitting with the approach for nature restoration focusing on system development. Combined, respondents subscribing to the flexibility perspective explained that the flood safety management methods are simply not compatible with nature management approaches: *"You can regulate what each square meter should look like and how we should maintain it, so they [the Public Works Authority] fall back on the vegetation layer and that is the safe way to guarantee flood safety."*

In the flexibility perspective, multiple respondents displayed the egalitarian rationality towards managing the floodplains; long-term, sustainable and pro-active solutions combined with more emphasis on integral management, nature development and resilience.

An attempt to bring perspectives together

In order to meet calls for more flexibility in floodplain management, water managers explained that the Public Works authority developed so-called mixed-types in the vegetation layer which specifies that an area can consist of multiple vegetation types given a more or less fixed partition, for example 10 percent of one type and 90 percent of the other. However, nature managers explained that these mixed-types do not provide them the flexibility as they are still presented with a spatial boundary; the mixed-types do not allow them to look for alternative measures to reduce the floodplain's hydraulic resistance outside the mixed-type's demarcated area. The solution

presented here is the introduction of new norms with a flexible component, following the hierarchist rationality. From the control perspective, this safeguards flood safety while providing flexibility. Respondents subscribing to the flexibility perspective however stated that their desired flexibility is not obtained as the fundamentals of the vegetation layer are still incompatible with nature management approaches.

Proposing resolution strategies

Respondents proposed multiple resolution strategies towards obtaining flexibility for nature restoration in a controlled river system. Two categories of strategies were identified. In the first category, respondents focused on increasing adaptivity in floodplain management. All mentioned the conserving perspective in current water and nature policies and management methods as obstructing. As an example, subscribers to both perspectives proposed more intensive vegetation management activities executed at longer intervals. A water manager proposed to perform rigorous vegetation management every 10 years over the current less intensive and preserving annual approach, putting less strain on the Public Works authority to monitor and manage floodplain vegetation. Another water manager proposed a similar strategy towards floodplain management in general, proposing to evaluate plans on whether they solve the bigger problem rather than comply with all rules and regulations. This line of argumentation focuses on the governmental regulation and managing its scarce resources, in line with the hierarchist rationality. Alternatively, nature managers suggested that when floodplain vegetation causes an increase in hydraulic resistance but also has ecological value, it should be possible to look for a solution – achieve water level reduction by reducing the hydraulic resistance – at a different location. They furthermore proposed to cut down vegetation altogether over reducing its hydraulic resistance to an acceptable level, mimicking natural processes that reset floodplain vegetation. More rigorous vegetation management is proposed by these nature managers as well, but in order to preserve developed nature in other locations. The line of argumentation here focuses on nature development where natural processes are guiding, following the egalitarian rationality.

In the second category, respondents discussed establishing integral river basin management organizations to replace the current fragmented governmental responsibilities. These respondents explained that these sectoral responsibilities are inefficient, counterproductive and leading to polarization. In their resolution strategies, subscribers to the control perspective proposed to form a single governmental management organization, integrally responsible for the river and floodplains. While they focused on governmental responsibilities for this management organization, associated with the hierarchist rationality, all cited increasing management effi-

ciency as the main driver, a view associated with the individualist rationality. In addition, a governmental manager also explicitly used another argument associated with the individualist rationality for the management organization: to pursue exploitation of the floodplain areas. Subscribers to the flexibility perspective also proposed to form single management organizations, however not necessarily governmental. They proposed floodplain management organizations on a more local or regional scale – single to a couple of floodplains – consisting of water and nature managers as well as local stakeholders. The proposed goals for these organizations are all in line with the egalitarian rationality: finding more sustainable and long-term solutions, creating more cohesion between water and societal aspects of river basin management and establishing more equality between stakeholders through participatory decision-making.

2.5.2 The challenge of sustaining the integrated approach in the maintenance of floodplains

Following the (near) completion of all RftR projects, many respondents reported on problems arising in the subsequent maintenance phase. Several respondents shared concerns that while RftR projects featured strong integral approaches in the plan-making, objectives might become impossible to achieve as a result of a lack of maintenance inclusion in plan-making. In the context of RftR, respondents pointed out a specific cause contributing to the lack of maintenance inclusion: the introduction of public tendering of floodplain areas. Before RftR, riverine projects were planned and implemented under the ownership of the Public Works authority with an intention to transfer floodplain ownership to a preselected terrain management organization. As a result of a state aid discussion, this transfer of ownership was no longer allowed. Instead, it had to be publicly tendered. Multiple respondents indicated that the introduction of public tendering during RftR added a market-oriented mechanism that worked against including maintenance in plan-making.

As an example, one RftR project discussed by multiple respondents was the Nijmegen-Lent project. A large project combining a dike relocation and a side-channel in the river Waal at the city of Nijmegen. A water manager explained how the State Forestry Agency was the intended terrain management organization for the floodplain area of the project. When it became apparent that ownership would not be transferred to the State Forestry Agency, but had to publicly tender for it instead, they withdrew themselves from the advising committee. The water manager explained that the public tendering discussion was not limited to the Nijmegen project: *"This change happened more or less during the plan-making of all RftR projects"*. As a result, input from the State Forestry Agency towards maintenance in

the project's plan-making and implementation was lost. In this instance, the State Forestry Agency acted along the fatalist rationality, withdrawing from the decision-making all together.

In addition, respondents explained that the introduction of public tendering meant the Public Works authority would retain ownership of RftR project areas. Following budget cuts, a financial dependency was created for the Public Works authority to generate revenue from its assets. A governmental manager explained how the objectives towards public use of the floodplains determined in the plan-making might become impossible. An example is the planned use of the floodplain area for public events: the cost for using the terrain became 20 times more expensive as the organizers were suddenly charged market rates. As expressed by multiple respondents, the introduction of public tendering changed the rules towards RftR projects' maintenance phases. In regard to this introduction of a market-oriented mechanism – associated with the individualist rationality – respondents displayed diverging perspectives.

The accepting perspective

On one side were water managers who focused their strategies on accepted public tendering as the given situation:

"Public tendering has become reality, thus we need to act accordingly. [...] But if you are an ecologist who deeply cares about the qualities of an area, then it is very painful to accept that these areas are no longer automatically transferred to the State Forestry Agency but are instead brought to the market, with the risk that a farmer will simply mow the grass, because that is a real possibility."

The same respondent proposed to bring areas to the market together with other stakeholders in order to at least agree on all the objectives pursued in the area. However, other stakeholders should financially contribute for pursuing goals – for example, nature development goals – which are not the responsibility of the Public Works authority. Another water manager would like to see that in a couple of years' time, an organization is found that performs maintenance activities and users are satisfied both with how the area has developed and how responsible authorities perform their roles, proposing more an ideal vision rather than a solution proposal. These respondents acted with the hierarchist rationality in regard to this challenge, but also showed elements of the fatalist rationality by accepting it is not going to change and stating it is not the responsibility of the Public Works authority. Their

proposed resolution strategies mainly reflect the hierarchist rationality in the procedural and sectoral approaches and searching for win-win solutions.

The rejecting perspective

Nature and governmental managers on the other hand looked to either reduce the – in their eyes – negative effects of public tendering or to remove the mechanism altogether. These respondents were critical of the segregation of project phases and the introduction of public tendering: *"You do not build a landscape for tomorrow, you build it for the future. [...] That means that you plan with maintenance in mind, not what others at time do, maintaining the plan."* The respondents specifically opposed the short-term contracts that public tendering introduced towards floodplain management. One nature manager explained how the six year contracts are much less interesting for the respondent's organization as they hold the philosophy to only manage terrains if they have durable ownership. These respondents expressed concerns following the egalitarian rationality towards public tendering such as negative consequences on sustainability as well as lack of long-term outlooks and pro-active strategies. One respondent proposed to make a governmental organization integrally responsible for the planning, implementation and maintenance of a project in order to sustain integral approaches. Another respondent stated that higher administrative levels should determine that a different economic profit model should apply to the public tenders if needed to make sure objectives determined in plan-making remain attainable. Although these respondents expressed concerns following the egalitarian rationality, they turn towards the hierarchist rationality of governmental responsibility and regulation to deal with the undesired, negative consequences.

2.5.3 The challenge of future river basin management policies to adapt to climate change

In regard to future challenges, several respondents discussed climate change in relation to river basin management. Some water and governmental managers extensively focused on the challenge of future river basin management policies to adapt to climate change. The challenge is related to the Delta Program (DP), which, as explained in the background section, uses RftR as an example for its river component. However, respondents pointed out two major differences, differences which currently lack specifications. Firstly, RftR's two objectives on flood safety and spatial quality were paid for by the same stakeholder: the Dutch national government. However, DP looks at *"combining efforts"*; if an opportunity arises to combine spatial

developments, other stakeholders are asked to contribute financially. As a governmental manager stated: *"This causes a discussion on cost sharing and that is of course a whole other principle than we had in RftR."*

Secondly, a different approach to flood safety management is taken in DP. Whereas RftR only looked at spatial measures for its flood safety measures, DP looks to, as respondents summarized, *"develop a powerful combination of spatial measures and dike reinforcements."* However, they pointed out that DP does not include a specification of how much spatial measures or dike reinforcements should each contribute to DP's objective of flood safety. As a water manager explained:

You can achieve flood safety targets with dike reinforcement and with spatial measures. And which targets you solve with which kind of measures is not specified. In RftR it was simple, you reach all targets through spatial measures unless it is impossible to reach this way.

The preference strategy

Combined, respondents discussed how these two non-specifications are causing uncertainty in the development of future river basin management plans. As an example, a province was asked to develop a *"preference strategy"*; a plan that combines dike reinforcements and spatial measures to achieve DP's long-term flood safety objectives (2050-2100). The province developed the strategy, but it was subsequently rejected by the DP management as the strategy was too expensive, it had to be adjusted. A water manager explained that the preference strategy therefore became *"a guiding compass"*; a map of how much water level reduction could be achieved, instead of a decision.

Another water manager expressed critique towards the rejection of the preference strategy as it made it uncertain whether or not spatial measures in the strategy are going to be implemented. As a result, water boards do not know the water levels for which they need to reinforce their dikes to comply with new protection norms as some of these dikes are in locations where spatial measures are planned in the preference strategy. Other respondents recognized this need to decide on whether or not spatial measures are going to be executed:

"If you do not make arrangements, the water boards will understandably heighten the dike to the maximum necessary height. [...] But then you do not need spatial measures anymore, at least, not for the water level reduction targets. While you can achieve many other targets through spatial measures and it makes the river system more robust."

A water manager however explained that the costs to achieve the same level of flood safety through dike reinforcement is far lower than through spatial measures, adding: *"The minister [of Infrastructure and Environment] takes a sober and effective approach, so you can imagine what the choice between dike reinforcement and spatial measures should be."*

Respondents did not display multiple perspective towards this challenge. For the most part, respondents displayed the hierarchist rationality towards this challenge, expressing predominantly positions such as expert norms as the primary motives for action, government regulation as management mechanism and water management focused on win-win solutions.

Resolution strategies to make decisions

In targeting this challenge, respondents also expressed the hierarchist rationality in their resolution strategies. Moreover, they all showed similar lines in their strategies. Overarching in all of these were the need to come to agreements on what measures are going to be taken. Specifically, the respondents stated that securing finances for long-term plans as one of the important aspects towards resolving the challenge. On this point, respondents advocated that the national government should make funds available for spatial measures to reach the requested agreement on measure implementation and provide water boards with the desired certainty. A respondent proposed to execute dike reinforcement and spatial measures projects as part of one organization in order to approach an area as one project instead of multiple projects in an area. In addition, this respondent would like to see more *"rules of play"* for the DP plan-making similar to those that existed in RftR. Another respondent echoed this view and proposed to formulate clear boundary objectives for decision-making, for water management, but also towards for example required nature development.

2.6 The framing of challenges and divergent perspectives

In this research, Sense-making methodology and Cultural Theory (CT) were combined to identify the challenges and analyze respondents' perspectives. The application of Sense-making enabled respondents to put forward and construct the challenges, their perspectives towards these and possible resolution strategies themselves. Cultural Theory subsequently enabled the analysis of how stakeholders frame both the challenges and their resolution strategies by analyzing the rationalities they used towards these situations. The combination proved to be a suitable approach to gain insight into and understand how issues are framed in river basin management. Moreover, the combination enabled the empirical assessment of the rationalities stakeholders use in framing a situation, rather than confirming the

researcher's beliefs (Billgren and Holmén, 2008). Furthermore, the combination provided a methodology using the complementation of "intensive explication" and "comparative generalizations"; an in-depth case study of a system and its stakeholders and limited generalizations regarding identifiable patterns respectively (Morrow and Brown, 1994, p. 211-212).

2.6.1 *Divergent perspectives following the introduction of uncertainty*

The identified challenges and divergent perspectives show how stakeholders frame changes to river basin management differently. Verweij et al. (2006) argue that at least three divergent perspectives exist that frame the issue – defining the problem and suggesting solutions in policy problems – corresponding to the three active rationalities in CT. However, in the results presented in this paper, only one or two distinctive perspectives on each challenge were identified. This may be explained by the limited representation of private organizations in both Dutch river basin management and the executed interviews that could be expected to frame these challenges using the individualist rationality. According to Thompson (2008), uncertainty is a prerequisite for divergent perspectives to emerge. In all three challenges, new sources of uncertainty are added to existing river basin management discourses asking for a response.

The challenge of creating flexibility in a controlled river system

The challenge of creating flexibility in a controlled river system relates to how newly created nature areas in the floodplains should be managed. In these areas, natural dynamics are allowed to run their course up to a certain extent. The unpredictable natural dynamics could however lead to an increase in hydraulic roughness of floodplains, adding uncertainty to flood safety management. In response, water managers frame the issue from the hierarchist rationality as needing to control the natural dynamics. Nature managers, on the other hand, frame the issue from the egalitarian rationality by focusing on allowing natural dynamics to run their course. In particular, water managers employ a fixation point of view while permitting change – focusing on controllability – and nature managers take a development point of view based on natural processes – focusing on sustainability – which seems incompatible. Yet, both water and nature managers agree that water discharge is the main function of the floodplains. Similarly, they both consider the floodplains as controllable lands and agree that nature in the floodplains requires regulation. The challenge seems purely rooted in the execution of floodplain management and regulation of nature restoration, not in a split point of view on its necessity. These results are in line with Wiering and van de Bilt (2006), who predicted that water and nature management

in the Dutch floodplains could become a marriage where spouse clash in the daily housekeeping, particularly when the maintenance aspect of floodplains comes in. The challenge also reflects results of [Fliervoet et al. \(2013b\)](#), who looked specifically at – as they defined it – the “*nature-safety dilemma*” and showed that floodplain management stakeholders are looking for more flexibility in river and nature policies. Moreover, they showed that the current static and conserving approaches in Dutch river basin management – exemplified in this paper by the vegetation layer – are not compatible with more adaptive floodplain management concepts.

The challenge of sustaining the integrated approach in the maintenance of floodplains

In the challenge of sustaining the integrated approach in the maintenance of floodplains, the introduction of public tendering to RftR added a market-oriented mechanism – associated with the individualist rationality – to floodplain management policy. Following this introduction, organizations now have to publicly tender for short-term contracts to manage the floodplain areas following the completion of RftR projects. As a result, it is no longer certain who or which organization would manage the floodplain areas. Governmental and nature managers rejected the introduction of public tendering as it introduced negative consequences towards their desire of pursuing sustainability, creating long-term outlooks and implementing pro-active strategies, framing the issue using the egalitarian rationality. Water managers on the other hand accepted public tendering as the new reality and looked for solutions that suits all involved while stressing that it is not their responsibility to pursue other goals such as nature development, framing the issue from both the hierarchist and fatalist rationalities. Similar to the results presented here, [Fliervoet et al. \(2017\)](#) also noted the effects of public tendering to floodplain management. Through an unsuccessful pilot study on collaborative floodplain management, they showed that the public tendering was obstructing to establish collaborative arrangements and could possibly exclude nature management organizations. Furthermore, they showed that it leads to segregation of activities rather than integrated floodplain management.

The challenge of future river basin management policies to adapt to climate change

In the challenge of future river basin management policies to adapt to climate change, lack of specifications in the river component of the Delta Program (DP) in comparison to RftR added uncertainty towards taking decisions. Firstly, RftR's primary objective, increasing flood safety, had to be reached only using spatial measures unless this was not possible. DP instead combines dike reinforcement

and spatial measures to increase flood safety, but lacks specification on how much each should contribute. Secondly, spatial quality was an objective fully paid for by the national government in RftR. Spatial quality is however not a DP objective and stakeholders who want spatial quality developed are asked to financially contribute to DP projects. Combined, the lack of specifications has resulted in the postponement of decisions. A consequence feared by respondents is that water boards will execute dike reinforcement to maximum necessary height to meet the flood safety norms, making spatial measures unnecessary. The challenge therefore relates to lengthy decision-making and the need to come to decisions. The challenge however relates to taking decisions – it is less important what these decisions are – in order for all stakeholders to know what they can expect.

The existing lack of specifications obstruct the respondents' desires of expert norms as the primary motives for action, government regulation as management mechanism and water management focused on win-win solutions. The respondents therefore all displayed the hierarchist rationality in relation to this challenge, whereas the other challenges displayed two perspectives each. This result may be attributed to a limited amount of respondents addressing this challenge in their interviews. Alternatively, it may explain why the challenge exists in the first place. As noted by [Van Asselt et al. \(2001\)](#), the hierarchist water management style pursues win-win situations, but avoids making real choices. As a result, decision-making can get stuck in conferences and become sluggish. [Schwartz \(1991, p. 765\)](#) explains how the CT's rationalities undermine themselves if left unchecked: *"Hierarchies, in turn, would be stagnant without the creative energy of individualism, incohesive without the binding force of equality, unstable without the passivity and acquiescence of fatalism."* The existence of the challenge may therefore be explained by the fact that the non-hierarchist rationalities are insufficiently represented.

2.6.2 A call for clumsiness and learning

In all challenges, divergent perspectives were socially constructed towards new situations in river basin management following the introduction of new sources of uncertainty. That divergent perspectives exist in these situations is however inevitable and even desirable; it indicates that the challenges matter ([Verweij et al., 2006](#)). [Verweij et al. \(2006\)](#) furthermore explain that each perspective tells a plausible, but selective, story. It is therefore not a debate about which perspective is right or wrong: *"If you're having to ask who's right (worse still, if you already know who's right), you're wrong!"* ([Thompson, 1997, p. 209](#)). Formulating a response based on only one perspective will therefore be only a partial solution at best and an ineffective, counterproductive solution at worst. For all challenges, it is therefore necessary to develop suitable

responses that make sure all stakeholders' rationalities are taken into account and all stakeholders have something to take home. Such responses where all rationalities are included and acknowledged by others are called "*clumsy solutions*" (Hartmann, 2011; Thompson, 2008; Verweij et al., 2006).

The vegetation layer, discussed extensively in relation to the challenge of creating flexibility in a controlled river system, is – in its current form – an example of a solution based on one perspective; it is not (yet) a clumsy solution. It is a typical command and control type of solution that satisfies water managers' desired hierarchist fundamentals, but fails to include nature managers' desired egalitarian fundamentals.

In order to develop clumsy solutions, the starting point to formulate policy responses should not be cost-benefit analysis or probabilistic risk assessment, but the understanding of the contending social framings of both the issue and the solution. (Thompson, 1997; Verweij et al., 2006). New tools – classified as the "*other tool-kit*" by Thompson (1997) – are therefore needed to enable stakeholders to not only express their own perspectives, but also to recognize and understand those of others. Ignoring these contending frames may lead to conflicts remaining unresolved (Mostert et al., 2008).

2.6.3 *Developing a serious gaming environment*

One category of tools that are able to facilitate the interaction and exchange of perspectives between stakeholders are learning environments. Learning environments support stakeholders to understand the diversity of frames used in decision-making process in order to help resolve conflicts and formulate collective action (Keen et al., 2005; Pahl-Wostl et al., 2007a). Ultimately, these environments should contribute to improving the efficiency, effectiveness and democratic legitimacy of decision-making (Sørensen and Torfing, 2017). A serious gaming environment (SGE) – a learning environment facilitated through a serious game – is seen as a suitable method for river basin management stakeholders to collaboratively explore challenges and debate responses under the inherent uncertainties found in river basin management (Valkering et al., 2013). In a SGE, players can play a role in river basin management other than their own in a safe environment – a game – making them familiar with other perspectives. This way, a SGE provides the necessary ingredients for *policy-oriented learning* as stakeholders have – and are in a way forced – to consider other perspectives (Sabatier and Jenkins-Smith, 1993) and *social learning* as it facilitates an inclusive, communicative and participatory process where stakeholders can exchange perspectives (Keen et al., 2005; Koppenjan and Klijn, 2004; Rist et al., 2006).

The research presented here serves as a preparatory step in the development of such a SGE for Dutch river basin management. Specifically, the identified challenges provide a scope for the SGE, providing input for gaming scenarios where stakeholders have to consider and discuss each other's perspective towards: (1) the need for flexibility versus control; (2) how to include the maintenance aspect of riverine projects in plan-making; and (3) decide about the balance between dike reinforcement and spatial measures towards achieving river basin management goals. Furthermore, the identified perspectives and resolution strategies inform player roles as well as game rules and options. As a next step, a case study will be set up in order to co-develop the SGE with relevant stakeholders.

2.7 Conclusion

The research presented in this paper aimed to identify shared challenges that river basin management stakeholders experience towards integrated river basin management in the Netherlands as well as the stakeholders' perspectives towards these challenges. The objective was to gain a better understanding of how issues are framed in integrated river basin management differently by involved stakeholders. Combining Sense-making and Cultural theory proved a suitable approach to gain this understanding. A strength of the approach is that it enabled an in-depth case study focused on the "world" of the respondent rather than the researchers, while able to make generalizations. The combination could be a useful approach towards understanding how stakeholders frame issues in contested policy areas other than river basin management as well. To utilize its full potential however, it is important to make sure all voices are represented in the study.

Three challenges were identified in the analysis. The first challenge, creating flexibility in a controlled river system, relates to managing nature restoration areas in the floodplains. Water managers emphasize the need for controllability of natural dynamics in these areas, while nature managers point out the need for sustainability by allowing natural dynamics to run their course. Both acknowledge that nature in the floodplains requires regulation to safeguard flood safety. Therefore, the challenge seems purely rooted in the execution of floodplain management and regulation in relation to nature restoration, not in a split point of view on its necessity.

The second challenge, sustaining the integrated approach in the maintenance of floodplains, relates to the fact that the introduction of publicly tendering of floodplain areas added a market-oriented mechanism that works against including the maintenance aspect in plan-making. As a result, river basin management stakeholders worry that floodplain areas are not going to develop as intended in the plan-making.

The third challenge, future river basin management policies to adapt to climate change, relates to two non-specifications in the Delta Program which are causing decisions in its plan-making to be postponed: (1) the lack of specification how much dike reinforcement and spatial measures should each contribute to flood safety objectives; and (2) the lack of including spatial quality development as a clear Delta Program objective. The challenge relates to taking decisions over postponing them – it is of less important what these decisions are – in order for all stakeholders to know what they can expect.

The results presented show how stakeholders use different rationalities in constructing perspectives following the introduction of new sources of uncertainty. Moreover, the results show how existing policy responses towards the challenges are based on only a single perspective and insufficiently incorporates other perspectives. As an implication, it is important for all stakeholders to consider and include these perspectives in integrated river basin management decision-making. Current tools like cost-benefit-analysis or probabilistic risk assessment ignore this essential aspect in the decision-making process. Therefore new tools are needed that facilitate stakeholders to express their own perspectives and help to recognize and understand the perspectives of others. Learning environments like a serious gaming environment are believed to have the potential to provide this facilitation.

Appendix 2.A

Cultural Theory beliefs and positions in relation to river basin management.

General beliefs and positions					
Belief	Hierarchist position	Egalitarian position	Individualist position	Fatalist position	Source
Position of man	Man partially dominates nature	Man is part of nature	Man dominates nature	Man has no influence on nature	Thompson, 1990
Primary motives for action	Expert norms	Collective interests	Self-interests	Surprises	Thompson, 1990
Myth of nature	Tolerant (disturbances have effect, but are not uncontrollable)	Fragile (disturbances break the fragile dynamic equilibrium)	Robust (disturbances have effect, but are of minor importance)	Capricious (disturbances have unknown effect, nature is random and unpredictable)	Thompson, 1990; Hoekstra, 1998
Risk	Risk-acceptance	Risk-averse	Risk-seeking		Thompson, 1990
Risk-handling style	Institutionalization	Reduction	Taking the opportunities	Acceptance	Hoekstra, 1998
Salient risks	Loss of control	Catastrophic developments	Threats to the free market	Surprises	Hoekstra, 1998
Management style / philosophy	Control, regulatory	Prevention	Adaptation	Passive	Thompson, 1990; Hoekstra, 1998
Management objectives	Social stability and safety	Environmental protection and equity	Economic growth and self-realization	No objectives, adjust to changes	Thompson, 1990

General beliefs and positions					
Belief	Hierarchist position	Egalitarian position	Individualist position	Fatalist position	Source
Management mechanism	Government regulation	Participatory decision-making	Free market	No preference, does not matter anyway	Thompson, 1990
Management responsibility	National & European governments	Regional governments & NGOs	Private sector & individuals	Individuals make their own decisions	Valkering et al., 2011; Offermans, 2012
Important values	Structure & stability	Harmony & solidarity	Freedom & independency	Comfort & pleasure	Offermans, 2012
Rationality	Procedural	Critical	Substantive	Fatalistic	Hoekstra, 1998
Knowledge	Almost complete, organized	Imperfect, holistic	Sufficient, timely	Irrelevant	Hoekstra, 1998
Needs	Given, unmanageable	Social, manageable	Individual, manageable	Unmanageable	Hoekstra, 1998
Resources	Scarce, manageable	Depleting, unmanageable	Abundant, manageable	Lottery, unmanageable	Hoekstra, 1998
Learning style	Anticipation	Trial without error	Trial and error	Luck	Hoekstra, 1998
Desired system's properties	Controllability	Sustainability	Exploitability	Capability	Hoekstra, 1998
System response	Re-active (defensive strategies)	Pro-active (preventive strategies)	Opportunity seeking	Cope with surprises	Hoekstra, 1998
Ideal scale	Large	Small	Appropriate	No preference	Hoekstra, 1998

General beliefs and positions					
Belief	Hierarchist position	Egalitarian position	Individualist position	Fatalist position	Source
Climate change (attitude)	Climate is sensitive, changes must be expected, additional research is required	Climate is very sensitive, large changes must be expected	Climate is insensitive, some changes anticipated	Climate may change or not, what will be will be*	Middelkoop et al., 2004
Climate change (expectation)	Average trend	Extreme trend (worst-case)	Low trend (best-case)	Not identifiable	Valkering et al., 2011; Offermans, 2012
Socio economic development	Average growth	Weak growth	Strong growth	Not identifiable*	Valkering et al., 2011

River basin management specific beliefs and positions					
Belief	Hierarchist position	Egalitarian position	Individualist position	Fatalist position	Source
Water	Manageable resource	Public property	Economic Good	Water is given to the rich	Hoekstra, 1998
Water problems vs manageability	Serious problem, but manageable	Serious problem, not manageable	No problem	Useless to consider	Offermans, 2012
Value of water	Diversity of functions	Well-being	Welfare	Comfort & pleasure*	Valkering et al., 2011
Water supply	Demand driven	Supply driven	Market driven	Remain the same, useless to consider	Hoekstra, 1998; Offermans, 2012
Water priorities	Preservation of current function	Compensation & ecology	Innovation & economy	Comfort & providing individual with enough supply	Offermans, 2012

River basin management specific beliefs and positions					
Belief	Hierarchist position	Egalitarian position	Individualist position	Fatalist position	Source
Water system organization	Control & regulation	Nature development & resilience	Opportunism & innovative technologies	Passive, interference is useless	Valkering et al., 2011; Offermans, 2012
Water management	Sustainable water management, win-win solutions and negotiations, time horizon varies depending on function (10-50 years)	Pro-active, sustainable water management with long-term horizon (> 50 years)	Short time horizon planning (10 years)	Enjoy water here and now (no outlook)*	Middelkoop et al, 2004
River function priority	Safety has priority	Society will adapt to environment, not vice versa	Environment can be exploited for economic use	Comfort & pleasure have priority*	Middelkoop et al, 2004
Floodplain function priority	Discharge of water	Nature and space	Prosperity	Pleasure*	Valkering et al., 2013
Floodplains	Controllable land; engineering solutions based on regulations, rules and norms	Dangerous land; landowners must be protected	Profitable land; free choice of land use	Inconspicuous land; floodplains are just land that require no special attention	Hartmann, 2011

River basin management specific beliefs and positions					
Belief	Hierarchist position	Egalitarian position	Individualist position	Fatalist position	Source
Floodplain management	Command and control; certain thresholds may not be exceeded (thus: building regulations, technical norms)	Retraction and protective measures	Innovative and risky approaches (e.g. floating homes)	Flood risk cannot be controlled, accept risk and make the best of it	Hartmann, 2011
Perspective on nature	Regulation of nature	Prevention and treat ecosystems with great care	Nature is benign	Enjoy nature*	Thompson et al. 1990; Offermans, 2012
Approach to nature	Nature is vulnerable, but can be managed by defining adequate standards	Nature is vulnerable	Economy is more important than nature	Nature is unpredictable*	Thompson et al. 1990; Middelkoop et al, 2004
Nature management	Based on standards	Natural processes are guiding	Cost-benefit analysis and economic risk assessment guide water management	No policy*	Middelkoop et al, 2004
River nature (development)	Conservation	Compensation & ecology	Exploitation	What will be, will be*	Valkering et al., 2011
Land use (spatial planning)	Water follows; preservation of existing space	Water is guiding; functions follow water, give up space if necessary	Water offers opportunities; functions utilize water, creation of space on water	Water should be used for comfort & pleasure	Valkering et al., 2011; Offermans, 2012

River basin management specific beliefs and positions					
Belief	Hierarchist position	Egalitarian position	Individualist position	Fatalist position	Source
Flood risk	Flood risk levels vary depending on development of area (divergent risk levels)	Flood risk levels are equal for all locations (equal risk principle)	Flood risk levels reduction based on economic trade-offs (economic trade-offs)	Flood risk levels are irrelevant; accepting flood-ing may occur (risk acceptance)	Hoekstra, 1998
Flood safety	Flood prevention	Avoid flood prone areas	Adaptation and innovation	Interference is useless	Valkering et al., 2011
Damage due to flooding	Should be prevented, otherwise refunded by government	Matter of solidarity; everyone is financially responsible	Matter of individual responsibility; known risk of living in flood prone areas	Why bother to consider before it happens	Offermans, 2012
Response to drought	Following guidelines & laws	Fair distribution between nature and human consumption	Market forces; rising prices in times of scarcity	Why bother to consider before it happens	Offermans, 2012
Level of integrality	Sectoral	Integral	Competition	Irrelevant*	Valkering et al., 2011
Decision-making based on	Norms & expert knowledge, research	Participatory processes with input of all stakeholders	Functioning of free market and privatization (cost-benefit analyses)	No decision-making, waste of time	Valkering et al., 2011; Offermans, 2012
Time outlook	Mid-term	Long-term	Short-term	Now	Offermans, 2012
Identity and knowledge	National identity & traditional export product	Catchment identity & solidarity	International identity and innovative image	Individuals own identity and pleasure	Valkering et al., 2011; Offermans, 2012

River basin management specific beliefs and positions					
Belief	Hierarchist position	Egalitarian position	Individualist position	Fatalist position	Source
Flood acceptability	Low	High	Medium	Why bother*	Offermans, 2012
Flood damage acceptability	Medium	High	Low	Why bother*	Offermans, 2012
False alarms acceptability	Low	High	Low	Why bother*	Offermans, 2012
Shipping suitability	Medium	Low	High	Why bother*	Offermans, 2012
Nature area and diversity	Medium	High	Low	Why bother*	Offermans, 2012

Chapter 3

On evaluating social learning outcomes of serious games to collaboratively address sustainability problems: A literature review

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Abstract

Serious games are increasingly explored as collaborative tools to enhance social learning on sustainable management of land and natural resources. A systematic literature review was conducted to examine the current state of the art of the different methods and procedures used to assess social learning outcomes of collaborative serious games. 42 publications were identified and included in the review following study selection and quality assessment steps. Extracted data from the publications were categorized in relation to five research questions. Approaches that were used to assess cognitive, normative and relational learning outcomes of collaborative serious games were subsequently identified based on the categorizations. As a result, these approaches distinguish between the nature of learning in the assessment of collaborative serious games. Combined, these approaches provide an overview of how to assess social learning outcomes of collaborative serious games, including the methods and procedures that can be used, and may serve as a reference for scholars designing and evaluating collaborative serious games.

3.1 Introduction

Environmental sustainability problems are typically complex and multi-scale, concern inherent uncertainty and affect multiple stakeholders and agencies. Solving sustainability problems concerns the management of land and natural resources in a way that creates and maintains prosperous social, economic, and ecological systems (Folke et al., 2002). To address such problems, decision-making needs to be adaptive to deal with the uncertainties and needs to include the diversity of knowledge and values of all affected stakeholders. To achieve this, scholars have advocated active experimentation and continuous evaluation, summarized as learning-by-doing, in natural resources management (Armitage et al., 2007; Berkes, 2009; Pahl-Wostl, 2007; Rodela, 2011). Central to these approaches is collaboration between and learning among researchers, resource managers and resource users in order to find sustainable solutions (Crona and Parker, 2012; Folke et al., 2002; Folke et al., 2005; Olsson et al., 2004).

Learning, in particular social learning, is therefore seen as a prominent driver and normative goal in natural resources management (Armitage, 2005; Armitage et al., 2008; Berkes, 2009; Pahl-Wostl, 2006; Reed et al., 2010). Although there is debate to find a commonly shared definition for social learning (see e.g. Cundill and Rodela, 2012; Muro and Jeffrey, 2008; Reed et al., 2010; Rodela, 2011), scholars increasingly agree that social learning has occurred when a change in understanding – related to for example the system, problem at hand, agreement and collective action – is achieved through interaction in collaborative and participatory settings (Baird et al., 2014; Keen et al., 2005; Muro and Jeffrey, 2008; Pahl-Wostl et al., 2007a; Reed et al., 2010). Social learning outcomes therefore require deliberative interactions, where multiple stakeholders work together and build relationships, which should ultimately lead to collective action (Cundill and Rodela, 2012; Keen et al., 2005; Pahl-Wostl et al., 2008). Baird et al. (2014) define three types of learning outcomes in relation to social learning: cognitive – the acquisition of new or restructuring of existing knowledge – normative – a shift in viewpoints, values or paradigms – and relational – an improved understanding of others' mind-sets and enhanced trust and ability to cooperate between stakeholders.

Serious games are increasingly explored as a method to establish social learning on sustainable natural resources management and urban planning (Ampatzidou et al., 2018; Furber et al., 2018; Marini et al., 2018; Medema et al., 2016). Serious games are generally referenced to as games that have a primary purpose other than entertainment, such as educating, training or informing players (Abt, 1970; Michael and Chen, 2005; Susi et al., 2007). More specifically towards policy-making, Mayer (2009, p. 825) defines games as *"experi(m)ent(i)al, rule-based, interactive environments,*

where players learn by taking actions and by experiencing their effects through feedback mechanisms that are deliberately built into and around the game". A recognized strength of such serious games is that games can include both the techno-physical complexity – the underlying physical elements of the system and its uncertainties – and the socio-political complexity – the strategic interactions between stakeholders in the policy arena – by combining role-play with in-game feedback mechanisms (Bekebrede, 2010; Marini et al., 2018; Mayer, 2009; Medema et al., 2016). Therefore, serious games fit well with the learning-by-doing approach in natural resources management; serious games offer stakeholders a place to negotiate, deliberate, exchange perspectives used in decision-making and learn about the trade-offs between decisions in the safe experimentation environment of a game (Bekebrede, 2010; Mayer, 2009). Moreover, multiplayer and multi-role serious games thereby offer the collaborative and participatory stakeholder interactions that are needed to establish social learning (Ampatzidou et al., 2018; Medema et al., 2016). The term collaborative serious games is used in the remainder of the paper to refer to serious games that follow the above definition by Mayer (2009), but are particularly focused to collaboratively – through mutual engagement of stakeholders in a coordinated effort to solve the problem (Roschelle and Teasley, 1995, p. 70) – explore sustainable management strategies.

The assumption is that any learning that occurs from playing collaborative serious games is transferable to the world outside the game (Geurts et al., 2007; Mayer, 2009). A collaborative serious game can therefore be seen as an intervention, or a transitional object (Geurts et al., 2007), that may lead to social learning outcomes. While calls exist for more systematic assessment of learning through serious games (see i.e. Mayer et al., 2014), assessing social learning outcomes of collaborative serious games is challenging. On a practical level, gathering data occurs in a collaborative setting that introduces many confounding variables such as players' prior relations, players' attitudes towards serious gaming and facilitators who have to make decisions on the spot while guiding sessions (de Caluwé et al., 2012; Hofstede et al., 2010; Mayer et al., 2014). On a higher level, the lack of consensus on the definition of social learning itself has made it difficult to assess (Crona and Parker, 2012) and indeed few studies empirically and directly assess the learning effects of interventions (Armitage et al., 2008; Baird et al., 2014; Rodela, 2011).

The research presented in this paper adds to this gap by answering the main research question: What is the current state of the art of the different methods and procedures used to assess social learning outcomes of collaborative serious games? To this end, a systematic literature review was conducted to survey the empirical assessment of social learning through collaborative serious games. As such, the contribu-

tions of this paper include: (1) Summarizing and categorizing different evaluation procedures applied and methods used to assess social learning outcomes of collaborative serious games; and (2) presenting a state of the art overview of approaches to assess social learning outcomes of collaborative serious games.

The next section presents the method of the systematic review and describes all the steps taken in detail. Sections three and four cover the search and categorization results of the review respectively. Section five discusses approaches used to assess cognitive, normative and relational learning outcomes of collaborative serious games. Section six finally sums up the conclusions drawn from the review and provides an overview of the identified assessment approaches.

3.2 Materials and methods

To perform the literature review, the guidelines by [Kitchenham and Charters \(2007\)](#) – an updated version of [Kitchenham \(2004\)](#) – were used. These guidelines are an established procedure for conducting systematic reviews, particularly in software engineering. Although collaborative serious games are not exclusively digital – a board game can also be used to explore sustainable management solutions – the use of these guidelines is appropriate as many serious games do make use of software and the guidelines are based on guidelines used in other disciplines.

[Kitchenham and Charters \(2007\)](#) prescribe three phases of a systematic review: planning, conducting and reporting. The planning phase covers confirming the need for a review, defining the research questions and producing a review protocol. The conducting phase involves developing a search strategy, executing as well as documenting the search, performing a study selection and extracting data relevant to the research questions. The reporting phase then covers reporting and disseminating the results of the study. In the next subsections, all the steps taken in performing the systematic literature review are described.

3.2.1 Related work

As a starting point in the study, a search was executed to confirm the need for a review. One literature review, by [Calderón and Ruiz \(2015\)](#), on the different methods and procedures used to evaluate serious games was identified in this step. Notably, the serious games included in this review are mostly evaluated using a questionnaire as the main assessment method and are mostly evaluated on the educational effectiveness – defined by [Calderón and Ruiz \(2015\)](#) as the learning outcomes, usability and user's experience. The study is similar in terms of its scope and research questions covered, but lacks the focus on social learning and the policy setting. The study

was therefore used as a reference for the overall search strategy, such as to sharpen the research questions and to formulate inclusion and exclusion criteria. Other reviews, both literature and meta reviews, focused on the effectiveness of serious games (Backlund and Hendrix, 2013; Boyle et al., 2016; Connolly et al., 2012; Girard et al., 2013; Wouters et al., 2009), not on the assessment procedures.

In addition to these studies, five review papers were identified which focus on serious games in relation to sustainable development (Katsaliaki and Mustafee, 2012), climate change (Flood et al., 2018; Reckien and Eisenack, 2013; Wu and Lee, 2015) and sustainable water resources management (Aubert et al., 2018). While these do not review the assessment approaches of learning outcomes, the serious games reviewed in these papers do all relate to sustainability and may therefore be of interest to this review. These studies were therefore used to inform the search strategy, for example to define keywords, and as snowball resources.

Concluding, no review was found that focuses specifically on evaluating collaborative serious games and this study therefore adds an in-depth review with this explicit focus to the literature.

3.2.2 *Research questions*

To examine the current state of the art of the different methods and procedures used to assess social learning outcomes of collaborative serious games, the following research questions were addressed to analyze publications:

- RQ1. How is learning through collaborative serious games conceptualized?
- RQ2. When is data collected in the evaluation of learning through collaborative serious games?
- RQ3. What methods are used in the evaluation of learning through collaborative serious games?
- RQ4. Do evaluations of learning through collaborative serious games use quantitative, qualitative or a combination between quantitative and qualitative data?
- RQ5. What are the learning effects of collaborative serious games according to their evaluations in relation to social learning?

Learning is used over social learning in these questions to not exclude publications that use a different learning conceptualization but do fall within the scope of this review. For all research questions, data was extracted from the publications and subsequently categorized, which is further explained in the data extraction and data analysis subsections (3.2.7 and 3.2.8).

3.2.3 Search strategy

The search strategy defines the systematic approach to identify publications to include in the literature review. Two categories of keywords were used to create search combinations. The first category (A) covered three keywords to identify publications that covered a game-based approach: serious gam* (A1), simulation gam* (A2) and policy gam* (A3). The asterisk was used in each keyword to cover for both *game* and *gaming*. *Simulation* and *policy gaming* were added to the search terms as

Table 3.1 Inclusion and exclusion criteria.

Inclusion criteria	<ul style="list-style-type: none">• Publications that describe a collaborative serious game on sustainable management of land or natural resources, or otherwise related to a complex sustainability issues (e.g. climate change)• Publications that describe the assessment of learning outcomes of a collaborative serious game• Publications that describe the procedure and methods applied to assess learning outcomes of a collaborative serious game
Exclusion criteria	<ul style="list-style-type: none">• Publications that describe a serious game, but which do not cover a collaborative serious game (e.g. a single-player serious game)• Publications that describe a collaborative serious game, but the game is not in any way related to sustainability• Publications that describe a collaborative serious game, but which do not assess its learning outcomes• Publications that describe the evaluation of the learning outcomes from a collaborative serious game, but offer no information on how this assessment was performed• Publications that describe the assessment of a larger learning process of which a collaborative serious game is a component that cannot be seen as separated from the larger process and its evaluation• Publications that describe a formative evaluation that only focuses on improving the design of a collaborative serious game and do not assess learning outcomes in any way• Publications that describe a serious game designed only for use in an educational setting• Publications that are not written in English• Publications that are only available as abstract ¹

¹ Abstracts were still reviewed, if the abstract seemed applicable, an attempt was made to obtain the entire publication, exclusion occurred if this was not possible.

pilot searches showed this term, unlike alternatives such as *applied gaming*, returned search results that were relevant to the scope.

The second category (B) covered 18 keywords to identify publications in relation to sustainability and disciplines dealing with sustainability issues: sustainability (B1), sustainable use (B2), sustainable development (B3), climate change (B4), climate adaptation (B5), environmental change (B6), energy transition (B7), adaptive *management (B8), collaborative management (B9), natural resource management (B10), environmental management (B11), spatial planning (B12), urban planning (B13), urban development (B14), water management (B15), water resources (B16), river management (B17) and river basin (B18). These keywords were selected based on the five identified review papers on games and sustainability (Aubert et al., 2018; Flood et al., 2018; Katsaliaki and Mustafee, 2012; Reckien and Eisenack, 2013; Wu and Lee, 2015), pilot searches and publications covering collaborative serious games already known to the authors. The asterisk in *adaptive *management* was added to also cover for both *comanagement* and *co-management*.

The keywords were subsequently used in search strings to search for all possible combinations between one keyword from category A and one keyword from category B. Using Boolean statements, the search strings therefore covered "(A1 OR A2 OR A3) AND (B1 OR B2 ... OR B18)."

Searches were limited to publications published since 2007 to review the state of the art. 2007 was chosen in order to cover the last ten years and as pilot searches found few publications providing sufficient information for the scope of the review before 2007 – consistent with the results of Calderón and Ruiz (2015).

Six databases were similarly determined through pilot searches for conducting the review: ACM Digital Library, IEEE Xplore Digital Library, ISI Web of Science, ScienceDirect, Scopus and SpringerLink. Searches were executed on title, abstract and keywords.

3.2.4 Study selection

To narrow down the publications obtained following the search strategy, an initial selection and a final selection step were performed following inclusion and exclusion criteria (Table 3.1). In the initial selection, each study was reviewed based on its title, abstract and keywords. This way, publications clearly not covering the scope of the literature review – i.e. a publication describing the economy and markets as a serious game – were excluded. In the final selection, the publications included in the initial selection were reviewed more rigorously according to the same criteria by scanning through each study and readings its conclusion. The entire study was read if necessary to determine inclusion or exclusion.

3.2.5 Study quality assessment

Following the study selection steps, the selected publications were looked at in more detail in relation to the research questions in a quality assessment step. Specifically, questions that can be answered with yes or no were formulated in relation to the research questions:

1. Does the publication provide a conceptualization of learning? (RQ₁)
2. Does the publication state when data is collected in the evaluation of the collaborative serious game? (RQ₂)
3. Does the publication discuss a method, technique or theory used to evaluate the collaborative serious game? (RQ₃)
4. Does the publication discuss whether the evaluation used a quantitative or qualitative approach, or both in the evaluation of the collaborative serious game? (RQ₄)
5. Does the publication describe learning outcomes of the collaborative serious game following evaluation? (RQ₅)

The publications included in the study selection step were assessed on each of these questions as yes or no, corresponding to a 1 or 0 score. If a publication included all relevant aspects in regard to the scope of the review, it would therefore score five out of five. Publications that scored four or higher were deemed of sufficient quality and included in the review. Publications that scored exactly three, and were thus

Table 3.2 Typology of learning effects (from Baird et al., 2014).

Type	Definition/indicators of learning effects	Measures of indicators
Cognitive learning	Acquisition of new knowledge; restructuring of existing knowledge	Test scores; change in centrality and specificity of knowledge presented in concept maps
Normative learning	Changes in norms; change in values; change in paradigms; convergence of group opinion	Change in, and convergence around, environmental beliefs; participant reflections; meeting proceedings
Relational learning	Improved understanding of mind sets of others; building of relationships; enhanced trust and cooperation	Change in social network structure; participant reflections

excluded, were checked again after completing the quality assessment to confirm exclusion was the correct decision.

3.2.6 *Snowballing*

To cover for relevant publications missed in the database searches, a snowballing approach was used to identify further relevant publications (Wohlin, 2014). Firstly, backward snowballing was applied by identifying possible relevant publications from the reference lists of publications passing the quality assessment step. Secondly, forward snowballing was applied by checking all publications citing the publications deemed of sufficient quality using Google Scholar. Thirdly, the five review papers on sustainable development, climate change and sustainable water resources management (Aubert et al., 2018; Flood et al., 2018; Katsaliaki and Mustafee, 2012; Reckien and Eisenack, 2013; Wu and Lee, 2015) identified earlier were used to snowball from as serious games covered in these reviews may be of interest to the scope of this review. All papers identified through snowballing were subsequently reviewed following the same study selection and quality assessment steps.

3.2.7 *Data extraction*

In the data extraction step, all the publications included in the study selection and deemed of sufficient quality were read in its entirety. Data was extracted from the publications in regard to the research questions. All extracted data, for all publications, were stored in a spreadsheet. At this point, if publications were identified covering the same collaborative serious game without providing additional insight into its evaluation – i.e. a conference paper covering a limited evaluation and a journal paper covering a more extensive evaluation by the same authors – the publication with the lower quality assessment was excluded from the review.

3.2.8 *Data analysis and categorization*

All data was subsequently categorized in regard to each research question. An inductive approach was used to create categories based on the data retrieved by identifying common themes, for example applied methods as surveyed in RQ3. On the first research question, for example, in regard to the conceptualization of learning, categories included social learning and experiential learning. For RQ5, the typology on social learning by Baird et al. (2014) (see Table 3.2) was used as a framework to define categories that differentiate between the three types of learning. From an assessment perspective, the typology is beneficial as it views learning outcomes from their nature – cognitive, normative or relational – rather than their perceived value. Moreover, the typology separates relational learning as an explicit learning outcome,

Figure 3.1 Number of publications included after each step. Flow chart based on the PRISMA guidelines (Moher et al., 2009).

which is of particular interest in the multi-stakeholder context of sustainable land and natural resources management.

The categorizations were subsequently used to identify assessment approaches used in the evaluation of learning outcomes of collaborative serious games.

3.3 Search results

The entire review, from developing the scope and performing the search, selection, data analysis and synthesis, was executed between October 2017 and November 2018. Initial database searches were executed on or a few days before the 7th of January, 2018, and all publications extracted through these searches were analyzed. After processing all retrieved publications, all database searches were updated on the 7th of November, 2018. [Figure 3.1](#) provides an overview of the number of publications found and subsequently included after each step.

As [Figure 3.1](#) shows, 78 publications retrieved through the database searches were included in the selection steps following the inclusion criteria, of which 41 publications were included following quality assessment. 66 additional publications were identified through snowballing, 45 publications from the publications identified through database searches and 21 from the five review papers ([Aubert et al., 2018](#); [Flood et al., 2018](#); [Katsaliaki and Mustafee, 2012](#); [Reckien and Eisenack, 2013](#); [Wu and Lee, 2015](#)). 6 of these 66 publications passed the same selection steps and quality assessment. Five publications were subsequently removed from the total publications as these covered the same collaborative serious game without providing additional insight into its evaluation. 42 publications were therefore included in the review.

[Figure 3.2a](#) shows an overview of how many publications included in the review were retrieved through each database as well as through snowballing. Some publications appeared in multiple databases and are added to these databases in the figure, explaining why the numbers added up are higher than 42. Scopus, as can be expected, provided the most publications included in the review. No publications retrieved from the IEEE database passed the selection criteria and quality assessment steps.

[Figure 3.2b](#) shows an overview of the publications included in the review in regard to their year of publication. The figure suggests an increasing trend in the use of collaborative serious games to explore sustainable management strategies. It must be noted that 2018 has the highest publications included in the review (10 publications), even though the review only covers the first 10 months of 2018.

[Table 3.3](#) provides an overview of the publications included in the review and the game each publication evaluates.

Figure 3.2 Overview of the publications retrieved and included in the review: (a) overview of publications retrieved per database or through snowballing (note: some publications appeared in more than one database); (b) overview of the number of publications included in the review per year of publication.

Table 3.3 Overview of all games and publications included in the review.

Game name	Reference
Aqua Republica	Jean et al. (2018)
CauxOperation	Souchère et al. (2010)
Climate Game	Zhou et al. (2013)
Community Cooperation Game	Tanwattana and Toyoda (2018)
Forage Rummy	Martin (2015)
FOWIS	Hertzog et al. (2014)
Futura	Antle et al. (2011)
GO2Zero	Bekebrede et al. (2018)
Grazing game	Villamor and Badmos (2016)
Invitational Drought Tournament	Hill et al. (2014)
IUP & NECAP	Rumore et al. (2016)
KEEP COOL	Eisenack (2013)
	Meya and Eisenack (2018)
Lords of the Valley	Magnuszewski et al. (2018)
LottoSIM	Becu et al. (2017)
MAE SALAE RPG 1 & 2	Barnaud et al. (2007)
Marine Spatial Planning Challenge	Mayer et al. (2013)
	Keijser et al. (2018)

Game name	Reference
New-District	Becu et al. (2015)
REEFGAME	Cleland et al. (2012)
ReHab	Page et al. (2016)
RESORTES	Speelman et al. (2014)
Shariva	Douven et al. (2014)
SimPhy	Ayadi et al. (2014)
SPRINTCITY	Duffhues et al. (2014)
Sustainable Delta Game (and adaptations)	Valkering et al. (2013)
	Lawrence and Haasnoot (2017)
	van der Wal et al. (2016)
	van Pelt et al. (2015)
TADLA	Dionnet et al. (2008)
Ter'Aguas	Ducrot et al. (2015)
The Floodplain Management Game	Stefanska et al. (2011)
The Multi-Hazard Tournament	Carson et al. (2018)
Unnamed game	Salvini et al. (2016)
Unnamed game	Haug et al. (2011)
Unnamed game	Meinzen-Dick et al. (2018)
Unnamed game	Sausse et al. (2013)
Unnamed game	Moser and Mußhoff (2016)
WeShareIt	Onencan et al. (2016)
WeShareIt Nzoia	Onencan and van de Walle (2018)
WORLD CLIMATE	Stermann et al. (2015)
WSP game	Ferrero et al. (2018)

3.4 Categorization results

This section covers the categorized findings in relation to the formulated research questions. Through an inductive approach, between three and 13 categories were identified for each research question. A complete overview of all the publications and assigned categories can be found in [Appendix 3.A](#). An overview of the underlying data can be found as a spreadsheet in the Supplementary Materials.

The next subsections present the results of categorization for each research question.

3.4.1 How is learning through collaborative serious games conceptualized?

The aim of this question was to obtain an overview of how learning through collaborative serious games is conceptualized. Thirteen categories were identified in the analysis. In most cases, publications mentioned the categories explicitly and

Table 3.4 Overview of categorization for Research Question 1 (RQ1) on the conceptualization of learning through collaborative serious games.

Category (number of publications)	Category definition	Assigned to publications
Social learning (16)	A change in understanding that goes beyond the individual to become situated within wider social units or communities of practice through social interactions between actors within social networks (Reed et al., 2010, p. 6)	(Becu et al., 2017; Carson et al., 2018; Cleland et al., 2012; Dionnet et al., 2008; Ducrot et al., 2015; Haug et al., 2011; Hill et al., 2014; Lawrence and Haasnoot, 2017; Magnuszewski et al., 2018; Meinzen-Dick et al., 2018; Page et al., 2016; Rumore et al., 2016; Salvini et al., 2016; Stefanska et al., 2011; van der Wal et al., 2016; Villamor and Badmos, 2016)
Experiential learning (9)	The process whereby knowledge is created through the transformation of experience (Kolb, 1984, p. 38)	(Antle et al., 2011; Becu et al., 2017; Becu et al., 2015; Ferrero et al., 2018; Page et al., 2016; Serman et al., 2015; Tanwattana and Toyoda, 2018; van der Wal et al., 2016; Zhou et al., 2013)
Other (11)	Other learning conceptualization (see Appendix 3.A)	(Barnaud et al., 2007; Douven et al., 2014; Duffhues et al., 2014; Jean et al., 2018; Keijser et al., 2018; Martin, 2015; Mayer et al., 2013; Onencan et al., 2016; Onencan and van de Walle, 2018; Souchère et al., 2010; Villamor and Badmos, 2016)
Not conceptualized (10)	Assessing whether or not playing the game led to actual changes beyond gameplay	(Ayadi et al., 2014; Bekebrede et al., 2018; Eisenack, 2013; Hertzog et al., 2014; Meya and Eisenack, 2018; Moser and Mußhoff, 2016; Sausse et al., 2013; Speelman et al., 2014; Valkering et al., 2013; van Pelt et al., 2015)

included relevant citations, while in some cases publications lacked these citations. In the latter case, publications were still assigned to the category if a definition or description was included that matches the category definition. Only the categories social learning and experiential learning covered more than one or two publications. [Table 3.4](#) provides the categories, their definitions and the publications assigned to these categories. Categories covering only one or two publications are grouped into the other category in [Table 3.4](#), but can be found in full in [Appendix 3.A](#).

3.4.2 *When is data collected in the evaluation of learning through collaborative serious games?*

The aim of this research question was to get an overview of when data is gathered in the assessment of learning through collaborative serious games. Categorizations were chosen based on game sessions as a reference point, with pre, during, post, and post-post data collection. [Table 3.5](#) provides the categories, their definitions and the publications assigned to these categories. Notably, 37 out of 42 publications gather data immediately after game sessions (post). Twenty-five of these 38 publications combine the post data collection with data collection during game sessions, while 21 of these combine it with a data collection before game sessions (pre) and 15 combine all three. Only 11 publications collected data well after game sessions (post-post).

Table 3.5 Overview of categorization for RQ2 on when data is collected in the evaluation of collaborative serious games.

Category (number of publications)	Category definition	Assigned to publications
Pre (22)	Data gathered before game sessions	(Becu et al., 2015 ; Bekebrede et al., 2018 ; Carson et al., 2018 ; Douven et al., 2014 ; Ducrot et al., 2015 ; Eisenack, 2013 ; Haug et al., 2011 ; Jean et al., 2018 ; Magnuszewski et al., 2018 ; Mayer et al., 2013 ; Meya and Eisenack, 2018 ; Moser and Mußhoff, 2016 ; Onencan et al., 2016 ; Onencan and van de Walle, 2018 ; Rumore et al., 2016 ; Salvini et al., 2016 ; Speelman et al., 2014 ; Stermann et al., 2015 ; Valkering et al., 2013 ; van der Wal et al., 2016 ; van Pelt et al., 2015 ; Zhou et al., 2013)

Category (number of publications)	Category definition	Assigned to publications
During (30)	Data gathered during game sessions	(Antle et al., 2011; Ayadi et al., 2014; Barnaud et al., 2007; Bekebrede et al., 2018; Cleland et al., 2012; Ducrot et al., 2015; Duffhues et al., 2014; Eisenack, 2013; Haug et al., 2011; Hertzog et al., 2014; Jean et al., 2018; Keijser et al., 2018; Lawrence and Haasnoot, 2017; Magnuszewski et al., 2018; Mayer et al., 2013; Meinzen-Dick et al., 2018; Meya and Eisenack, 2018; Onencan et al., 2016; Onencan and van de Walle, 2018; Page et al., 2016; Sausse et al., 2013; Speelman et al., 2014; Stefanska et al., 2011; Tanwattana and Toyoda, 2018; Valkering et al., 2013; van der Wal et al., 2016; van Pelt et al., 2015; Villamor and Badmos, 2016; Zhou et al., 2013)
Post (37)	Data gathered immediately after game sessions	(Barnaud et al., 2007; Becu et al., 2017; Becu et al., 2015; Bekebrede et al., 2018; Carson et al., 2018; Cleland et al., 2012; Dionnet et al., 2008; Douven et al., 2014; Ducrot et al., 2015; Duffhues et al., 2014; Eisenack, 2013; Ferrero et al., 2018; Haug et al., 2011; Hertzog et al., 2014; Hill et al., 2014; Jean et al., 2018; Keijser et al., 2018; Lawrence and Haasnoot, 2017; Magnuszewski et al., 2018; Martin, 2015; Mayer et al., 2013; Meinzen-Dick et al., 2018; Meya and Eisenack, 2018; Onencan et al., 2016; Onencan and van de Walle, 2018; Page et al., 2016; Rumore et al., 2016; Salvini et al., 2016; Souchère et al., 2010; Speelman et al., 2014; Stefanska et al., 2011; Valkering et al., 2013; van der Wal et al., 2016; van Pelt et al., 2015; Villamor and Badmos, 2016; Zhou et al., 2013)
Post-post (10)	Data gathered well after game sessions; not on the same day	(Barnaud et al., 2007; Carson et al., 2018; Dionnet et al., 2008; Ducrot et al., 2015; Haug et al., 2011; Meinzen-Dick et al., 2018; Rumore et al., 2016; Speelman et al., 2014; Sterman et al., 2015; van Pelt et al., 2015)

3.4.3 What methods are used in the evaluation of learning through collaborative serious games?

The aim of this research question was to obtain an overview of the methods and techniques that are used to evaluate collaborative serious games. [Table 3.6](#) provides the

categories used to represent different methods, their definitions and the publications assigned to these categories. Thirty-one out of the 42 publications used multiple methods – combinations of the five most used methods; questionnaires, observations, debriefings, interviews and data logging.

Table 3.6 Overview of categorization for RQ3 on the methods used in the evaluation of collaborative serious games.

Category (number of publications)	Category definition	Assigned to publications
Questionnaires (25)	Written or electronic questionnaires or surveys filled out by participants	(Becu et al., 2015; Bekebrede et al., 2018; Carson et al., 2018; Dionnet et al., 2008; Douven et al., 2014; Ducrot et al., 2015; Duffhues et al., 2014; Eisenack, 2013; Ferrero et al., 2018; Haug et al., 2011; Hill et al., 2014; Jean et al., 2018; Keijser et al., 2018; Magnuszewski et al., 2018; Mayer et al., 2013; Meinzen-Dick et al., 2018; Meya and Eisenack, 2018; Moser and Mußhoff, 2016; Onencan et al., 2016; Onencan and van de Walle, 2018; Rumore et al., 2016; Speelman et al., 2014; Sterman et al., 2015; van Pelt et al., 2015; Zhou et al., 2013)
Observations (24)	Observations performed in-situ or based on recordings	(Antle et al., 2011; Barnaud et al., 2007; Bekebrede et al., 2018; Ducrot et al., 2015; Duffhues et al., 2014; Eisenack, 2013; Haug et al., 2011; Hertzog et al., 2014; Keijser et al., 2018; Lawrence and Haasnoot, 2017; Magnuszewski et al., 2018; Mayer et al., 2013; Meya and Eisenack, 2018; Onencan et al., 2016; Page et al., 2016; Sausse et al., 2013; Speelman et al., 2014; Stefanska et al., 2011; Tanwattana and Toyoda, 2018; Valkering et al., 2013; van der Wal et al., 2016; van Pelt et al., 2015; Villamor and Badmos, 2016; Zhou et al., 2013)

Category (number of publications)	Category definition	Assigned to publications
Debriefings (18)	Formal analysis of the game's debriefing(s)	(Becu et al., 2017; Cleland et al., 2012; Ducrot et al., 2015; Ferrero et al., 2018; Haug et al., 2011; Hertzog et al., 2014; Hill et al., 2014; Lawrence and Haasnoot, 2017; Onencan et al., 2016; Page et al., 2016; Rumore et al., 2016; Souchère et al., 2010; Speelman et al., 2014; Stefanska et al., 2011; Valkering et al., 2013; van Pelt et al., 2015; Villamor and Badmos, 2016; Zhou et al., 2013)
Interviews (14)	Interviews conducted with individual participants	(Barnaud et al., 2007; Dionnet et al., 2008; Ducrot et al., 2015; Duffhues et al., 2014; Haug et al., 2011; Hertzog et al., 2014; Lawrence and Haasnoot, 2017; Mayer et al., 2013; Meinzen-Dick et al., 2018; Rumore et al., 2016; Salvini et al., 2016; Speelman et al., 2014; van der Wal et al., 2016; van Pelt et al., 2015)
Data Logging (8)	Data logged during gameplay, such as player decisions	(Ayadi et al., 2014; Duffhues et al., 2014; Mayer et al., 2013; Meinzen-Dick et al., 2018; Moser and Mußhoff, 2016; Onencan and van de Walle, 2018; Sausse et al., 2013; van der Wal et al., 2016)
Control group (3)	Data gathered through the use of a control group	(Meinzen-Dick et al., 2018; Moser and Mußhoff, 2016; van Pelt et al., 2015)
Perspective mapping (2)	Classifying, interpreting and analysing different perspectives on promising paths for sustainable strate- gies (Offermans et al., 2011)	(Valkering et al., 2013; van der Wal et al., 2016)
Concept maps (1)	Participants drawing structural representation of associations in relation to a topic (Ruiz-Primo and Shavelson, 1996)	(Haug et al., 2011)

Category (number of publications)	Category definition	Assigned to publications
Interaction Analysis (1)	Analysis of human-to-hu- man as well as human-en- vironment interactions (Jordan and Henderson, 1995)	(Jean et al., 2018)
Social Network Analysis (1)	Analysis of the affordances and hindrances to knowl- edge co-creation by struc- turing relationships (Serrat, 2017)	(Jean et al., 2018)
Real world data (1)	Data gathered from the ‘real world’ research context or environment	(Meinzen-Dick et al., 2018)

3.4.4 Do evaluations of learning through collaborative serious games use quantitative, qualitative or a combination between quantitative and qualitative data?

The aim of this research question was to see whether the evaluation of collaborative serious games relied on qualitative or quantitative or qualitative and quantitative data. Table 3.7 provides an overview of which publications based evaluations on either of these three categories. Thirty-seven out of the 42 publications used qualitative data. Sixteen of these 37 publications combined the qualitative data with quantitative data. Qualitative data resulted from questionnaires (open questions), observations (unstructured observations by researchers), debriefings and interviews. Quantitative data on the other hand resulted from questionnaires (closed questions using Likert scales), observations (structured observations i.e. noting and counting certain behaviour), and data logging (i.e. player choices and group decisions).

Table 3.7 Overview of categorization for RQ4 on use of qualitative and/or quantitative data in the evaluation of collaborative serious games.

Category (number of publications)	Category definition	Assigned to publications
Qualitative (21)	Evaluations based only on qualitative data	(Antle et al., 2011; Barnaud et al., 2007; Becu et al., 2017; Cleland et al., 2012; Dionnet et al., 2008; Ducrot et al., 2015; Duffhues et al., 2014; Eisenack, 2013; Ferrero et al., 2018; Haug et al., 2011; Hertzog et al., 2014; Hill et al., 2014; Lawrence and Haasnoot, 2017; Martin, 2015; Salvini et al., 2016; Souchère et al., 2010; Speelman et al., 2014; Stefanska et al., 2011; Tanwattana and Toyoda, 2018; Valkering et al., 2013; Villamor and Badmos, 2016)
Quantitative (5)	Evaluations based only on quantitative data	(Ayadi et al., 2014; Meya and Eisenack, 2018; Moser and Mußhoff, 2016; Onencan and van de Walle, 2018; Sterman et al., 2015)
Qualitative & quantitative (16)	Evaluations based on both qualitative and quantitative data	(Becu et al., 2015; Bekebrede et al., 2018; Carson et al., 2018; Douven et al., 2014; Jean et al., 2018; Keijser et al., 2018; Magnuszewski et al., 2018; Mayer et al., 2013; Meinzen-Dick et al., 2018; Onencan et al., 2016; Page et al., 2016; Rumore et al., 2016; Sausse et al., 2013; van der Wal et al., 2016; van Pelt et al., 2015; Zhou et al., 2013)

3.4.5 What are the learning effects of applying collaborative serious games according to their evaluations in relation to social learning?

The aim of this research question was to get an overview of the learning outcomes of collaborative serious games. Categories were formulated based on the data extracted from the publications and in relation to the learning typology by Baird et al. (2014). Table 3.8 provides the categories, their definitions and relation to the social learning typology and the publications assigned to these categories. Thirty-seven out of 42 publications report on cognitive learning outcomes, increased system understanding or raised awareness or both. Only five publications report that playing a collabora-

tive serious game led to a change in views, the category linked to normative learning. Seventeen publications report on relational learning outcomes in the form of understanding other perspectives or building relationships and trust or both.

To formulate and assign categories for this research question, the choice was made to assign publications to categories based only on the text as written in the publications – the data – regardless of whether or not publications described their results as representative for the entire population or as highly or weakly significant. For example, [Keijser et al. \(2018\)](#) and [Lawrence and Haasnoot \(2017\)](#) both noted results related to the category increased system understanding although [Keijser et al. \(2018\)](#) only noted it for those less familiar with the topic, yet both publications were assigned to this category. Making distinctions would otherwise add a selection mechanism susceptible to subjective interpretations of the publications. The results as presented here should therefore only be viewed in relation to the learning outcomes of collaborative serious games can have in general and should not be used to draw direct conclusions on individual publications.

Table 3.8 Overview of categorization for RQ5 on the learning effects of applying collaborative serious games according to their evaluations in relation to social learning.

Category (number of publications)	Category definition	Assigned to publications
Increased system understanding (34)	Learning about the topic covered in the game, its complexity and possible trade-offs between decisions (cognitive learn- ing)	(Ayadi et al., 2014 ; Barnaud et al., 2007 ; Becu et al., 2017 ; Bekebrede et al., 2018 ; Carson et al., 2018 ; Cleland et al., 2012 ; Dionnet et al., 2008 ; Douven et al., 2014 ; Ducrot et al., 2015 ; Duffhues et al., 2014 ; Eisenack, 2013 ; Haug et al., 2011 ; Hertzog et al., 2014 ; Hill et al., 2014 ; Keijser et al., 2018 ; Lawrence and Haasnoot, 2017 ; Martin, 2015 ; Mayer et al., 2013 ; Meinzen-Dick et al., 2018 ; Meya and Eisenack, 2018 ; Moser and Mußhoff, 2016 ; Onencan et al., 2016 ; Onencan and van de Walle, 2018 ; Page et al., 2016 ; Rumore et al., 2016 ; Salvini et al., 2016 ; Sausse et al., 2013 ; Souchère et al., 2010 ; Serman et al., 2015 ; Tanwattana and Toyoda, 2018 ; Valkering et al., 2013 ; van Pelt et al., 2015 ; Villamor and Badmos, 2016 ; Zhou et al., 2013)

Category (number of publications)	Category definition	Assigned to publications
Raised awareness (14)	Learning about the seriousness of an issue (cognitive learning)	(Antle et al., 2011; Carson et al., 2018; Douven et al., 2014; Duffhues et al., 2014; Ferrero et al., 2018; Martin, 2015; Meya and Eisenack, 2018; Onencan and van de Walle, 2018; Rumore et al., 2016; Souchère et al., 2010; Stefanska et al., 2011; Stermann et al., 2015; Tanwattana and Toyoda, 2018; van Pelt et al., 2015)
Change in views (5)	Observing partic- ipants changing their viewpoints, values or para- digms (normative learning)	(Ducrot et al., 2015; Lawrence and Haasnoot, 2017; Meya and Eisenack, 2018; Stermann et al., 2015; van der Wal et al., 2016)
Understanding other roles and perspectives (13)	Learning about other participants' roles, mind-sets and points of view (relational learning)	(Barnaud et al., 2007; Becu et al., 2015; Carson et al., 2018; Douven et al., 2014; Ducrot et al., 2015; Ferrero et al., 2018; Haug et al., 2011; Jean et al., 2018; Lawrence and Haasnoot, 2017; Mayer et al., 2013; Rumore et al., 2016; Souchère et al., 2010; Villamor and Badmos, 2016)
Building relationships and trust (7)	Enhancing par- ticipants' ability to collaborate by building relation- ships and enhanc- ing trust (relation- al learning)	(Bekebrede et al., 2018; Carson et al., 2018; Jean et al., 2018; Martin, 2015; Salvini et al., 2016; Souchère et al., 2010; Speelman et al., 2014)

3.5 Discussion

This section covers the findings on the approaches to assess social learning outcomes of collaborative serious games. The findings are discussed in relation to the three types of learning as defined by Baird et al. (2014); cognitive, relational and normative learning. In addition, as social learning should lead to collective action, the real world impact of collaborative serious games – as reported in the reviewed publications – are discussed. The section ends with a reflection on and limitations of the review.

Forty-two publications were included in the review. In relation to the first research question, social learning and experiential learning were the only conceptualizations of learning used by more than two publications. While some publications provided learning conceptualization related to social learning – i.e. collective learning (Barnaud et al., 2007; Souchère et al., 2010) and boundary crossing (Jean et al., 2018) – other publications provide conceptualizations that do not explicitly include the relational learning component of social learning. This is reflected in the review as the latter publications, as well as the publications that do not provide an identifiable conceptualization of learning, mostly report on cognitive learning outcomes. The next subsections discuss the assessments of cognitive, relational and normative learning outcomes of collaborative serious games in detail.

3.5.1 *Cognitive learning*

Cognitive learning relates to the acquisition of new or the restructuring of existing knowledge. Almost all of the publications in the review – 37 out of 42 – report on cognitive learning outcomes of collaborative serious games. Two categories were linked to cognitive learning, increased system understanding and raised awareness, although both can relate to acquiring new knowledge and restructuring existing knowledge. Three common approaches were identified in the assessment: (1) self-reflective questions after game sessions; (2) pre-post measurements of self-reported knowledge on issues; and (3) observed acquisition or restructuring of knowledge. Firstly, 21 publications asked participants self-reflective questions in questionnaires, interviews or debriefings after game sessions, sometimes in combination with other methods (Barnaud et al., 2007; Becu et al., 2017; Bekebrede et al., 2018; Carson et al., 2018; Cleland et al., 2012; Dionnet et al., 2008; Ducrot et al., 2015; Duffhues et al., 2014; Ferrero et al., 2018; Haug et al., 2011; Hill et al., 2014; Lawrence and Haasnoot, 2017; Martin, 2015; Mayer et al., 2013; Onencan et al., 2016; Page et al., 2016; Rumore et al., 2016; Souchère et al., 2010; Valkering et al., 2013; van Pelt et al., 2015; Zhou et al., 2013). For example, Dionnet et al. (2008) assessed their TADLA approach, which aims to facilitate farmers in the collective modernization of their irrigation system, by combining a questionnaire after game sessions with follow-up interviews. They showed that their approach helped farmers to acquire a more comprehensive understanding of how the different system components work together. Becu et al. (2017) asked self-reflective questions on what local policymakers learned during their structured, round-table debriefing of LottoSim, a game to support social learning on coastal risk prevention measures. According to their evaluation, the participants especially learned about the dynamics of water expansion in flooding events as a result of the game's integrated simulations. Moreover, the game helped participants

to discuss long-term strategies, although participants did not pursue other prevention measures than those already applied in practice. [Keijser et al. \(2018\)](#) in turn assessed the ability of the Marine Spatial Planning Challenge to communicate the dynamic and complex interactions between shipping and spatial planning in the maritime environment. Questionnaires after game sessions were applied to assess self-reported learning through closed questions and a five-point Likert scale. Their results show that the game worked well as an introduction to marine spatial planning where participants gain a grasp of its complexities, particularly for those with limited knowledge on the topic.

Secondly, 12 publications analyzed self-reported learning through pre-post measurements of participants' knowledge on the issues addressed in the game ([Carson et al., 2018](#); [Douven et al., 2014](#); [Ducrot et al., 2015](#); [Eisenack, 2013](#); [Haug et al., 2011](#); [Keijser et al., 2018](#); [Meya and Eisenack, 2018](#); [Onencan and van de Walle, 2018](#); [Rumore et al., 2016](#); [Salvini et al., 2016](#); [Serman et al., 2015](#); [van Pelt et al., 2015](#)). Questionnaires were the common method for this approach, complemented with other methods, although [Salvini et al. \(2016\)](#) and [Haug et al. \(2011\)](#) instead used interviews and concept maps respectively. [Salvini et al. \(2016\)](#) assessed the effects on social learning of their game, that aims to induce Brazilian farmers to explore agroforestry practices, by conducting interviews with participants. The interviews covered the same questions before and after game sessions and included questions on the farmers' practices, knowledge of different systems and opinions on forming cooperatives. The farmers learned about the technical aspects of agroforestry, such as the amount of investments needed for new infrastructure, and its benefits, such as increased productivity, product quality and profitability. [Haug et al. \(2011\)](#) assessed social learning outcomes through a policy game on EU climate change policy and the member states' sharing arrangements. Participants were asked to draw concept maps ([Ruiz-Primo and Shavelson, 1996](#)) before and after game sessions. The analysis of the concept maps was complemented with self-reflective questions asked in questionnaires and interviews after game sessions. Their results showed there were some cognitive learning outcomes as certain issues became more central and specific in the post session concept maps – in indication of restructuring of knowledge.

Pre-post measurements of cognitive learning outcomes through questionnaires were based on qualitative assessment of open questions or quantitative assessment of closed questions using Likert scales or a combination of the two. For example, [Douven et al. \(2014\)](#) assessed the impact on both raising awareness and upgrading knowledge of playing the Shariva game, which aims to stimulate collaboration among water and related professionals and to resolve transboundary river basin issues. They used questionnaires with both open and closed questions before and

after game sessions in this assessment. Their results show that participants acquired knowledge on addressing and resolving transboundary river basin issues. [Onen-can and van de Walle \(2018\)](#) assessed whether or not participants gained increased situational awareness – the perception of system elements, comprehension of their meaning and projection of their near future status – from playing WeShareIt Nzoia. To this end, they applied questionnaires based on SART ([Taylor, 1990](#)), using 10-dimensional subjective ratings, before and after game sessions in combination with in-game performance measures to measure the game's effects. Their results showed an increase in participants' situational awareness, on all dependent variables, between the pre-test and post-test of local policymakers.

Thirdly, 10 publications assessed cognitive learning outcomes without asking participants, but rather assessed observed acquisition or restructuring of knowledge by analyzing observations and data resulting from game sessions ([Antle et al., 2011](#); [Ayadi et al., 2014](#); [Hertzog et al., 2014](#); [Magnuszewski et al., 2018](#); [Meinzen-Dick et al., 2018](#); [Moser and Mußhoff, 2016](#); [Sausse et al., 2013](#); [Stefanska et al., 2011](#); [Tanwattana and Toyoda, 2018](#); [Villamor and Badmos, 2016](#)). To assess whether or not participants improved their understanding of the complexity of planning for a sustainable future through their game Futura, [Antle et al. \(2011\)](#) analyzed field notes on participant behaviour and quotes by identifying themes through coding. Their results show that participants did not necessarily acquire new knowledge from playing the game, but do obtain a better sense of the sheer complexity of sustainable development. [Sausse et al. \(2013\)](#) developed a game for local stakeholders to explore management of both genetically modified and conventional crops in an area. To analyze how farmers manage the coexistence of both crop types, they analyzed data collected from gameplay, such as the simulation results, player actions and maps drawn by the participants, complemented with observations from notes and audio recordings, to understand why players made certain decisions and why certain events occurred. They showed that farmers learned about how to technically implement management measures and to better assess the risk of coexistence of both genetically modified and conventional crops in fields next to each other.

3.5.2 Normative learning

Normative learning relates to a shift in viewpoints, values or paradigms. Assessing changes in viewpoints and values is particularly challenging as these are difficult to measure and require reflection – and thus time – to occur. How normative learning has been assessed in collaborative serious games is therefore of particular interest. Five publications reported on normative learning outcomes ([Ducrot et al., 2015](#); [Lawrence and Haasnoot, 2017](#); [Meya and Eisenack, 2018](#); [Stermann et al., 2015](#); [van](#)

der Wal et al., 2016). In addition, Haug et al. (2011) did assess normative learning, but did not find evidence of it taking place. Their assessment was based on pre-post measurements, participants rating the extent they agreed or disagreed on propositions before and after game sessions, in combination with participant interviews after game sessions.

Three of the five publications that do report on normative learning outcomes assess individual changes in views and values and use one of the two measurements either through pre-post measurements or self-reflective questions after gameplay. In the evaluation of Ter'Aguas, a game used to simulate negotiations related to land-use planning in a Brazilian municipality, Ducrot et al. (2015) applied a short-term and long-term learning assessment. In the long-term assessment, through interviews conducted eight months after the game sessions, they found that participants had changed their opinion on their role and position in relation to water management issues. For example, a participant noted that (s)he no longer threw away oil after becoming aware of a water quality issue through playing the game.

Two publications applied pre-post measurements that asked participants to indicate to what extent they agreed with propositions, an approach similar to Haug et al. (2011). Meya and Eisenack (2018) assessed how playing the board game KEEP COOL, which aims to enhance public understanding of climate change science and to raise awareness among public, scientific and environmental organizations, changes participants' beliefs on international climate politics. To this end, they asked participants to rate their opinions on for example personal responsibility towards climate change mitigation and the confidence in politics to act against climate change on a five-point Likert scale in questionnaires before and after game sessions. Their results showed that participants perceive increased responsibility and become more confident in the potential of politics to act. Similarly, Sterman et al. (2015) used pre-post measurements of closed question questionnaires to assess changes in attitudes towards climate change from playing the game WORLD CLIMATE, which aims to help participants understand the dynamics and geopolitical implications of climate change. Their results showed that participants become more worried about climate change, believe it to be more personally important and are more likely to urge for immediate action.

The other two publications that reported normative learning outcomes cover different versions of the Sustainable Delta Game, which aims to help participants learn about preparing water management strategies for an uncertain future. Lawrence and Haasnoot (2017) applied an adapted version of the game in a regional water management project in New Zealand to test how dynamic pathways, pro-active planning to adapt to uncertain future developments, can be adopted in deci-

sion-making. Based on observations during game sessions complemented with analyses of the debriefings and interviews with participants after game sessions, they concluded that the game led to group convergence on the necessities to make decisions in uncertain conditions. [Van der Wal et al. \(2016\)](#) in turn explicitly assess such group convergence by measuring changes in group perspectives. They applied perspective mapping, a method rooted in Cultural Theory to classify, interpret and analyze different individual perspectives ([Offermans et al., 2011](#)). Specifically, participants were asked to select statements they agreed with in relation to a topic during each phase of the game. The method is therefore quite similar to the agreement or disagreement ratings applied by [Haug et al. \(2011\)](#), [Meya and Eisenack \(2018\)](#) and [Stermann et al. \(2015\)](#). Group convergence was subsequently assessed by comparing the agreement on statements between participants. The analysis was complemented with analyzing recordings of game sessions to understand why perspectives changed and participant interviews after the game to validate that participants found the game and its underlying model credible. Their results show that individual perspectives changed during gameplay, leading to group convergence in most game sessions.

3.5.3 *Relational learning*

Relational learning relates to obtaining an improved understanding of others' mind-sets, enhanced trust and ability to cooperate. Around half of the publications – 17 out of 42 – report on relational learning outcomes. Two categories were identified in regard to relational learning outcomes: Understanding other roles and perspectives and building relationships and trust. The first category, reported by 13 publications, relates to participants acquiring an increased understanding on other participants' roles, mind-sets and points of view ([Barnaud et al., 2007](#); [Becu et al., 2015](#); [Carson et al., 2018](#); [Douven et al., 2014](#); [Ducrot et al., 2015](#); [Ferrero et al., 2018](#); [Haug et al., 2011](#); [Jean et al., 2018](#); [Lawrence and Haasnoot, 2017](#); [Mayer et al., 2013](#); [Rumore et al., 2016](#); [Souchère et al., 2010](#); [Villamor and Badmos, 2016](#)). The second category, reported by seven publications, instead relates to enhancing participants' ability to collaborate by building relationships and enhancing trust ([Bekebrede et al., 2018](#); [Carson et al., 2018](#); [Jean et al., 2018](#); [Martin, 2015](#); [Salvini et al., 2016](#); [Souchère et al., 2010](#); [Speelman et al., 2014](#)). Both learning outcomes were assessed mostly qualitatively, based on self-reflective questions in questionnaires, interviews and debriefings conducted after game sessions or well after game sessions (post-post). However, building relationships and trust was reported more often when collaborative serious games were used in a community or an existing project; when participants address a shared problem that directly impacts them.

For example, in the same long-term assessment as described in the previous section, [Ducrot et al. \(2015\)](#) participants indicated in the interviews that they learned about the relationships between issues and stakeholders, and obtained a better understanding of other stakeholders' positions. Similarly, [Rumore et al. \(2016\)](#) interviewed participants four to six weeks after game sessions in the assessment of a tailored role-playing game to enhance engagement in the NECAP project, a project that aims to increase the climate change adaptation readiness of coastal communities in New England. In the interviews, participants showed increased empathy and appreciation for other perspectives as a result of playing the game. In particular, participants noted these learning outcomes as they took on another role, engaging the issue from another perspective, and engaged openly with other stakeholders' point of views. Different from these examples, [Carson et al. \(2018\)](#) used questionnaires both directly after game sessions and three months later to assess the effect of the Multi Hazard Tournament on decision-making, social learning, and relationship building in watershed management. The post-game questionnaire showed that learning about other stakeholders' perspectives was the main learning outcome. Moreover, participants indicated in the follow-up questionnaire that game sessions had led to them pursuing potential projects with other participants.

Exception to this approach is [Jean et al. \(2018\)](#), who combined self-reflective questions with interaction and social network analysis to assess how playing Aqua Republica – a game focused on sustainable watershed management – enhanced collaboration and knowledge co-creation. In particular, participants were asked to rate the collaboration in their game session both during – after completed phases – and after the session. Interaction analysis and social network analysis were applied on session recordings of the game phases to analyze the amount of interactions between participants, the quality of interactions and the effect pre-existing relationships had on group dynamics. Their analysis shows that participants share ideas and build relationships in game sessions, providing evidence that collaborative serious games can help to enhance connections and develop a mutual understanding between stakeholders.

3.5.4 *Collective action*

Apart from cognitive, relational and normative learning outcomes, social learning should ultimately lead to collective action ([Cundill and Rodela, 2012](#); [Keen et al., 2005](#); [Pahl-Wostl et al., 2008](#)). Arguably, the best indicator of collective action is showing that using a collaborative serious game led to real world impact. Indeed, a few publications describe how game sessions within a project or community led to real world initiatives and decisions. For example, the application of the Sustain-

able Delta Game in a water management project in New Zealand by [Lawrence and Haasnoot \(2017\)](#) led to the adoption of adaptive pathways strategy in the project's climate adaptation strategy. In the interviews conducted before game sessions by [Salvini et al. \(2016\)](#), farmers indicated that they had had negative experiences with farmer cooperatives in the past. In interviews after game sessions, farmers individually indicated that they were considering to create a new cooperative together with other participants.

One publication however set out to measure the real world impact of using a collaborative serious game. [Meinzen-Dick et al. \(2018\)](#) used two different follow-ups after game sessions to improve local community understanding of groundwater interrelationships and to stimulate collective governance of groundwater in India: (1) interviewing locals who did not participate in game sessions to measure whether or not there were any spill-over learning effects; and (2) gathering community-level data of different communities in the region, both communities where the collaborative serious game was used and where it was not used, to evaluate whether or not the game led to changes in community practices. In relation to the latter, more communities – statistically significant – where the game was used adopted lessons from the game, leading [Meinzen-Dick et al. \(2018\)](#) to conclude that playing the game led to real world impact.

3.5.5 *Reflection and limitations*

All literature reviews aim to provide the complete overview of relevant publications and the state-of-the-art. There are however some threats and limitations to note in that regard. Firstly, a literature review is always limited in the keywords that it uses in the document search. In this case, a combination of generic and specific keywords was used in relation to sustainability and disciplines dealing with sustainability issues. The generic keywords aimed to make sure collaborative serious games on a variety of sustainability topics were found. The specific keywords were added based on relevant review papers and collaborative serious games known to the researchers. A threat here is that the prior knowledge results in a bias. the generic keywords in combination with snowballing off identified publications however limited any influence of such a bias.

Another threat is that the analysis of the identified publications, and particularly during the study selection and quality assessment steps, contains some subjectivity. After all, the majority of these analysis steps were conducting by a single researcher, the first author of this paper. To limit this threat, a systematic approach to the review was applied, following the guidelines by [Kitchenham and Charters \(2007\)](#). Firstly, the study selection protocol enabled an initial selection that excluded publi-

cations clearly out of scope of the review, but included publications that required more scrutiny and in-depth assessment. Secondly, the quality assessment step added a structured way of selecting the publications relevant to include in the review and while answering the quality assessment questions may still have included some subjectivity, this could only affect publications that scored just short of the threshold and were thus excluded. These publications were carefully looked at again after completing the entire quality assessment to check whether or not exclusion was a correct conclusion. None of these publications were subsequently added to the review.

3.6 Conclusion

Serious games are increasingly explored as a method to establish social learning on sustainable natural resources management and urban planning. The aim of this review was to answer the main research question: What is the current state of the art of the different methods and procedures used to assess social learning outcomes of collaborative serious games? A systematic literature review was conducted, which reviewed 42 publications that applied serious gaming to collaboratively explore sustainable management strategies of land and natural resources. The publications were analyzed in order to determine how three types of learning outcomes – cognitive, normative and relational learning – were assessed. To this end, data was extracted from the publications in relation to five research questions and were categorized following an inductive approach. The categorizations made it possible to identify approaches used in relation to assessing cognitive, normative and relational learning outcomes of collaborative serious games.

Most evaluations of collaborative serious games focus on assessing cognitive learning, which relates to the acquisition of new or the restructuring of existing knowledge, for example whether or not participants obtain a better understanding of the complexities of climate change. Few evaluations focus explicitly on normative learning, which relates to a shift in viewpoints, values or paradigms, for example on an individual's feeling of responsibility towards climate change mitigation. That few evaluations assess normative learning is not surprising as it generally requires experience, reflection and time before a person would shift viewpoints, values or paradigms. Nevertheless, the reviewed publications do show that collaborative serious games can lead to normative learning. About half of the reviewed publications report on relational learning outcomes, which relates to obtaining an improved understanding of others' mind-sets, enhanced trust and ability to cooperate. That only half assess this learning type seems to relate to whether or not relational learning is seen as part of the conceptualization of learning and whether or not the collabora-

tive serious game is used in an existing project or community. Table 3.9 provides an overview of the approaches used in the assessment of the three learning outcomes, including the common methods and procedures used.

Table 3.9 Overview of approaches used to assess cognitive, relational and normative learning through collaborative serious games.

Type	Assessment approach	Data collection	Methods
Cognitive learning	Self-reflective questions	Post-game	Questionnaires (open or closed questions); interviews; debriefings
	Knowledge measurements	Pre- & post-game	Questionnaires (open or closed questions); interviews; concept maps
	Observed knowledge acquisition	In-game	Observations (structured or unstructured, in-situ or from recordings); analyzing data logged during gameplay
Normative learning	Self-reflective questions	Post- & post-game	Interviews
	Shifts in opinion measurements	Pre- & post-game	Questionnaires (closed questions); perspective mapping
Relational learning	Self-reflective questions	Post- & post-game	Questionnaires (open or closed question); interviews; debriefings
	Group dynamics analysis	In-game	Questionnaires (closed questions); interaction analysis; social network analysis

The review shows that three common approaches are used to assess cognitive learning outcomes. Firstly, asking participants self-reflective questions such as what they learned after game sessions, either in a qualitative assessment through open questions or a quantitative assessment using closed questions. Secondly, applying measurements of participants’ knowledge before and after game sessions, also based on self-reporting by asking open or closed questions to participants. Thirdly, assessing observed acquisition or restructuring of knowledge by analyzing observations, either qualitatively or quantitatively, and in-game collected data.

Two approaches are used to assess normative learning outcomes. Firstly, asking participants to rate their views on propositions in pre–post measurements, optionally complemented with such ratings during game sessions, through closed questions questionnaires. Next to assessing individual shifts in viewpoints, pre–post

measured individual shifts can be compared within the group of participants to determine whether or not convergence of group opinion occurs. Secondly, interviews with participants well after game sessions – weeks to months – can be used to reflect on the impact of collaborative serious games on normative learning.

Two approaches are also used to assess relational learning outcomes. Firstly, asking participants self-reflective questions following game sessions – the approach used in all but one publication reviewed – in order to determine whether or not participants gained a better understanding of other stakeholders. Secondly, asking participants to self-report the level of collaboration in combination with analyzing participants' interactions during game sessions. This approach quantitatively analyzes the group dynamics during game sessions in order to determine whether or not relationships are enhanced and a mutual understanding is developed.

Of course, evaluation approaches are not exclusive from one another. Many of the reviewed publications in fact combine approaches or use multiple methods to assess learning outcomes. A multi-method evaluation approach is also recognized to fit well with serious gaming in general. However, explicitly assessing cognitive, normative and relational learning may help to separate the nature of learning through collaborative serious games. The overview provided in this paper may therefore serve as a reference for scholars designing and evaluating collaborative serious games, particularly those that address sustainability problems, but may also be useful in relation to serious games that aim to collaboratively address problems in complex systems in general.

Appendix 3.A

Overview of all publications included in the review, the quality assessment and the categorization of the data in relation to the research questions.

Game name	Reference	Quality assessment	Learning conceptualization (RQ1)	Data collection (RQ2)	Assessment methods (RQ3)	Quantitative or qualitative data (RQ4)	Social learning outcomes (RQ5)
Aqua Republica	(Jean et al., 2018)	5	Boundary crossing	Pre & During & Post	Questionnaires & interaction analysis & social network analysis	Quantitative & qualitative	Understanding other perspectives Building relationships and trust
CauxOperation	(Souchère et al., 2010)	5	Collective learning	Post	Debriefing	Qualitative	Raised awareness Increased system understanding Understanding other perspectives Building relationships and trust
Climate Game	(Zhou et al., 2013)	5	Links to experiential learning	Pre & During & Post	Questionnaires & observations & debriefs	Quantitative & qualitative	Increased system understanding
Community Cooperation Game	(Tanwattana and Toyoda, 2018)	5	Links to experiential learning	During	Observations	Qualitative	Increased system understanding Raised awareness
Forage Rummy	(Martin, 2015)	5	knowledge co-production	Post	Direct feedback	Qualitative	Increased system understanding Raised awareness Building relationships and trust

Game name	Reference	Quality assessment	Learning conceptualization (RQ1)	Data collection (RQ2)	Assessment methods (RQ3)	Quantitative or qualitative data (RQ4)	Social learning outcomes (RQ5)
FOWIS	(Hertzog et al., 2014)	4	Not conceptualized	During & Post	Observations & debriefs & Interviews	Qualitative	Increased system understanding
Futura	(Antle et al., 2011)	5	Experiential learning	During	Observations	Qualitative	Raised awareness
GO2Zero	(Bekebrede et al., 2018)	4	Not conceptualized	Pre & During & Post	Questionnaires & Observations	Quantitative & qualitative	Increased system understanding Building relationships and trust
Grazing game	(Villamor and Badmos, 2016)	5	Social learning & Anticipatory learning	During & Post	Observations & debrief	Qualitative	Increased system understanding Understanding other perspectives
Invitational Drought Tournament	(Hill et al., 2014)	5	Social learning	Post	Questionnaires & debriefs	Qualitative	Increased system understanding
IUP & NECAP	(Rumore et al., 2016)	5	Social learning	Pre & Post & Post-post	Questionnaires & debriefs & interviews	Quantitative & qualitative	Increased system understanding Raised awareness Understanding other perspectives

Game name	Reference	Quality assessment	Learning conceptualization (RQ1)	Data collection (RQ2)	Assessment methods (RQ3)	Quantitative or qualitative data (RQ4)	Social learning outcomes (RQ5)
KEEP COOL	(Eisenack, 2013)	4	Not conceptualized	Pre & During & Post	Questionnaires & observations	Qualitative	Increased system understanding
	(Meya and Eisenack, 2018)	4	Not conceptualized	Pre & During & Post	Questionnaire & Observations	Quantitative	Increased system understanding Raised awareness Change in views
	(Magnuszewski et al., 2018)	4	Social learning	Pre & During & Post	Questionnaires & observations	Quantitative & qualitative	No learning effects reported
Lords of the Valley	(Becu et al., 2017)	5	Links to social learning & experiential learning	Post	Debriefs	Qualitative	Increased system understanding
MAE SALAE RPG 1 & 2	(Barnaud et al., 2007)	5	Collective learning	During & Post & Post-post	Observations & Interviews	Qualitative	Increased system understanding Understanding other perspectives
Marine Spatial Planning Challenge	(Mayer et al., 2013)	5	Constructivist learning philosophy	During & Post	Questionnaires & observations	Quantitative & qualitative	Increased system understanding
New-District	(Keijser et al., 2018)	5	Policy-oriented learning	Pre & During & Post	Questionnaires & observations & data logging & interviews	Quantitative & qualitative	Increased system understanding Building relationships and trust
	(Becu et al., 2015)	5	Experiential learning	Pre & Post	Questionnaires	Quantitative & qualitative	Understanding other perspectives

Game name	Reference	Quality assessment	Learning conceptualization (RQ1)	Data collection (RQ2)	Assessment methods (RQ3)	Quantitative or qualitative data (RQ4)	Social learning outcomes (RQ5)
REEFGAME	(Cleland et al., 2012)	5	Links to social learning	During & Post	Debriefs	Qualitative	Increased system understanding
ReHab	(Page et al., 2016)	5	Social learning & experiential learning	During & Post	Observations & debriefings	Quantitative & qualitative	Increased system understanding
RESORTES	(Speelman et al., 2014)	4	Not conceptualized	Pre & During & Post & Post-post	Questionnaires & observations & debrief & interview	Qualitative	Building relationships and trust
Shariva	(Douven et al., 2014)	5	Meaningful play	Pre & Post	Questionnaires	Quantitative & qualitative	Raised awareness Increased system understanding Understanding other perspectives
SimPhy	(Ayadi et al., 2014)	4	Not conceptualized	During	Data logging	Quantitative	Increased system understanding
SPRINTCITY	(Duffhues et al., 2014)	5	Policy oriented learning	During & Post	Questionnaires & observations & data logging & interviews	Qualitative	Raised awareness Increased system understanding

Game name	Reference	Quality assessment	Learning conceptualization (RQ1)	Data collection (RQ2)	Assessment methods (RQ3)	Quantitative or qualitative data (RQ4)	Social learning outcomes (RQ5)
Sustainable Delta Game (and adaptations)	(Valkering et al., 2013)	4	Not conceptualized	Pre & During & Post	Observations & debriefs & perspective mapping	Qualitative	Increased system understanding Understanding other perspectives
	(Lawrence and Haasnoot, 2017)	5	Social learning	During & Post	Observations & interviews & debriefs	Qualitative	Increased system understanding Change in views
	(van der Wal et al., 2016)	5	Social learning & experiential learning	Pre & During & Post	Observations & data logging & interviews & perspective mapping	Quantitative & qualitative	Change in views
	(van Pelt et al., 2015)	4	Not conceptualized	Pre & During & Post & Post-post & Control Group	Questionnaires & observations & debriefs & interviews & control group	Quantitative & qualitative	Increased system understanding Raised awareness Establish experiential environment
	(Dionnet et al., 2008)	5	Individual learning & Social learning	Post & Post-post	Questionnaires & Interviews	Qualitative	Increased system understanding
Ter'Aguas	(Ducrot et al., 2015)	5	Social learning	Pre & During & Post & Post-post	Questionnaires & observations & debriefs & interviews	Qualitative	Increased system understanding Understanding other perspectives Change in views

Game name	Reference	Quality assessment	Learning conceptualization (RQ1)	Data collection (RQ2)	Assessment methods (RQ3)	Quantitative or qualitative data (RQ4)	Social learning outcomes (RQ5)
The Floodplain Management Game	(Stefanska et al., 2011)	5	Social learning	During & Post	Observations & debriefs	Qualitative	Raised awareness
The Multi-Hazard Tournament (MHT)	(Carson et al., 2018)	5	Social learning	Pre & Post & Post-post	Questionnaires	Quantitative & qualitative	Increased system understanding Raised awareness Understanding other perspectives Building relationships and trust
Unnamed game	(Salvini et al., 2016)	5	Social learning	Pre & Post	Interviews	Qualitative	Increased system understanding Building relationships and trust
Unnamed game	(Haug et al., 2011)	5	Social learning	Pre & During & Post & Post-post	Questionnaires & Observations & Debriefs & Interviews & Concept maps	Qualitative	Increased system understanding Understanding other perspectives
Unnamed game	(Meinzen-Dick et al., 2018)	5	Social learning	During & Post & Post-post & Control group	Questionnaires & data logging & interviews & community-level data	Quantitative & qualitative	Increased system understanding Real world adoption
Unnamed game	(Sausse et al., 2013)	4	Not conceptualized	During	Observations & data logging	Quantitative & Qualitative	Increased system understanding

Game name	Reference	Quality assessment	Learning conceptualization (RQ1)	Data collection (RQ2)	Assessment methods (RQ3)	Quantitative or qualitative data (RQ4)	Social learning outcomes (RQ5)
Unnamed game	(Moser and Mußhoff, 2016)	4	Not conceptualized	Pre & During	Questionnaires & data logging & control group	Quantitative	Increased system understanding
WeShareIt	(Onencan et al., 2016)	5	Effective learning	Pre & During & Post	Questionnaires & observations & debrief	Quantitative & qualitative	Increased system understanding
WeShareIt Nzoia	(Onencan and van de Walle, 2018)	5	Situational awareness	Pre & During & Post	Questionnaires & data logging	Quantitative	Raised awareness Increased system understanding
WORLD CLIMATE	(Sterman et al., 2015)	5	Links to experiential learning	Pre & Post-post	Questionnaires	Quantitative	Increased system understanding Raised awareness Change in views
WSP game	(Ferrero et al., 2018)	5	Experiential learning	Post	Questionnaires & debrief	Qualitative	Raised awareness Building relationships and trust

Chapter 4

How a tangible user interface contributes to desired learning outcomes of the Virtual River serious game

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Abstract

Serious games are increasingly used to facilitate stakeholder discussion and collaboration. Much attention is given in the game design literature on how to choose and design a serious game's scope, content, mechanics, and link to reality in order to achieve the game's intended learning outcomes. In this paper, we focus on how a serious game's interface and the interaction it elicits contributes to achieving learning outcomes. We do so in the context of the Virtual River, a serious game focused on river management. Following the design and evaluation of a paper prototype of the Virtual River, a design challenge arose as the highly simplified models of reality used was perceived as a black box by non-expert participants, while expert participants perceived it as oversimplified and unrealistic. As hydrodynamic models used in river management practice are in itself perceived by non-experts as a black box, we decided to look for ways to simplify the interaction with such models in the game. Here, we present a tangible user interface for the Virtual River. The interface enables participants to get a better grip on the hydrodynamics of a river system. The system is set up as a discussion platform where the game board and its tangible game pieces help participants express their thoughts and ideas. We argue that using tangible interaction in Virtual River contributes to social learning outcomes by providing hypotheses based on literature and present how we intend to test these hypotheses.

4.1 Introduction

Serious games are increasingly explored as tools to facilitate stakeholder discussion and collaboration in multidisciplinary settings (Ampatzidou et al., 2018; Furber et al., 2018; Marini et al., 2018). Serious games are generally referred to as games designed with a purpose other than entertainment, such as training, educating or informing players (Michael and Chen, 2005; Susi et al., 2007). More specifically towards the use of games to facilitate discussion and collaboration in a policy-making setting, Mayer (2009, p. 825) defines serious games as “*experi(m)ent(i)al, rule-based, interactive environments, where players learn by taking actions and by experiencing their effects through feedback mechanisms that are deliberately built into and around the game.*” By combining role-play with in-game feedback mechanisms, such serious games provide stakeholders with an environment to negotiate, deliberate, and exchange their perspectives on both the problem at hand and its solution in the safe experimentation environment of a game (Barreteau et al., 2007; Bekebrede, 2010; Mayer, 2009). This way, stakeholders learn both about the techno-physical complexity—the system covered in the game, including its underlying physical elements and its uncertainties—and the socio-political complexity—the strategic interactions between stakeholders in the policy arena (Bekebrede, 2010; Marini et al., 2018; Mayer, 2009).

As with any product, the design of the game is crucial to achieve its purpose. The game’s goal, scope, content and mechanisms require careful considerations. To help designers in this effort, various guidelines exist on how to develop (serious) games and what design choices to consider (Harteveld, 2011; Ritterfeld et al., 2009; Salen et al., 2004). These guidelines go in-depth on how to set up the rules and content of the game, how to create a link to reality, and how to facilitate play in order to establish intended interaction and learning outcomes. However, these guidelines pay less attention to the interface design and how the interface can contribute to achieving the specific purpose of the serious game.

In this paper, we focus on the design process of the Virtual River, a multiplayer serious game on river management, and argue that the game’s tangible user interface contributes to intended learning outcomes. Specifically, we are developing the tangible user interface – an interface that provides physical forms to digital information (Hornecker and Buur, 2006; Ishii, 2008) – to overcome a design challenge that arose from formative evaluation sessions of a Virtual River paper prototype. Specifically, non-expert participants perceived the game and its models as complex, while expert participants found the same models oversimplified and unrealistic. The design challenge therefore relates to incorporating hydrodynamic models, numerical models that calculate water flow, in Virtual River while at the same time offering a

way to easily and intuitively interact with these models. In this paper, we use the case of Virtual River's tangible user interface, in development at the time of writing, to combine theory on tangible interaction and social learning to discuss how tangible interaction may not only overcome the design challenge, but also enhance specific social learning outcomes of playing the game.

In [Section 4.2](#), we further introduce river management with a particular focus on the Netherlands and serious games in relation to river management. In [Section 4.3](#), we present the theoretical framework in relation to both social learning and tangible interaction. In [Section 4.4](#), we discuss Virtual River, including its goal, a previously developed paper prototype and its evaluations, and the tangible user interface currently in development. In [Section 4.5](#), we present three hypotheses, based on literature, on how tangible interaction may contribute to specific learning outcomes and discuss how we intend to test these hypotheses. Finally, in [Section 4.6](#), we state some concluding remarks and explain our next steps in the development and evaluation of Virtual River and its tangible user interface.

4.2 Background and related work

4.2.1 River management

Rivers are in many ways important to society, from providing a source of water to channels for shipping to habitats for animals and plants. At the same time, rivers can also pose a threat to society as rivers are prone to flooding. Therefore, rivers, especially in low-lying countries, are nowadays actively and carefully managed. However, river management issues are generally multi-scale ([Gurnell et al., 2016](#); [Vreugdenhil et al., 2010](#)), concern inherent uncertainties ([Berends et al., 2018](#); [Warmink et al., 2011](#)), and affect multiple stakeholders and agencies ([Wiering and Arts, 2006](#); [Wolsink, 2006](#)). Therefore, decision-making processes need to be adaptive to deal with the uncertainties and need to include the diversity of knowledge and values of all affected stakeholders. To this end, scholars have advocated active experimentation and continuous evaluation, summarized as learning-by-doing, in natural resources management and in river basin management specifically ([Armitage et al., 2007](#); [Berkes, 2009](#); [Pahl-Wostl, 2007](#); [Rodela, 2011](#)).

In the Netherlands, a country known for its continuous combat with water, the main priority in river management is flood safety; protecting the hinterland from flooding. The historic approach has been the construction and reinforcement of dikes, but a recent paradigm shift has changed the approach from protection to include resilience by applying intervention measures that create space for water

(Klijn et al., 2013; Rijke et al., 2012; van Herk et al., 2012). Examples of such space creating measures include side channels, i.e. secondary river channels in the rivers' floodplains, or moving a dike further away from the river to increase the size of the floodplain. While the paradigm shift still holds flood safety as the most important priority, it also focuses on nature restoration efforts along the Dutch rivers. The paradigm shift has therefore also introduced new stakeholders to Dutch river management (Wiering and Arts, 2006; Wolsink, 2006). However, Dutch river management is predominantly expert- and model-driven. Water managers rely on complex hydrodynamic models to estimate how the river will react to certain intervention measures. The tools used by water managers are perceived as black boxes to stakeholders from non-water backgrounds (den Haan et al., 2018a). In such a setting, serious games could serve as boundary objects; shared objects that may serve as references in discussions and that "*are both adaptable to different viewpoints and robust enough to maintain identity across them*" (Star and Griesemer, 1989, p. 387). In other words, a serious game—through its interaction design, its physical or abstract representation of reality, and its rules—integrates scientific and political worlds into a shared object in a way that is recognizable yet interpretable by all stakeholders in order to serve as a reference for discussion (Barreteau et al., 2007; White et al., 2010).

4.2.2 *Serious gaming in river management*

Serious games that integrate scientific and political worlds are increasingly finding their way in the water domain (Aubert et al., 2018; Magnuszewski et al., 2018; Marini et al., 2018; Medema et al., 2016). In relation to river management specifically, there are a number of examples of serious gaming approaches to facilitate stakeholder discussion and collaboration (Douven et al., 2014; Hill et al., 2014; Lankford and Watson, 2007; Onencan and van de Walle, 2018; Rusca et al., 2012; Savic et al., 2016; Stefanska et al., 2011; Valkering et al., 2013). For example, Stefanska et al. (2011) describe the Floodplain Management Game, where players play the roles of farmers, local authorities, or water boards in a small area in the river basin each with their own objectives, such as profit, biodiversity, and control of water flow, often conflicting with those of others. This way, players explore technical problem-solving as well as relational issues. Valkering et al. (2013) developed the Sustainable Delta Game in which players are given the objective to develop collective strategies to limit the probability of both floods and droughts from occurring. As a higher level goal, players learn about the complex interactions between river management, climate change and changes in society. Douven et al. (2014) developed the Shariva game in which players have to make trade-offs between hydropower production in upstream areas and agricultural development in downstream areas. The objective of the Shariva

game is to create awareness, to upgrade knowledge, and to design procedures for cooperation in transboundary river basins among water and related professionals.

While these serious games all cover different scopes and learning objectives, they have in common that they provide stakeholders with a means to collaboratively explore both the problem at hand and its solution. In doing so, stakeholders learn about how a river system functions, how management decisions affect certain key performance indicators, and how decisions lead to trade-offs between these indicators—the techno-physical complexity—as well as how other stakeholders look at the problem, how stakeholders prefer to address the problem, and how stakeholders might be willing to compromise—the socio-political complexity.

4.3 Theoretical framework

4.3.1 *Social learning*

Serious games—particularly the multiplayer and multi-role serious games following the definition by Mayer (2009)—are recognized to offer the necessary collaborative and participative interactions needed to establish social learning (Ampatzidou et al., 2018; Medema et al., 2016). Social learning is considered to be a normative goals and prominent driver to manage natural systems in natural resources management (Armitage et al., 2008; Berkes, 2009; Pahl-Wostl et al., 2007a; Reed et al., 2010). Scholars have yet to find a commonly shared definition for social learning (see Cundill and Rodela, 2012; Muro and Jeffrey, 2008; Reed et al., 2010; Rodela, 2011), but scholars do share the view that social learning has occurred when a change in understanding is achieved through interaction in collaborative and participatory settings (Baird et al., 2014; Keen et al., 2005; Muro and Jeffrey, 2008; Pahl-Wostl et al., 2007a; Reed et al., 2010). Collaborative and deliberative interactions between stakeholders are required to achieve social learning, which should ultimately lead to collective action (Cundill and Rodela, 2012; Keen et al., 2005; Pahl-Wostl et al., 2008). Changes in understanding may relate to the natural system that is managed, the problem that is addressed, or agreement on either the problem or its solution. Therefore, social learning outcomes relate to the techno-physical complexity of the system, the socio-political complexity, or both. To differentiate between these different forms of social learning, Baird et al. (2014) offers a typology that contains three types of learning outcomes:

- cognitive, acquisition of new or restructuring of existing knowledge;
- normative, changes in norms, values or paradigms, as well as convergence of group opinion; and

- relational, improved understanding of others' mind-sets, building relationships, and enhancing trust and cooperation with others

The typology is beneficial as it separates social learning outcomes by their nature—cognitive, normative or relational—as opposed to their perceived value—learning may in fact have a negative effect on taking collective action. Moreover, the typology recognizes relational learning as a separate, explicit learning outcome, which is of particular importance to the multi-stakeholder setting found in river management and learning about its socio-political complexity. We therefore used the typology by [Baird et al. \(2014\)](#) to distinguish between learning outcomes in connection to the literature on tangible interaction.

4.3.2 *Tangible interaction*

Tangible interaction is a theoretically informed interaction design framework that combines physical object manipulation and digitally controlled interactive behavior ([Hornecker and Buur, 2006](#); [Ishii, 2008](#)). As a response to the increasing digitalization of everyday life, tangible interaction starts from the point of view that human beings have evolved to deal with the physical world and that physical objects as a result have a specific cognitive, affective, and social interaction quality. This quality may easily get lost in the transition to purely graphical (screen-based) interfaces ([Klemmer et al., 2006](#)). In response, tangible interaction proposes to combine the familiar physical and social world with the digital world in a way that preserves the desired properties of each and that achieves a seemingly “natural” human-computer interaction ([Jetter et al., 2014](#)). A tangible user interface can therefore be defined as an interface that provides physical forms to digital information ([Ishii, 2008](#)). Known examples of tangible user interfaces include the reacTable, a musical instrument where users can caress, rotate, and move physical objects on a tabletop surface to create music ([Jordà et al., 2007](#)), and Illuminating Clay, where users apply landscape analysis directly by manipulating the clay model of a landscape ([Piper et al., 2002](#)).

Previous research suggests that tangible user interfaces offer qualities to facilitate learning and collaboration (see e.g. [Antle and Wise, 2013](#); [Marshall, 2007](#) for more elaborate overviews), both of particular interest to the design of a serious game. Firstly, by using physical objects as part of the interface's interaction invites hands-on engagement ([Marshall et al., 2003](#); [Price et al., 2003](#); [Price et al., 2008](#); [Resnick, 1998](#); [Zuckerman et al., 2005](#)), providing users with tools to engage in new ways of thinking ([Resnick et al., 1998](#)). Secondly, a tangible user interface invites trial-and-error behavior ([Xu, 2005](#)) and experiential learning through exploration, discovery, and reflection ([Marshall et al., 2003](#); [Price et al., 2009](#); [Price et al., 2003](#)). Thirdly, from

the perspective of cognition, by using physical objects as external representations eases problem solving as processing the representations does not have to be done in mind, but can simply be inspected in the world (Zhang and Norman, 1994), aiding users to grasp abstract concepts through the interaction with physical objects (Antle, 2007; Clements, 2000; O'Malley and Fraser, 2004). Lastly, tangible user interfaces also enable users to engage in collaborative activities (Fernaes and Tholander, 2006; Hornecker and Buur, 2006; Price et al., 2009) – a prerequisite to social learning – by offering a multi-user interface where control is shared (Xu, 2005; Zuckerman et al., 2005) and making the actions and activities of other users visible (Stanton et al., 2001; Suzuki and Kato, 1995). Specifically, the social-collaborative value of tangible interaction has been emphasized since its initial formulation (see Dourish, 2004), focusing on how users working with tangible objects in social settings may contribute to creating a shared understanding of the problem at hand (Arias et al., 2000).

4.4 Virtual River

As part of the RiverCare research programme (Hulscher et al., 2014), we are developing the Virtual River, a multiplayer serious game, which aims for players to experience how the river system functions and what the implications of different management choices and interventions are. In addition, we are particularly focusing on facilitating stakeholders to exchange perspectives following previous research that analyzed the different perspectives held and used by river management stakeholders in decision-making (den Haan et al., 2018a). By playing the Virtual River, players learn about the socio-political complexity as they engage in active collaborations and negotiations with other players playing different river management roles. On the techno-physical complexity, players learn about how management measures affect the system and how such measures impact indicators like flood safety, biodiversity, and costs. Moreover, players learn about the trade-offs that measures present between these indicators.

4.4.1 Initial game design and paper prototype

In the Virtual River game, players are given specific roles and tasked to manage a typical Dutch river stretch in turns representing time steps of five years each. Each player role has its own goal, its own budget, and a special rule it can use throughout the game. Players have to make decisions collectively on the whole game area as well as individually on floodplain areas they own. Management interventions for the whole area include applying spatial measures such as creating side-channels or reinforcing dikes. Both these choices increase the discharge capacity of the river stretch, positively contributing to the indicator of flood safety. Spatial measures generally

have the added benefit of positively contributing to the indicator of biodiversity. However, to increase the same discharge capacity, spatial measures generally cost more than dike reinforcement—and players need to reach an agreement on how to share the costs either way—and spatial measures need to be constructed on floodplain land owned by players.

Management choices for the floodplain areas relate to how individual players manage the land under their control. For the flood safety indicator, the best option would be to turn all floodplain areas to grass—which has low hydraulic resistance and therefore leads to a high river discharge capacity—and performing active maintenance—in the case of grass, mowing and making sure no other type of vegetation starts to grow. However, for the biodiversity indicator, floodplains with mixed vegetation—including grass, bushes, and trees—that is allowed to grow and develop offers a much wider variety of plant species and a much richer habitat for animals.

Whereas the nature manager, a role in the game, prefers to stimulate the latter, the water manager could be opposed to such arrangements when flood safety is at stake. Therefore, the water manager has a special rule that says that it can enforce other participants to lower hydraulic resistance—basically, remove vegetation like trees and bushes—on their lands whenever flood safety is at stake, a rule that corresponds to reality in terms of the Dutch Public Works Authority's powers.

In a previous design iteration, we developed a board game prototype of the Virtual River to evaluate its scope, game indicators, and initial rules and roles ([den Haan et al., 2018b](#)) ([Figure 4.1](#)). Formative evaluations showed that participants found the game engaging and insightful, and that players understood the link to reality. However, participants, in particular non-expert participants, found the game

Figure 4.1 Paper prototype impression with the main game board on the left with a river stretch, game score indicators on the right, and a role card on the left bottom.

complex and perceived the game's models—calculations on the flood safety, biodiversity, and costs indicators and how players were scored on these—as a black box. This prevented these participants from gaining the techno-physical insights into how a river system functions and responds to changes. However, expert participants questioned the realism of the models behind the paper prototype, finding these instead to be oversimplified and unrealistic.

4.4.2 *Tangible user interface*

Following the formative evaluations of the paper prototype, our focus for the design and further development of Virtual River shifted from addressing the gap in complexity perception between participants to lowering or helping to navigate the game's complexity and removing the perceived black box. Simultaneously, we aimed to increase the link to reality and real-world models. On the one hand, although the paper prototype used a highly simplified cause-effect model for the hydrodynamics of the game, non-expert participants already perceived it as complex and as a black box. On the other hand, experts participants questioned the realism of the model as oversimplified. Simply incorporating a more elaborate model in the next iteration of Virtual River could help solve the latter, but not the first. Moreover, hydrodynamic models are in itself perceived as a black box by non-experts. Therefore, we decided to look for ways to simplify the interaction with hydrodynamic models. To address this design challenge, we looked to tangible interaction and are currently developing a tangible user interface where players are provided with a physical representation of a river stretch that players can alter to directly manipulate a hydrodynamic model.

As a basis for the interface, we are using an existing framework called the Sand-Box, an augmented reality collaborative modeling tool (Ottevanger et al., 2017). Inspired by the LakeViz project (Reed et al., 2016), the SandBox consists of a box of sand, a color and depth camera (RGBD, Kinect), the relevant hydrodynamic model, and a projector (Figure 4.2). The sand can be molded by end users to design a river. The sand is measured by the RGBD camera. This information is used to change the schematization (the geometry of the river stretch) of the numerical model. Delft3D Flexible Mesh, a 1D, 2D, 3D hydrodynamic model, is used in this study for rivers, but other models that use the Basic Model Interface (Peckham et al., 2013) are also supported. The model results are visualized on the sand using the projector. The SandBox adds an easy to use interface to real world engineering models and has shown to invite users to experiment and, through trial and error, experience how a hydrodynamic model works and generate understanding of how a river system functions. In a group setting, the SandBox has contributed to enhanced communication between stakeholders.

Figure 4.2 SandBox setup and interface (photo from [Ottevanger et al., 2017](#)). The SandBox uses a Kinect to measure the geometry of the sand, representing a river stretch. Molding the sand into a new shape changes the schematization used by the hydrodynamic model and a projector projects the model's output back on the box of sand.

For the Virtual River, we replaced the sand with game pieces of different heights on a hexagonal grid. We took this approach to retain the full benefit of the SandBox framework, while adding structure that limits the amount of options for players to consider in order to make it suitable for gameplay. In our approach, we are transforming the board from the paper prototype into a 3D game board, where the shape of the game board, based on hexagon game pieces of different heights, correspond to the geometrical shape of a river stretch. The geometrical shape is used as input for a hydrodynamic model and the output of the hydrodynamic model is projected back on the 3D game board (see [Figure 4.3](#) for an impression).

To address calibration issues with the Kinect—and to eliminate the possibility of having to recalibrate it during a game session—we developed an alternative

Figure 4.3 Game board impression with (a) an initial river basin, in a typical Dutch layout, and elevation projection; (b) game board after the construction of a side-channel, a secondary channel next to the main river channel; (c) game board after constructing a longitudinal training dam, a dam constructed in the main river in parallel to the water flow; and (d) game board after a dike relocation, moving a dike away from the river to increase the size of the floodplains. Water flow is not included in this impression.

method to detect the game pieces on the board based on markers and image processing. Specifically, we constructed the game board on a transparent underlayer and attached colored markers to the bottom of all game pieces. There are two types of game pieces: (1) geometry pieces, different heights of hexagon shaped pieces assigned red markers; and (2) land use pieces, different flat pieces representing different land use that fit on top of the geometry pieces assigned blue markers (Figure 4.4). A photograph is taken from beneath the game board and a Python script subsequently calibrates the picture to detect the correct positions of all hexagon grid cells and analyzes the amount of both red and blue markers of game pieces at each grid cell location (Figure 4.5).

We are currently developing a prototype for the Virtual River's tangible user interface (Figure 4.6). At the time of writing, the physical part of prototype is built

Figure 4.4 The geometry and land use type of game pieces (a), which combined (b) make up the position of one cell.

and we are in the processes of calibrating and refining the detection script as well as the link to the SandBox framework. As can be seen in Figure 4.6, all game pieces are only primed with a grey color and although the geometry pieces can be identified by their actual height, we do plan to see if using a greyscale gradient, where a specific color value between white and grey corresponds to a specific height, can be used to help identification. We intend to test if using different color values do not interfere with the projected visualizations. The land use pieces are not yet identifiable in Figure 4.6, these are all flat surfaces. We plan to add icons to match different land uses, for example a tree to represent a forest and a building to represent built environment. These icons could be flat using physical shapes or stickers. Our preference is the first, as physical shapes add concrete representations, in line with our approach of using tangible interaction, as well as help players to more easily grab and move pieces on the board. However, this similarly requires testing whether this interferes, or does not interfere with the projected visualizations as well as the icons remain, or do not remain, identifiable under the projection.

Figure 4.5 (a) Game board with pieces and markers as seen from below. Four red markers indicates that a geometry piece of four levels high is positioned in the grid cell. The four white circles are used for calibration; and (b) possible output of the detection script.

Figure 4.6 Game board prototype with (a) the empty board showing the grid and transparent underlayer; and (b) a filled board with game pieces that combined form the geometry of a river stretch.

To summarize, the Virtual River's tangible user interface provides players with a shared gaming environment where players directly interact with a hydrodynamic model by changing the arrangement of game pieces. For example, by replacing higher geometry pieces with lower ones—basically excavating the area—increases the discharge capacity of game area by creating more floodplain areas, effectively creating space for water. By changing land use pieces that have high hydraulic resistance—therefore limiting water flow—with pieces with low resistance similarly increases discharge capacity. Based on the arrangement of game pieces as input, the hydrodynamic model is updated and the resulting output in the form of water flow is projected back on the game board, providing players with instant feedback on their actions.

4.5 Discussion

Tangible user interfaces have been applied in other tabletop (serious) game settings. Bakker et al. (2007) developed *Weathergods*, a game where players try to earn the favor of weather gods in order to make it rain and save the player's village harvest. *Weathergods* uses a digital surface in combination with tangible game pieces, physical representations of for example players' avatars, that can be moved between different board positions. Speelpenning et al. (2011) developed physical objects as tangible controllers for the serious game *Futura*, a serious game where players experience the complexity of planning for a sustainable future. In their approach, players use physical magnifying glasses to open visualization layers in the game that provide players with additional information. Inspired by *The Incredible Machine*, Leitner et al. (2008) developed the *IncreTable* where players solve puzzles by combining physical and virtual game pieces. The *IncreTable* allows users to combine and connect for example physical domino stones with virtual ones. All these applications use a digital surface as a game board in combination with tangible objects. In our approach, the game board itself is formed by physical objects that serve as both the control of

the hydrodynamic model and the representation of the river stretch. The approach follows the tangible user interface as an interactive surface genre as explained by Ishii (2008), which focuses on supporting collaborative design and simulation.

In the next subsections, we discuss the benefits of the tangible user interface for Virtual River from the perspective of social learning by presenting hypotheses in relation to the three types of social learning outcomes: cognitive, normative, and relational learning (see 4.3.1 and Baird et al., 2014). Specifically, the hypotheses are presented from the perspective of the Virtual River's tangible interface, they are provided with arguments from literature on tangible interaction, and they are discussed in terms of intended assessment. The latter is based on earlier work that analyzed the different approaches used to evaluate social learning outcomes (den Haan and van der Voort, 2018).

4.5.1 *Hypothesis 1: the Virtual River's tangible user interface enables players to gain an increased understanding of how a river system functions*

The first hypothesis relates to cognitive learning, which covers the acquisition of new knowledge and the restructuring of existing knowledge. The hypothesis also relates directly to our design challenge to incorporate realistic hydrodynamic models in the Virtual River while at the same time offer easy and intuitive interactions with hydrodynamic models. To address the design challenge, we expect that especially non-expert players learn about how hydrodynamic models work and, therefore, how the river system functions. Furthermore we expect that, from the perspective of cognition, the tangible user interface using a physical representation of a river stretch helps players to gain the increased system understanding. As part of the information needed during gameplay is not 'kept in mind', but can simply be inspected in the world, what Don Norman famously called 'knowledge in the world' (Norman, 2013). Furthermore, knowledge in the world allows for 'epistemic action'. Players can use their embodied skills to manipulate the information in the environment, the game board itself, and can use their visual pattern recognition routines to inspect the result – the visualized projection – which together assists in making inferences. Instead of heavy mental gymnastics, players can reorganize the world and then simply 'see' the answer to a problem before them (Kirsh, 2010). In other words, in line with the tradition of Distributed Cognition (Hutchins, 1995), using tangible interaction allows players to 'offload' information into the physical structure of the local environment, releasing the brain of work and making thinking easier (van Dijk, 2018).

We intend to test this hypothesis by first applying pre- and post-game knowledge measurements, including knowledge on hydrodynamic models. In addition, we intend to compare individual pre- and post-measurements with video recordings

of game sessions to observe if the use of the tangible user interface contributed to differences in measurements. Open questions could furthermore be asked directly to players in interviews or questionnaires after game sessions to gain additional qualitative insights into how the tangible user interface enabled learning about the functioning of a river system.

4.5.2 Hypothesis 2: Using a tangible user interface in the Virtual River aids players in understanding each other's perspectives

The second hypotheses relates to relational learning, which covers understanding others' mind-sets, building relationships, and enhancing trust and cooperation with others. In general, providing players with a shared environment where players engage in collaboration and negotiation creates a setting where players exchange views and opinions. Following the ethnomethodological tradition in sociology (Suchman, 2007), the use of tangible objects to express our thoughts makes these thoughts become public. Therefore, we speculate that allowing players to literally see another player think by how they are manipulating the game board, i.e. representing that thought process, provides players with a platform that helps them observe the point of view of others and empathize with it (Dourish, 2004; Klemmer et al., 2006). Moreover, we speculate that these insights could contribute to the converging of group opinion, associated with normative learning, as players may also intervene while observing others, which leads to a shared process of manipulating objects: a collaborative process of sensemaking (Arias et al., 2000; Dourish, 2004). Therefore, collaboratively negotiating on how to best structure the physical pieces on the game board may help to not just align the pieces as such, but also to align the different perspectives of the players (Ehn, 2011; van Dijk and van der Lugt, 2013).

To test this hypothesis, we intend to ask players self-reflective questions on what they learned about the perspectives of others after game sessions in either questionnaires or individual interviews. In addition, game session recordings can be analyzed and observations can be compared to the players' answers to these questions.

4.5.3 Hypothesis 3: Using a tangible user interface in Virtual River contributes to players building relationships and trust

The third hypothesis relates to relational learning as well. While the literature acknowledges that using tangible objects may create a shared understanding of the problem at hand (Arias et al., 2000), people engaging in collaborative efforts in itself creates a dimension of relationship building and trust formation. Moreover, as van Dijk and van der Lugt (2013) showed, working together in a physical space helps

people to interact nonverbally—look each other in the eye, ‘open up’ to the other by turning the body, gesture to another to take their turn, and so on. Looking at the same screen together—even if it is a large projection—tends to focus attention to the information on the screen, and away from the actual people using that information and being together in a social situation. While the tangible interaction literature has not often emphasized this aspect, we speculate that in the present context having a tangible river setting that people can stand around, work with, and point to could in this way help building relationship and trust.

We intend to test this hypothesis by applying interaction analysis (Jordan and Henderson, 1995) to recordings of game sessions to analyze both interaction between players as well as between players and the interface. This approach could be complemented with follow-up interviews some time after game sessions to gain insights into if any relationship building led to any cooperation.

4.6 Concluding remarks and next steps

We are developing a tangible user interface for the Virtual River, a serious game that aims for players to experience how the river system functions and what the implications of different management choices are. In particular, we discussed why we looked to tangible interaction as a way to overcome the design challenge to incorporate hydrodynamic models in Virtual River while providing players with an easy to use interface to manipulate these models. Moreover, we applied a theoretical perspective on why tangible interaction offers benefits from the perspective of Virtual River’s learning objectives, captured in three hypotheses. Firstly, we speculate that the Virtual River’s tangible user interface contributes to cognitive learning outcomes as it enables players to gain an increased understanding of how a river system functions (hypothesis 1). Specifically, the tangible user interface provides players what an tool to directly manipulate a hydrodynamic model and see the results. At the same time, by using physical representations, the tangible user interface enables players to inspect information ‘in the world’, releasing the brain of work and making thinking easier. Secondly, we further speculate that Virtual River’s tangible user interface contributes to relational learning outcomes as it aids players in understanding each other’s perspectives (hypothesis 2). By manipulating the physical game board, players make their though process explicit and other players may be able to observe their point of view and empathize with it. Lastly, we speculate that that Virtual River’s tangible user interface contributes to players building relationships and trust (hypothesis 3). Specifically, offering a physical board to stand around, work with, and point to over a screen-based interface may be beneficial to building relationship and trust.

As next steps, we plan to first operationalize the whole interface, including developing and testing representations, icons in either physical or sticker form, for the land use of each game tile. From there, we intend to first run game sessions as formative evaluations; does the game design achieve its design goal and does the interface design effectively overcome the design challenge. Afterwards we intend to hold summative game evaluation sessions that focus on evaluating social learning outcomes of playing Virtual River as well as evaluating how tangible interaction contributes to these outcomes.

Chapter 5

The Virtual River Game: Gaming using models to collaboratively explore river management complexity

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Abstract

Serious games are increasingly used as tools to facilitate stakeholder participation and stimulate social learning in environmental management. We present the Virtual River Game that aims to support stakeholders in collaboratively exploring the complexity of a changed river management paradigm in the Netherlands. The game uses a novel, hybrid interface design that features a bidirectional coupling of a physical game board to computer models. We ran five game sessions involving both domain experts and non-experts to assess the game's value as a participatory tool. The results show that the game was effective in enabling participants to collaboratively experiment with various river interventions and in stimulating social learning. As a participatory tool, the game appears to be valuable to introduce non-expert stakeholders to Dutch river management. We further discuss how the hybrid interface combines qualities usually found in board and computer games that are beneficial in engaging stakeholders and stimulating learning.

Software availability

Software name: Virtual River

Developers: Robert-Jan den Haan, Fedor Baart

Year first official release: 2020

Hardware requirements: PC, game table (drawings available) including a webcam, touchscreen monitor and projector (a test version can be run on just a PC)

System requirements: Windows or Linux, Delft3D FM Suite 2019.01 (1.5.1.41875)

Program language: Python

Program size: 1.7 GB

Availability: <https://github.com/erjeetje/Virtual-River-prototype>

License: GPL-3.0

Documentation: README in the Github repository

5.1 Introduction

Stakeholder involvement and participatory approaches are increasingly important in environmental decision-making (Pahl-Wostl et al., 2008; Reed, 2008; Voinov et al., 2016). A recent shift from sectoral towards more integrated natural resources management has made stakeholder participation essential to the pursuit of cross-disciplinary objectives (Berkes, 2009; Pahl-Wostl, 2007; Reed, 2008). At the same time, stakeholder participation is recognized as an effective way to improve the quality of and acceptance in decision-making (Cundill and Rodela, 2012; Reed, 2008; Voinov et al., 2016). One method that is receiving increasing attention to facilitate stakeholder participation in environmental management is serious gaming (Aubert et al., 2018; Rusca et al., 2012; Voinov et al., 2016).

Serious games are generally referred to as games that have a primary purpose other than mere entertainment (Michael and Chen, 2005; Susi et al., 2007). In the context of environmental management and participation, serious games are defined by Mayer (2009, p. 825) as “*experi(m)ent(i)al, rule-based, interactive environments, where players learn by taking actions and by experiencing their effects through feedback mechanisms that are deliberately built into and around the game.*” To provide feedback on actions, such serious games include a simplified representation of reality in terms of both the environmental system and its stakeholders (Harteveld, 2011; Redpath et al., 2018; Rodela et al., 2019). In this way, serious games enable stakeholders to explore environmental challenges, interventions, and the effects of such interventions in an environment in which it is safe to experiment. Furthermore, serious games enable stakeholders to experience the strategic interactions between stakeholders by explicitly including interaction rules and assuming stakeholder roles in the game. Therefore, serious games facilitate stakeholders’ learning about both the

physical-technical and the inherent socio-political complexities (Bekebrede, 2010; de Caluwé et al., 2012; Geurts et al., 2007; Mayer, 2009). The lessons learned while playing serious games can be both relevant and transferable to real-world decision-making (Geurts et al., 2007; Mayer, 2009).

One promising opportunity for serious games in the context of stakeholder participation in environmental management is their use as what Rodela et al. (2019) categorize as learning-based interventions. Such games are developed to engage stakeholders in dialogue and activity in order to contribute to what is commonly referred to as social learning: changes in understanding through interaction in collaborative and participatory processes that go beyond the individual (see e.g. Cundill and Rodela, 2012; Muro and Jeffrey, 2008; Reed et al., 2010; Rodela, 2011). As learning-based interventions, games are therefore developed under the assumptions that these: (1) provide stakeholders with participatory environments that facilitate the stakeholder interactions and collaborative experimentation that are essential to establish social learning; and (2) contribute to individuals or groups experiencing a change in understanding as a result of the game's collaborative activity (Ampatzidou et al., 2018; Flood et al., 2018; Medema et al., 2016). In the literature, social learning is usually operationalized as: (1) cognitive learning: acquiring new or restructuring existing knowledge; (2) normative learning: changing viewpoints, values, or paradigms; and (3) relational learning: increasing the understanding of the mind-set and perspectives of other stakeholders as well as fostering the ability to cooperate among stakeholders (Baird et al., 2014; Ensor and Harvey, 2015).

In the context of environmental management, there are various examples of serious games as learning-based interventions (see e.g. reviews by Aubert et al., 2018; den Haan and van der Voort, 2018; Flood et al., 2018 for games on water management, sustainability, and climate change respectively). As one of a few recent examples (from a far longer list), Craven et al. (2017) developed SimBasin to bring stakeholders together with the aim of developing a shared understanding and sense of urgency around the management of the Magdalena-Cauca river basin in Colombia. They showed that the game was successful in creating an open discussion space to bring stakeholders and scientists together. The Sustainable Delta Game (Valkering et al., 2013; van der Wal et al., 2016) challenges stakeholders to develop collective strategies to manage a fictional stretch of a Dutch river and aims to help them to learn about the complex interactions between river management, climate change, and changes in society. Results from twelve sessions showed that playing the game led to the convergence of the players' perspectives (van der Wal et al., 2016). Becu et al. (2017) developed LittoSim to enable social learning among local authority managers on Oléron Island in France about prevention measures to reduce the risk of

coastal flooding. They showed that LittoSim facilitated stakeholder experimentation with and learning about risk prevention measures in relation to possible flood events. [Van Hardeveld et al. \(2019\)](#) developed the RE:PEAT game to explore collaborative management strategies to help reduce soil subsidence in the Netherlands. Results from ten sessions showed that RE:PEAT improved cooperation among peatland stakeholders, increased their understanding of the problems, and led them to possible strategies for reducing soil subsidence.

Recent changes in Dutch river management provide a valuable case study for designing and evaluating a serious game as a participatory tool. Traditionally, river management has been dominated by dike strengthening and was therefore within the field of hydraulic engineering. A new management paradigm, involving spatial measures and multifunctional design, brings in many other stakeholders that are traditionally not usually involved with river management. The challenge of collaboration between these diverse groups of stakeholders, in what is still a rather technical field, demands a shared understanding of the physical system. In this paper, we present the Virtual River Game, a serious game to collaboratively explore river management complexity in the Netherlands. The game was played in five sessions involving both domain experts and non-experts to assess its value as a participatory tool. It was guided by the research questions: (1) to what extent does the game facilitate stakeholders collaboratively exploring and experimenting with river interventions; and (2) to what extent does playing the game lead to social learning outcomes?

The paper is structured as follows. The next section discusses the game and particularly the fact that it facilitates stakeholders to apply river interventions on a game board that has a bidirectional link to computer models. [Section 5.3](#) presents the assessment approach of the game, including an overview of the sessions and the methods to collect and analyze the data in order to address the research questions. [Section 5.4](#) reports on the factual game output of the sessions, observations of the in-game discussions, and the participants' self-reported learning outcomes. The paper ends with a discussion of the value of the game as a participatory tool as well as on how the game's hybrid interface combines those qualities found in board and computer games that benefit and support stakeholder participation and social learning processes.

5.2 Game description

5.2.1 Background and aim

To protect the deltaic floodplains from flooding, the traditional approach in the Netherlands has been to build and reinforce dikes. However, near-flood events in the

1990s shifted the approach of Dutch river management towards applying so-called spatial measures that aim to create more space for rivers to safely discharge water (Rijke et al., 2012; Warner et al., 2012); for example, by digging side channels, lowering floodplains, and moving back dikes (see e.g. Berends et al., 2019; Straatsma et al., 2019; van Stokkom et al., 2005). In addition to lowering peak water levels, such spatial measures also aimed to restore the local ecology (Fliervoet et al., 2013; Klijn et al., 2013; Straatsma et al., 2017). This paradigm shift, while still retaining flood safety as its primary focus, led to an increasingly more integrated river management approach. As a result, it attracted new stakeholders to river management (Verbrugge et al., 2019) and emphasized the importance of stakeholder participation in decision-making (Edelenbos et al., 2017; Fliervoet et al., 2013; Zevenbergen et al., 2015).

In the context of the new Dutch river management paradigm, we set out to develop the Virtual River Game as a tool to increase and support stakeholder participation. The game can beneficially be played at an early stage of a project, as an icebreaker activity but that is disconnected from the project's actual decision-making. The game enables stakeholders to collaboratively experiment with river interventions in order to increase their understanding of Dutch river management – including both the physical system and the effects and trade-offs of specific interventions – and the perspectives and interests of other stakeholders in relation to such interventions. During the game's design process, we found that some stakeholders – particularly those introduced to river management as a result of the paradigm change – view the hydrodynamic models central to Dutch river management decision-making as mysterious black boxes (den Haan et al., 2018). Therefore, to support stakeholder participation, we set out to develop the Virtual River Game to enable stakeholders – regardless of background and expertise – to work with a hydrodynamic model that is widely used in practice. To that end, we developed a hybrid interface based on tangible interaction; linking physical forms to digital information (Hornecker and Buur, 2006; Ishii, 2008). The interface features a bidirectional coupling of a physical game board to a hydrodynamic, ecological, and cost model. An impression of the Virtual River Game and its interface is shown in Figure 5.1. The Virtual River Game uses hexagonal tiles to represent a typical stretch of a Dutch river that includes a main channel and floodplains and dikes on both sides of the channel. The changing of the tiles on the game board provides input to the models, while the models' output is visualized both on the game board through projection and in a game engine shown on a touchscreen monitor. An overview of the game's software and hardware components is shown in Figure 5.2. In the following sections, we first introduce the models and their integration in the Virtual River Game, followed by a description of the game itself.

Figure 5.1 An impression of the game table, including the physical board, touchscreen monitor, projector, and webcam. The projection on the board in this figure shows the hydraulic roughness of floodplain and channel locations, visualized in a green to red color range to represent smooth to rough. The touchscreen monitor has two functions: (1) as a controller for players to initiate model updates and to switch visualizations; and (2) as an overview of the current state in the game by providing a virtual world of the board as well as information on the in-game performance.

5.2.2 Monodisciplinary models integrated in the platform

Delft3D Flexible Mesh hydrodynamic model

To model water flow and water levels in the game area, we incorporated the Delft3D Flexible Mesh (FM) hydrodynamic model to compute the hydrodynamic response to system change (Berends et al., 2019; Kernkamp et al., 2011). We use a rectangular

Figure 5.2 Overview of the Virtual River Game's hardware and software. The software components shaded in gray are plug-ins.

numerical grid of cell size 20 m by 20 m. Initial bed levels and Chézy friction coefficients are determined at the start of a game and are updated as the game progresses. The boundary conditions are given by an upstream constant discharge and a downstream constant water level. We use default parameter settings. Water levels and flow velocities are the model outputs of interest.

BIOSAFE biodiversity model

To model the potential biodiversity of the game area, we integrated the BIOSAFE model as developed by [Lenders et al. \(2001\)](#), [de Nooij et al. \(2004\)](#), and [Straatsma et al. \(2017\)](#). The model calculates biodiversity scores based on the potential occurrence of protected and endangered species in each ecotope, the laws and regulations protecting the species, and the surface area distribution of the main channel and floodplain ecotopes between the dikes. Ecotopes are defined as “*spatial landscape units that are homogeneous as to vegetation structure, succession stage, and the*

main abiotic factors that are relevant to plant growth” (Klijn and de Haes, 1994). As input, the model needs the ecotopes and their surface areas. As output, the model provides potential biodiversity scores for seven taxonomic groups: mammals, birds, herpetofauna, fish, butterflies, dragonflies and damselflies, and higher plants.

VRCost cost model

To model the costs of interventions, we created a model in Python by translating unit prices for costs for interventions in Dutch river management (Straatsma et al., 2019) to interventions in the game. Unit prices relate to costs per volume, area, or length (hexagon cross section). For example, a volume of soil may have to be excavated to construct a side channel in the river’s floodplain. The model distinguishes four cost categories: excavations, construction of hydraulic structures, land use changes, and land acquisition. As input, the model needs the elevation and land use change. As output, the model calculates the total costs for changes on the board as well as the costs per type.

5.2.2 Interface design and model integration

For the Virtual River Game’s hybrid interface, we designed and built a physical table (Figure 5.1) that includes the game board plus an off-the-shelf webcam, touchscreen monitor, and projector. The game board consists of 143 hexagonal tiles representing a stretch of river. The tabletop has an open aluminum mesh into which the tiles slot, leaving the bottom side of each tile visible to the webcam. Each tile contains information on terrain height and land use, which can be independently varied. Table 5.1 shows the five elevation levels and twelve land use types and their potential combinations. We chose the five elevation levels as a representation of the varying elevations found in Dutch rivers. For the land use types, we took inspiration from the classification of vegetation types used by the Dutch Public Works Authority (Rijkswaterstaat, 2012). Markers on the bottom of the tiles enable the conversion of the physical board to a digital board, defining each tile’s elevation and land use in the game’s software, based on a picture taken by the webcam. Throughout the game, the system can be updated, triggering the software to process the latest board state. In the following subsection, we explain the additional processing steps in the software needed to link the board to the models.

Model interface

The game software converts the digital board to a digital elevation model (DEM) and a roughness distribution as input to Delft3D FM. The DEM is created by an inverse distance interpolation (power of 2) of the terrain height at the center of the three

Table 5.1 The five elevation levels and twelve land use types used in the Virtual River Game, including the feasible elevation level and land use combinations.

	Reinforced dike	Dike	Mixtype (30% forest/70% natural grassland)	Forest	Shrubs	Reed and brushwood	Natural grassland	Production meadow	Built-up environment	Side channel	Channel with longitudinal training dam	Channel with groins	Land use types
Elevation levels													
0 Main channel											•	•	
1 Secondary channel										•			
2 Lower floodplain			•	•	•	•	•	•	•				
3 Higher floodplain (natural levee)			•	•	•	•	•	•	•				
4 Dikes	•	•											

nearest tiles to a regular grid, indexed to the computational grid used in Delft3D FM. The roughness classes are based on a lookup table from land use to roughness class (Appendix 5.A). Subsequently, the software calculates the hydraulic roughness by retrieving the water levels of locations from Delft3D FM and applying the vegetation friction model of Klopstra et al. (1996). The software sets the elevation and roughness coefficients and also retrieves water levels and flow velocity from Delft3D FM through the Basic Model Interface (BMI) (Peckham et al., 2013), using the Python BMI (Baart, 2017).

For BIOSAFE, the software converts the digital board to an ecotope distribution through a lookup table that links terrain height and land use to ecotopes (Appendix 5.A). A subset of 15 ecotopes out of the 82 fluvial ecotopes defined in the Dutch ecotope classification (van der Molen et al., 2003) are included. Composite land use, such as ‘main channel with a longitudinal training dam’, are split up into their pure ecotope classes in order to calculate the surface areas of all ecotopes. The Python version of BIOSAFE (Straatsma et al., 2017) is integrated in the game’s software to enable sending of the ecotopes and retrieving the potential biodiversity score for the taxonomic groups.

For VRCost, the software compares the previous and new board states to detect changes in elevation and land use. Changes on the board are sent directly to the model and the costs of changes, including their breakdown into the four categories, are retrieved.

Model feedback

The Virtual River Game offers model output in two locations: on the game board itself and on the touchscreen. On the physical game board, the software visualizes the DEM, water flow patterns from Delft3D FM, and hydraulic roughness coefficients by converting these into colormaps, which are subsequently projected on the board. The flow pattern is visualized as diffusive paint blobs that follow the flow lines. The hydrodynamic effects of changing tiles on the board are therefore visualized based on the model's output and projected on the same location as which changes take place. Through these choices, we aimed at making the hydrodynamic model more accessible and transparent by providing a tangible, easy-to-use interface and by enabling players to link their actions to the model's output.

On the touchscreen, the game shows the Tygron Geodesign Platform, a 3D spatial planning modeling tool that is also used as a virtual game engine for those serious games that have a spatial development component ([Bekebrede et al., 2015](#); [van Hardeveld et al., 2019](#); [Warmerdam et al., 2006](#)). The game interfaces with the Tygron game engine through its API ([Tygron, 2018](#)). The inclusion of the engine serves two purposes. First, the DEM and land use types of the digital board are converted to a virtual game world that matches the game board. For example, the engine shows trees for tiles on the game board that represent the forest land use. Second, interactive panels in the engine provide players with the output from and information about all three models.

We deliberately developed the game in such a way that players are able to fully control the interface without needing the game's facilitator. Players change tiles on the board, switch visualizations through the Graphical User Interface (GUI) displayed on the touchscreen and inspect the virtual world as well as open panels in the game engine. Updating the board state – which involves processing changes on the board, running the models, and updating both the visualizations and information in the Tygron engine – only takes between 15 and 30 seconds, depending on the time needed for water levels in the hydrodynamic model to stabilize. The update times are based on a dedicated, portable computer utilizing an AMD Ryzen X3700 desktop processor to run the game and models locally.

5.2.3 *Virtual River Game*

In the Virtual River Game, players are challenged to manage a 3500 m long deltaic stretch of river incorporating a navigable main channel that has floodplains and dikes on both sides. The game scenario reflects a high river discharge as result of which the floodplains are inundated. Three teams, each consisting of one or two players, play the roles of flood manager, nature manager, and financial manager. Collectively, the players are given a budget and are tasked to improve the flood safety status and ecological value of the area. Each team is given additional objectives as well as special abilities to block implementations of interventions based on real-world stakeholders, legislation, and European Union development targets. The flood manager mirrors the Dutch Public Works Authority, which is responsible for ensuring and maintaining adequate flood safety levels. The flood manager can block interventions if these decrease flood safety levels or if land use is changed to a type leading to high hydraulic roughness (reed and brushwood, shrubs, forest, and mixtype), which reflects the legislative power of the Public Works Authority. The nature manager represents larger nature management organizations such as the Dutch State Forestry Agency, which own and manage a large percentage of the Dutch floodplains and aim to develop their ecological value. The nature manager can block interventions if those decrease the area's ecological value. To reflect the common view that nature organizations hold less power than for example the Dutch Public Works Authority in real world decision-making, this ability can only be used once during each game. The financial manager represents a combination of the Dutch national government, which allocates budget for river projects, and regional governments, which are the commissioners of river projects and responsible for managing the floodplains as Natura 2000 areas under the EU Birds and Habitats Directives. The financial manager can block interventions if those would take more than half of the initial budget or if these require expensive land acquisition (buildings and agricultural land), which reflects the interest of governments to pursue cost-effective, win-win solutions. If players are part of any of these or similar organizations, they are assigned a role that is different from their regular role to let them experience river management from another point of view.

Each game consists of a maximum of four rounds. During each round, players apply one of six interventions: side channel construction, floodplain lowering (grading), floodplain smoothing (changing the floodplain vegetation to lower roughness), replacement of groins (alternatively termed 'wing dikes' or 'spur dikes') with longitudinal training dams, dike relocation, or dike reinforcement. Players first discuss

and agree which intervention they wish to apply. They subsequently implement the chosen intervention by changing tiles on the game board while following the intervention's rules. During this implementation phase, players can continually change tiles and collectively evaluate the intervention's effects before agreeing on a final implementation.

In-game scoring

In the Virtual River Game, we included performance indicators on flood safety, biodiversity, and budget. Therefore, interventions are evaluated on hydrodynamics, ecology, and costs, as in the Delft3D FM, BIOSAFE, and VRCost models. Each indicator has its own progress bar across a 0-100% score range. Minimum (50%), good (65%), and excellent (80%) scores are provided for both the flood safety and biodiversity indicators. We determined these scores as a balance between the game's representation of reality and its playability (see [Harteveld, 2011](#)) that: (1) reflects Dutch river management practice in terms of performance; and (2) corresponds to the difficulty of attaining good scores in the game. Players can click each indicator's progress bar on the touchscreen to see graphics on the effects of interventions on that indicator. In addition, separate information panels are available to players where they can see simplified scores after each tile change to anticipate the effects of interventions.

The flood safety score is based on the water levels along the river axis in comparison to the crest height of the dike at each tile location on the board. The water levels can be at or above, just below, or well below the dike's crest height, corresponding to that location being considered unsafe, moderately safe, and substantially safe, respectively. Unsafe, moderately safe, and substantially safe locations each contribute to the flood safety score as zero, half, and full score, respectively. Consequently, the overall flood safety score is 0% when all dike locations are considered unsafe and 100% when all dike locations are considered substantially safe. Flood safety is visualized in the indicator panel as a longitudinal profile of the stretch of river that includes initial and current water levels and as a top view with each dike tile colored red, yellow, or green representing unsafe, moderately safe, and substantially safe, respectively.

The biodiversity score is based on the potential biodiversity, the sum of the scores on the seven taxonomic groups, over the whole river reach. This sum is converted to a percentage in the 0-100% range for simplicity. We determined the 0% and 100% scores for biodiversity by running a Monte Carlo simulation to find the board layouts that result in the lowest and highest potential biodiversity scores respectively that can be achieved in the game. In the indicator panel, the potential biodiversity of the taxonomic groups, the sum, and the corresponding score are

provided. Furthermore, a bar graph shows the scores on the seven taxonomic groups for both the initial and the current game board. A second bar graph shows the change for each taxonomic group expressed as a percentage.

The budget score reflects the remaining budget that players have available as a percentage of the initial budget that they received at the start of a game. The initial budget is therefore equivalent to a 100% score. Spending the whole budget results in a 0% score and spending more than the budget results in a negative score. A graph shows the budget spent per round as well as the remaining budget in the budget indicator panel, expressed both in Euros and a percentage of the initial budget. In a second graph, the breakdown of the costs incurred per round is shown as stacked bars.

In-game objectives

Teams are scored on each indicator separately throughout the game. As a collective objective, the players have to achieve the minimum score (50%) for both flood safety and biodiversity in the four rounds while (preferably) staying within the budget. Collectively, the teams may decide not to play all rounds if they reach the collective objective before the fourth round. Additionally, each team is given one main and two secondary objectives. The teams receive the instruction that, in order to win the game, they have to reach both the collective objective and their role-specific main objective. The role-specific secondary objectives are presented as bonus points that they can earn. The flood manager is given the main objective to achieve a good flood safety score (65%). The secondary objectives are to achieve an excellent flood safety score (80%) and ending the game without any unsafe dike locations. The nature manager has the main objective of achieving a the good biodiversity score (65%) and the secondary objectives of achieving an excellent biodiversity score (80%) and to end the game with five or more forest locations within the floodplains. The budget manager is tasked to limit spending to the collective budget. The secondary objectives are to achieve good scores for flood safety and biodiversity (65%). The collective objective is known to all players. Each team is given its main and secondary objectives at the start of the game by blindly drawing one of four role-specific objective cards. Players do not know that these four cards all list the same main and secondary objectives for their team. Players are not told whether or not to share their team's objectives with other players.

5.3 Virtual River Game evaluation

We developed the Virtual River Game to support stakeholder participation in the new Dutch river management paradigm. In this study, we set out to assess the poten-

tial of the game as a participatory tool guided by the research questions: (1) to what extent does the game facilitate stakeholders collaboratively exploring and experimenting with river interventions; and (2) to what extent does playing the game lead to social learning outcomes? The research questions address what [Aubert et al. \(2019\)](#) refer to as the process-oriented (how are these outcomes achieved) and variance-oriented (what outcomes are achieved) assessment of serious games.

The first research question focused on the game itself to evaluate its ability to engage stakeholders in dialogue and activity – a prerequisite to stimulating social learning. Following the scope of the game and its interface design, we were particularly interested in evaluating the extent to which the game facilitates both domain experts and non-experts to engage in collaborative experimentation with river interventions. We considered the game to be successful as a participatory tool when participants – regardless of their background and expertise – (1) developed a shared understanding of the problem; (2) developed a collaborative strategy to address that problem; (3) engaged in discussions on how interventions affect indicators and role objectives; and (4) applied and tested various implementations of interventions.

The second research question focused on evaluating to what extent playing the game led to social learning by individual participants. Following the game's scope, we focused on learning outcomes related to cognitive and relational learning ([Baird et al., 2014](#); [Ensor and Harvey, 2015](#)). Cognitive learning outcomes that were assessed included gaining an improved understanding of: (1) the functioning of the river system; (2) the effects of interventions and their trade-offs; (3) how hydrodynamic models work and are used in decision-making; and (4) the conflicts and opportunities for cooperation between the various stakeholder roles. Relational learning outcomes that were assessed relate to gaining an improved understanding of the mind-sets and perspectives of other participants. We considered the game to be successful when both domain experts and non-experts achieve cognitive or relational learning outcomes or both. As experts bring their knowledge and experience to the game, we expected that they would achieve fewer cognitive learning outcomes than non-experts.

To address the research questions, we organized five sessions playing the Virtual River Game. In the following subsection, we describe the setup of the sessions and their participants. In [Subsection 5.3.2](#), we describe the data collection methods and the data analysis used to address both research questions.

5.3.1 Sessions and participants

The description of a session playing the Virtual River Game is provided in [Appendix 5.B](#). We invited both domain experts (professionals working in Dutch river manage-

ment) and non-experts (participants without river management expertise) to the sessions. None of the sessions were linked to a real-world river project. This made it difficult to engage with non-experts who are also real-world stakeholders in Dutch river management. Therefore, we invited design researchers and game designers to represent non-expert stakeholders. We organized two sessions that included only expert participants and three sessions of experts and non-experts (Table 5.2). Each session had between four and six participants in a total of 26 participants. The length of each session, including the explanations and debriefings, was around three hours. The actual length of gameplay ranged between 78 and 109 minutes. All sessions had the same experienced facilitator and a trained observer. We prepared an initial board (Figure 5.3) as a scenario that we used in every session. The scenario reflected a stretch of river with a hydrodynamic bottleneck formed by narrow flood-

Table 5.2 Overview of the sessions and participants.

Session	Type of session	Number of participants (N _{total} = 26)	Description of participant backgrounds	Length of the game (minutes)
1	Experts	5	Flood safety experts, river management advisors	91
2	Mixed	5	River management advisor, design researchers	109
3	Experts	6	Flood safety experts, project managers, ecologists	84
4	Mixed	4	Water management researchers, design researchers	102
5	Mixed	6	River management advisors, public policy researchers, serious games designers	78 *

* The reported length of the game in this session includes a correction for internet issues that resulted in a loss of 20 minutes to play the game.

Figure 5.3 Initial board layout that was used as a starting situation in all sessions.

plains, higher floodplain terrain, and vegetation that causes high hydraulic roughness, resulting in unsafe water levels upstream from the bottleneck. After the second session, we changed one parameter of the scenario by lowering the initial budget by 30% to € 17.5 million because the initial budget was found to be too high. Although reducing the budget between sessions was undesirable, we aimed to stimulate more discussions that also addressed the cost-effectiveness of interventions – one of the main criteria in real world decision-making. We chose the 30% reduction as this aligned with the budget spent during the first session.

5.3.2 *Data collection and analysis*

We applied a multi-method approach to collecting and analyzing both quantitative and qualitative data. Our approach consisted of: (1) a pre-game questionnaire; (2) in-game data logging; (3) in-game observations; (4) a post-game questionnaire; and (5) a post-game debriefing. Before starting the game, the participants filled out a short questionnaire stating their age, expertise, experience related to river management, and experience with serious gaming, all so as to separate expert from non-expert participants. During the game, the participants' decisions and performance for each update were stored in a log file. In addition, we observed the participants' discussions during the game. We used an observation recording form to document a timeline of each session by linking discussions to the three indicators as well as to intermediate and final decisions taken in the game. We used this timeline to analyze each session's outcomes (e.g. interventions applied, final layout, score progression) and processes (e.g. discussions, consideration of options, contributions of participants) in order to address the first research question. Directly after playing the game, the participants completed a second questionnaire that focused on their overall impressions of the game and the insights gained by playing the game. In closed questions, the participants were asked to self-report their experiences by rating their agreement with statements on a 5-point Likert scale that ranged from 'strongly agree' to 'strongly disagree': a common approach in game studies (Bekebrede et al., 2018; Keijser et al., 2018; Mayer et al., 2013). In one open question, the participants were asked to list a maximum of three main insights obtained by playing the game. We categorized the open question answers in relation to cognitive and relational learning to determine what experts and non-experts identify as the main insights from playing the game. We used the data from the completed questionnaires to address the second research question. One non-expert participant did not complete the post-game questionnaire and was therefore excluded from the results ($N_{\text{total}} = 25$ for the questionnaire). To conclude each session, we conducted a debriefing to collectively reflect on the game activity. The debriefing was set up along the lines proposed by

Kriz (2010): six phases to structurally reflect on the game activity. To confirm that the discussions and considerations in the game reflect those encountered in practice, we expanded the third phase of the debriefing – which includes reflecting on the game’s external validity (van den Hoogen et al., 2014) – in the two expert sessions. Following informed consent, we recorded the debriefings to transcribe these for later analysis. We used the debriefing data to further interpret the analyses to help address both research questions. In addition, we compared the data to address the two research questions with each other to strive for data triangulation.

5.4 Results

5.4.1 Collaborative experimentation with river interventions (RQ1)

The first research question was to what extent the game facilitates stakeholders to collaboratively exploring and experimenting with river interventions. Here, we present the chosen interventions and indicator scores as the factual game output, as well as the observations of the in-game discussions about and experimentations with those interventions.

Interventions and scores

The choice and implementations of interventions during the game sessions showed that good scores (between 65% and 79%) for both flood safety and biodiversity can be achieved in several ways (Figure 5.4). For flood safety, only the participants in the fourth session (71%) did not achieve an excellent score (80% or higher). Excellent scores for biodiversity were not achieved in any session. In all sessions, the participants first focused on increasing the flood safety scores, generally spending most of the budget during the first two rounds.

Increasing the biodiversity scores became the focus during the later rounds. Participants in the third and fifth sessions used their remaining budget to achieve good biodiversity scores (between 65% and 79%), but only after achieving satisfactory flood safety scores. During all sessions, participants applied the floodplain smoothing intervention to increase their biodiversity scores while at times also optimizing their flood safety scores. During the second and third sessions, participants also chose the side channel construction and replaced groins with longitudinal training dams to increase their biodiversity scores.

Strategies and discussions

At the start of each session, participants explored the game scenario by changing the board visualizations, inspecting the information on the touchscreen, and link-

Figure 5.4 Overview of the game sessions, with each row showing the result of one session. The first column shows the interventions applied during the four game rounds and the resulting progression of indicator scores, with the final indicator scores listed to the right of the graphs. The number shown below each intervention icon indicates the number of implementations that participants tested during the respective round. The budget indicator scores for the first two sessions are adjusted to match the lowered budget. The second column shows the final board layout for the bed elevation and the third column shows the final layout for the land use.

ing the information from these two sources. Initial discussions focused on establishing a shared understanding of the flood safety bottleneck and on how flood safety could be improved. During the mixed sessions, expert participants were observed taking prominent roles in these early discussions. These experts supplemented the in-game information by explaining what they saw as problems, for example that the bottleneck caused higher water levels upstream, and suggested what could be done to improve the indicator scores. Non-experts initially followed their lead but then started to make their own suggestions as the games progressed. During the sessions that included only professionals, experts who regularly work with hydrodynamic models were similarly observed to take more prominent roles at the start of the game. The discussions during these sessions moved more quickly from identifying the bottleneck to possible interventions than in the mixed sessions. During these discussions, flood safety specialists were observed to start the games as if they were in their real-world roles, even though they had not been assigned to the flood safety manager team. Game discussions during the early rounds did include how tackling the flood safety bottleneck could simultaneously improve biodiversity without the costs of interventions rising unacceptably. However, no change in general direction of these discussions was observed as a result of lowering the budget after the second session.

After establishing a shared understanding of the problem, the discussions during all sessions focused on deciding which intervention to implement in the first round. In no session did the participants develop a collaborative strategy at the start of the game. During the sessions, the participants were observed to plan ahead by discussing how the intervention they were implementing could be made more effective by applying a different intervention in the next round. Experts continued to supplement the in-game information, for example by explaining that changing land use to a type with high hydraulic roughness to increase biodiversity (e.g. to a forest) is best done at locations where there is a low flow velocity (e.g. next to a dike) to limit its effect on flood safety. Discussions during the later stages of the game featured more bargaining between the teams, each seeking to pursue their main and secondary objectives. For example, discussions during the third and fifth sessions included teams agreeing on the choice of intervention in one round only if the other teams agreed beforehand on the intervention to be made in the subsequent round. During these bargaining discussions, participants started to share their team objectives. Only in the fifth session did the participants share their team objectives at the start of the game to establish their own common objectives, guided mostly by one expert participant who advocated forgetting about the politics. No notable

differences in late-game discussions were observed between the expert and mixed sessions. Non-experts were as active in proposing implementations of interventions as experts were and their suggestions were also applied on the board. In the three sessions after reducing the budget, the costs of interventions were emphasized more during the late-game discussions, in particular by the budget manager teams.

During the debriefings, participants confirmed that they did not have a collective strategy for the game, but that it felt natural to them to plan ahead while testing implementations of interventions. Additionally, participants in the second, third, and fifth sessions explicitly indicated that it seemed logical to them to start with the most drastic intervention and to subsequently optimize from there. Before asking about the connection of the game activity to reality during the third session (expert session), the following discussion took place:

Expert A: *"... and that [the game] more or less reflects how things work in reality. I am working together with Expert D on an area, in which we have the same type of discussions."*

Expert B: *"I really liked that you could quickly update and inspect the results. Like, how does this work out? How far are we now? That is very useful. The risk is that you start micro-managing the environment, but yeah..."*

Expert C: *"But that is also realistic."*

Expert B: *"Yes, true."*

Expert D: *"[The game] feels very realistic, because the discussions we were having, about the board where we were working with, those are the same discussions you have in practice and the advantage is that you can quickly update the situation and inspect the effects, so you really get a feel of what the interventions do."*

The discussion illustrates that these experts found that using the board to apply interventions felt sufficiently realistic and elicited discussions similar to those occurring in practice. Experts in other sessions provided feedback that supported these findings during the debriefings and in written statements made in the post-game questionnaire. Experts in the first, third, and fifth sessions did mention that they missed a role that directly represents the interest of agriculture in the game. As a result, although facing a financial penalty for the compulsory purchase of land, they mentioned that they could convert agricultural land into other land use types without the emotional discussions associated with the compulsory purchase of land by the government that would occur in real life.

Experimentation approach

In all sessions, participants used the opportunity to experiment with interventions. In sessions 1 to 4, the participants applied and evaluated between 17 and 20 implementations of interventions while playing the game (Figure 5.4). The number of applied interventions in the fifth session was notably lower, which was probably caused by internet problems during the session that resulted in a loss of time to play the game. To help propose interventions, participants used the board as a map to suggest interventions by hand gestures and used the information both from the visualizations as well as on the touchscreen to formulate arguments. Participants experimented with interventions both to test implementations at several locations, e.g. constructing a side channel on the other side of the main channel (comparison), and to improve the implementation at a chosen location (optimization). Especially the floodplain smoothing intervention led to experimentation, with participants in the second and third sessions trying eight and eleven implementations, respectively. In these experimentations, non-experts were observed to realize that lowering the hydraulic roughness from locations with higher water flow velocity is effective in increasing the flood safety score. Furthermore, participants were observed to realize, through experimentation, that changing a production meadow (intensively managed grassland) to a more natural setting (less managed) is most effective at increasing biodiversity.

Figure 5.5 Overall impressions of the game as reported in the post-game questionnaire based on a 5-point Likert scale. Rating strongly agree counts as 5; strongly disagree as 1. Graphical representation based on Heiberger and Robbins (2014).

5.4.2 Experience and social learning outcomes (RQ2)

The second research question was: to what extent does playing the game lead to social learning outcomes? Here, we describe the participants' overall impression on the game and their self-reported learning outcomes with respect to both cognitive and relational learning.

The questionnaire results indicate that the game was well received by both domain experts and non-experts (Figure 5.5). Most participants indicated that the game's goal was clear and that they enjoyed playing the game. During the debriefings, participants also frequently mentioned that they regarded the game as a fun activity.

Regarding the learning outcomes, the questionnaire results indicate that participants gained insights into both cognitive and relational learning (Figure 5.6). Compared to experts, an equal or higher percentage of the non-expert participants gave answers to the statements that showed strong agreement. Below, we discuss the results for experts and non-experts separately.

Figure 5.6 shows that non-experts mostly agreed or strongly agreed with the twelve statements. Non-experts agreed most with statements 11 and 12 ($\mu = 4.40$ and 4.60 respectively) related to relational learning. In relation to cognitive learning, non-experts agreed most with statements 1 and 10 (both $\mu = 4.20$). Only on statement 4 ($\mu = 3.40$) about the costs of interventions did two non-experts give answers that showed strong disagreement. These participants explained that they had difficulty interpreting information about costs during the game. In the open question, non-experts most frequently mentioned insights related to the functioning of the river system (10) and interventions and trade-offs (6) categories, both associated with cognitive learning. Most of these insights were broadly formulated, such as “the relation between flow velocity and flood safety” and “trade-offs between decisions”.

Experts gave more mixed responses to the statements than non-experts. Experts agreed most strongly with statement 5 ($\mu = 3.87$) related to the trade-offs between interventions. They also rated statements 11 and 12 ($\mu = 3.67$ and 3.80 respectively) on relational learning positively, with most experts only agreeing but a few strongly agreeing. Statements 6 and 7 ($\mu = 2.67$ and 2.93 respectively) on hydrodynamic models were rated poorly, with more experts disagreeing than agreeing with both statements. This was not an unexpected result as experts regularly work with these models anyway. In the open question, experts most frequently mentioned insights related to interventions and trade-offs (8) and player perspectives (7), associated with cognitive learning and relational learning, respectively. On the interventions and trade-offs, insights were formulated more specifically than by non-experts, such as “insight into the ratio of costs of different interventions” and “more insights into

Figure 5.6 Learning outcomes of the game as reported in the post-game questionnaire based on a 5-point Likert scale. Rating strongly agree counts as 5; strongly disagree as 1. The statements relate to the functioning of the river system (1), the effects of interventions and their trade-offs (2-5), how hydrodynamic models work and are used in decision-making (6-7), the roles of and conflicts between stakeholder roles (8-10), and the views and perspectives of other players (11-12). Graphical representation based on Heiberger and Robbins (2014).

the costs of interventions in relation to their effectiveness". Experts indicated in both the questionnaires and the debriefings that they gained such insights as a result of playing a role different from their day-to-day role.

During the debriefings, participants collectively reflected on what helped them to obtain their main insights and mentioned the game's feedback (all sessions), the shared exploration and experimentation with interventions (sessions 2, 3, 4 and 5), explanations from other participants (sessions 1, 2, 4 and 5), and finding it easier to interpret information from the game board than from a screen (session 5). In all three mixed sessions, non-experts explicitly pointed out that the experts had helped them to understand the problem as well as to predict the consequences of interventions. Experts in turn indicated that collaborative experimentation with interventions – in combination with the game's feedback – helped them to explain river management principles to non-experts.

5.5 Discussion

In this section, we first reflect on the potential value of the Virtual River Game as a participatory tool based on the study's results. Next, we discuss the design of the game and its interface. We end the section by reflecting on the study and outlining its limitations.

5.5.1 *Game as a participatory tool*

The results of the sessions indicate that the game was successful at engaging both domain experts and non-experts in collaboratively exploring and experimenting with river interventions. In all sessions, the participants developed a shared understanding of the problem. To address the problem, they applied and tested various implementations of interventions. Although the participants did not develop a collective strategy from the start, they did collaboratively plan ahead while applying interventions, discussing how future interventions could further improve the indicator scores and contribute to achieving the various objectives. Experts and non-experts were both active in the games' discussions, with experts taking more of a leading role, especially at the start of the games. Furthermore, experts noted that the discussions and considerations that they had during the game reflect well those found in real-world projects.

The results further indicate that the Virtual River Game stimulated social learning for both experts (N = 15) and non-experts (N = 10). Considering the game's scope and the operationalization of social learning, we looked specifically at cognitive learning (acquiring new or restructuring existing knowledge) and relational learning (increasing the understanding of the mind-set and perspectives of others) (Baird

et al., 2014; Ensor and Harvey, 2015). With only a few exceptions, non-experts rated all statements in relation to the game's learning outcomes positively. According to their comments, the main insights that non-experts emphasized were almost exclusively associated with cognitive learning. However, experts rated the statements in a more mixed way, with some statements rated positively but some statements associated with cognitive learning neutrally to negatively. We expected that experts would report less cognitive learning given their background knowledge. The statements on relational learning were rated positively by experts, which was also reflected in their reported main insights. Taken together, we conclude that both domain experts and non-experts learned by playing the game. However, the extent to which they learned and emphasis they placed on it varied. The game appears to be particularly valuable as a participatory tool to introduce non-expert stakeholders to river management in the Netherlands. Keijser et al. (2018) reported similar results from their game on marine spatial planning, showing that their game worked well as an introductory game to engage non-experts on the topic.

On learning more generally, our results are in line with evaluations of other serious games (see e.g. reviews by Aubert et al., 2018; den Haan and van der Voort, 2018; Flood et al., 2018), which have shown that serious games are an effective way of increasing the understanding of physical systems (Becu et al., 2017; Carson et al., 2018; Keijser et al., 2018), of raising awareness (Onencan and van de Walle, 2018; Stefanska et al., 2011; van Pelt et al., 2015), and of increasing the understanding of alternative views and perspectives (Douven et al., 2014; Jean et al., 2018; Souchère et al., 2010). Combining the results on collaborative exploration and learning, this study offers further evidence that serious games are effective ways of improving social learning (Hofstede et al., 2010; Medema et al., 2016; Savic et al., 2016).

5.5.2 Game and interface design

Serious games are increasingly explored as learning-based interventions in environmental management (Aubert et al., 2019; Flood et al., 2018; Rodela et al., 2019). In terms of the design of such games, this work contributes to the growing body of literature by proposing a new, hybrid interface design concept: the bidirectional coupling of a physical game board to computer models. Whereas other serious games on environmental management tend to use simplified, custom computer models that are location-specific (e.g. Craven et al., 2017; Valkering et al., 2013), our focus was on creating a simplified – yet realistic – 3D representation of a typical stretch of a Dutch river in combination with models currently used in practice. Designing serious games always requires some form of simplification to strike a good balance between an accurate representation of reality, the playability of reality, and the meaning of the

game (Harteveld, 2011). In our approach, the biggest simplification of the physical reality was not in the models, but in the fact that the board uses a fixed, hexagonal grid. We applied this simplification mainly to increase playability; the fixed number and shape of the tiles reduces the level of detail in relation to a real stretch of river and provides a manageable structure by limiting the number of possible arrangements in the game. The sessions showed that the game board design facilitated participants working together and, as an interface, enabled especially non-experts to work with models currently used in practice. Moreover, experts determined that the game triggered discussions that also occur in practice. Therefore, simplifying a river stretch to a hexagonal grid proved to be a suitable approach to balancing a good representation of reality with playability. Increasing the level of detail in the game could be further explored, but is not necessary to facilitate the collaborative exploration of and experimentation with river interventions.

In addition to serving its specific purpose, the hybrid interface offers qualities that we see as beneficial to facilitating stakeholder participation in environmental management and to improving social learning. Serious games have been developed as board games (Hertzog et al., 2014; Keijser et al., 2018; Speelman et al., 2014), as digital games (Ayadi et al., 2014; Carson et al., 2018; Craven et al., 2017; Hill et al., 2014), and as hybrid games combining elements of board and digital games (Cleland et al., 2012; Magnuszewski et al., 2018; Valkering et al., 2013; van der Wal et al., 2016). Such games have a common feature that participants are provided with an experimentation environment in which they can collaboratively and safely explore both the techno-physical and socio-political complexity of an environmental system. With the hybrid interface design of the Virtual River Game, we combined three qualities that are separately found in board and computer games. These qualities are described below.

First, the hybrid interface provides participants with a physical, tangible object to engage with in shared exploration. Through the game board and touchscreen, control of the game is shared and not limited to a facilitator or one participant controlling an input device. Participants engage in discussions by moving game tiles or pointing to locations on the game board, making their views explicit to other participants (Stanton et al., 2001; Suzuki and Kato, 1995).

Second, as an interface, the game board appeared to lower the threshold for participating while allowing participants to collaboratively work with computer models by using tangible objects, removing the need to have specific expertise in using these models. Computer games have been developed as interaction layers to models based on a GUI (Chew et al., 2013; Craven et al., 2017; van Hardeveld et al., 2019), but without the use of tangible objects as a direct source of input. In

turn, games have been developed that use a non-digital board in combination with computer models (Magnuszewski et al., 2018; Stefanska et al., 2011), but without either a direct connection to the models or the models' output being visualized on the board. In the Virtual River Game, the bidirectional link between the board and models provides participants with visualizations of their actions at the same location as where they made them.

Third, for a serious game in general, being able to experiment with interventions is a valuable way of triggering learning (Becu et al., 2017; Ferrero et al., 2018). Multiplayer serious games that focus on managing a spatial area generally include interventions as binary options that can be turned on or off for defined locations (Carson et al., 2018; Craven et al., 2017; Rusca et al., 2012). This can include a few options of the same interventions at the same locations, such as small, medium, and large versions (Onencan et al., 2016; Savic et al., 2016; Valkering et al., 2013). In the Virtual River Game, participants determine the location, direction, shape, and size of interventions by replacing tiles on the board while following rules defined outside the software. Therefore, the interface increases the experimentation potential by including the design of interventions rather than choosing predefined intervention options. In serious games, similar functionality is found in tile-based computer games (e.g. Becu et al., 2017; Chew et al., 2013), but not in combination with tangible tiles. This type of functionality is also found in planning support systems in which participants can draw and apply interventions on a tabletop surface (see e.g. Leskens et al., 2014; Vonk and Ligtenberg, 2010). To summarize, the hybrid interface combines the strengths of board games (accessibility, tangibility) with the power and flexibility of computer games (modeling, visualizations) which, in combination, are beneficial to supporting stakeholder participation and improving social learning.

5.5.3 *Reflection and limitations*

In all sessions, the participants focused mainly on increasing the flood safety score in the early game rounds and only focused on the biodiversity score during later rounds. This approach is consistent with current Dutch river management practice in which improving flood safety is the primary objective (see e.g. Deltaprogramma, 2019). However, some choices in the Virtual River Game's design and the choice of participants invited to the sessions may have influenced the participants' focus on improving their flood safety scores. Although no distinction between primary and secondary objectives is made in the game, the in-game interventions are based on interventions implemented in reality that do have the improvement of flood safety as the primary objective. The sessions' starting conditions may have further nudged participants to first focus on the flood safety indicator as its initial score (29%) was

lower than the biodiversity score (47%). In addition, some flood safety specialists were observed to approach the game as if they were initially in their real-world roles.

Besides these possible influences on the results, the study has two other limitations. In general, a serious game aims to provide participants with a safe space to experiment, to take on another role, and to defend positions that they may not take in reality (de Caluwé et al., 2012; Geurts et al., 2007; Mayer, 2009). The results of this study suggest that the game provides this sense of safety as participants experimented with interventions to pursue the objectives of their assigned role. In particular, domain experts were observed to propose and experiment with interventions that ran counter to objectives that they would normally pursue in their real-world roles. However, the sessions were organized outside of a real-world policy-making setting. Therefore, the first limitation of the study is that we do not know if the game would also establish the same sense of safety in experimenting with interventions and defending positions of other stakeholder roles when played in the context of a real-world river project. This needs to be explored in future research. Before the game is used in a real river project, the roles in the game must be reviewed. In particular, based on the results of this study, adding an additional role that actively defends the interests of the agricultural sector must be considered. This role was initially left out to limit the game's complexity. In order not to increase the game's complexity, an alternative could be to consider the current game as an introductory level and add a second game level with additional objectives, indicators, roles, and interventions.

The second limitation lies in the limited number of sessions and participants. Conducting studies on serious games is time-consuming, both for the participants and for the researchers. As a result, the number of expert and non-expert participants was too low to be able to draw statistically significant conclusions. Consequently, we looked at these two groups separately and have not made comparisons between the learning outcomes of experts and non-experts. However, despite the limitations, the results indicate that the game may well be useful as a tool to help support stakeholder participation in Dutch river management.

5.6 Conclusion

In this paper, we presented the design of the Virtual River Game and investigated its potential value as a participatory tool in Dutch river management. Based on the results of five sessions, we showed that the game was successful in: (1) facilitating domain experts and non-experts to collaboratively experiment with river interventions that are commonly applied in the Netherlands and to elicit discussions similar to those that occur in real-world river projects; and (2) establishing social learning outcomes as both experts and non-experts indicated that they had learned by

playing the game. Through self-reporting, non-experts indicated that most gained insights into the game's learning objectives and emphasized their learning about the functioning of the river system and about river interventions and their inevitable trade-offs. Experts, in turn, reported more mixed results regarding the learning objectives and emphasized learning about river interventions and their inevitable trade-offs, as well as about the views and perspectives of other participants. As a participatory tool, we conclude that the substantial value of the game lies in introducing non-expert stakeholders to Dutch river management.

Appendix 5.A

Land use options in the game and the translation to specific roughness classes (Scholten and Stout, 2013) and ecotopes (van der Molen et al., 2003), including their fractional surface area in a tile. For example, the tile representing the main channel that includes a longitudinal training dam is assigned roughness class 102 and has a fractional surface area of 0.6 in the ecotope labeled as 'deep main channel' (RzD in the Dutch ecotope system of large water bodies) and 0.4 of the surface area is taken by the ecotope for medium depth side channel (RnM).

Land use of hexagon	Roughness class of hexagon	Dominant ecotope in hexagon	Subdominant ecotope in hexagon	Fraction dominant ecotope	Fraction subdominant ecotope
Elevation level 0 on the game board – main channel					
main channel with groin	102 *	RzD	II.2	0.75	0.25
main channel with LTD	102 *	RzD	RnM	0.6	0.4
Elevation level 1 – secondary channel					
secondary channel	105	RnM	RnM	1	0
Elevation level 2 – lower floodplain					
builtup, floodplain	114	UA-2	UA-2	1	0
production meadow, floodplain	1201	UG-2	UG-2	1	0
natural grassland, floodplain	1202	UG-1	UG-1	1	0

Land use of hexagon	Roughness class of hexagon	Dominant ecotope in hexagon	Subdominant ecotope in hexagon	Fraction dominant ecotope	Fraction subdominant ecotope
reed, floodplain	1215	IV.9	IV.9	1	0
shrubs, floodplain	1231	UB-2	UB-2	1	0
forest, floodplain	1245	UB-1	UB-1	1	0
mixtype, 70 natural grass-land 30 forest, floodplain	1202 / 1245	UG-1	UB-1	0.7	0.3
Elevation level 3 – higher floodplain					
builtup, natural levee	114	OA-2	OA-2	1	0
production meadow, natural levee	1201	OG-2	OG-2	1	0
natural grass-land, natural levee	1202	OG-1	OG-1	1	0
reed, natural levee	1215	HM-1	HM-1	1	0
shrubs, natural levee	1231	OB-2	OB-2	1	0
forest, natural levee	1245	OB-1	OB-1	1	0
mixtype, 70 natural grassland 30 forest, natural levee	1202 / 1245	OG-1	OB-1	0.7	0.3
Elevation level 4 – dikes					
dike	1201	- **	- **	- **	- **
reinforced dike	1201	- **	- **	- **	- **

* The groins and LTDs could only be included through the BMI by manipulating the DEM to include their shapes in the elevation. As a result, the main channel is used as a roughness class for both.

** Dikes are not considered part of the area evaluated for biodiversity and thus are not assigned an ecotope.

Appendix 5.B

Description of a game session:

1. The facilitator welcomes the participants and provides an overview of the session.
2. The participants fill in the pre-game questionnaire.
3. The facilitator briefs the participants on the game. The facilitator explains the scope of the game, the game indicators, and models behind these, the collaborative objective, the rules, and how the game interface works.
4. The participants engage in a trial round, in which they select one intervention and implement it by making changes on the board to familiarize themselves with the game's interface.
5. After the trial round, the participants take a short break, during which the facilitator resets the game system and rearranges the board to the game scenario.
6. Before starting the game, the facilitator assigns the participants to their roles in the game and lets them draw their objective cards. The facilitator explains the roles to all the participants, including their abilities to block the implementation of interventions.
7. The game starts, for a maximum of four game rounds. During each round, the participants first discuss and decide which intervention they want to apply using any and all information available to them*. If no consensus is reached, participants vote on the intervention to apply, with each role having one vote.
8. As a second part of the round, participants implement the chosen intervention. They discuss and make changes on the board based on the intervention's rules. For example, to relocate a dike, participants move dike tiles further away from the main channel, enlarging the floodplains, in such a way that all dike tiles on that side of the river remain connected (i.e. no gaps are allowed). Participants are able to continuously make changes on the board and update the game system to inspect the intervention's effects on the indicators*. The participants can use their assigned role's abilities to block the intervention during this step.
9. The participants end the round by finalizing the implementation of the intervention. Preferably, the participants decide through consensus that they are satisfied with the intervention's implementation*. If no consensus is reached, participants vote on finalizing the implementation, with each role again having one vote. No implementation may be finalized under a legitimate use of an ability to block the intervention. Steps 7 to 9 are repeated until the fourth round finishes or sooner if the participants are satisfied with their results before reaching the fourth round.

10. Directly after finishing the game, participants fill in the post-game questionnaire.
11. To conclude the session, the participants collectively reflect on the game activity in the debriefing, moderated by the facilitator.

** During all stages of a game round, the participants themselves are in charge of deciding, testing and implementing interventions. Only if participants seem stuck in any phase of the round does the facilitator pose a question or push for a decision. Otherwise, the facilitator stays mostly passive apart from making sure that the game rules are followed. The facilitator is available at all times to answer participants' questions, but does not advise or tell players what to do or not do.*

Chapter 6

Discussion

In this thesis, we developed the Virtual River Game, a serious game on Dutch river management. We developed the game as a case study to explore how a human centered design of serious games contributes to foster exploring complexity, facilitating stakeholder participation and stimulating social learning in environmental management. In this chapter, we discuss both the Virtual River Game case study as well as its implications towards the thesis' aim. To do so, we first discuss the main contributions of the thesis. Next, we reflect on the overall research, on conducting the research as part of the RiverCare program and on the research's limitations. We end with brief concluding remarks.

6.1 Main contributions

We proposed that applying a human centered design approach to designing the Virtual River Game may enrich its design and enhance its ability to foster exploring complexity, facilitating stakeholder participation and stimulate social learning. We researched and developed an approach to evaluate the Virtual River Game's social learning outcomes and showed that the game was successful in facilitating the collaborative exploration of complexity and to stimulate social learning (Chapters 3 and 5). As a whole, the Virtual River Game case study provides further proof of the effectiveness to use games to stimulate social learning in environmental management to the existing literature (see e.g. Aubert et al., 2018; Edwards et al., 2019; Flood et al., 2018; Marini et al., 2018; Medema et al., 2016; Savic et al., 2016).

Below, we discuss the four main contributions of this thesis in regard to the design of serious games to collaboratively explore complexity. These contributions are: (1) applying a human centered design process to the design of serious games; (2) developing a novel interface design that uses a physical game board to make environmental models accessible and transparent; (3) adding the ability to experiment with the design of interventions as a game mechanic over selecting predefined interventions; and (4) creating a platform through which the Virtual River Game can be customized and new serious games with a spatial component can be developed. We discuss each contribution and place it in context to existing literature.

6.1.1 Human centered design process

The use of serious games in environmental management is receiving increased attention in environmental management (Aubert et al., 2018; Edwards et al., 2019; Flood et al., 2018; Marini et al., 2018; Medema et al., 2016; Savic et al., 2016). Although serious games have been successfully designed and applied in environmental management, the interest in serious games has mostly been driven by advances in computational power and in developments in the entertainment gaming industry (Aubert et al., 2018; Bekebrede, 2010; Mayer, 2009). Recently, scholars have advocated to consider the stakeholders, the policy context and the (social) processes of the problem at hand as the driving force to design serious games rather than technical aspects (Aubert et al., 2019; Rodela et al., 2019). Taking the stakeholder needs and wishes as a design's point of departure places emphasis on prospective users and context of use and should therefore lead to game designs that cater to their actual needs. Failure to take the prospective users into account in the design of serious games may lead to limited adoption in practice, as has happened with decision support systems

(Borowski and Hare, 2007; Brugnach et al., 2007; McIntosh et al., 2011; McIntosh et al., 2007; Vonk et al., 2005).

The application of serious games in environmental management is generally associated with facilitating stakeholder participation and supporting decision-making, e.g. by exploring complexity and stimulating social learning (Furber et al., 2018; Marini et al., 2018; Savic et al., 2016). Such associations imply expectations that serious games provide meaning and value to the stakeholders and the decision-making process (Aubert et al., 2019; Rodela et al., 2019). If we are to meet the expectations around serious games in environmental management, game designers therefore need to understand what that meaning and value is that their games offer to stakeholders. In our view, it is therefore imperative that game designers gain understanding of the actual needs and desires of stakeholders and involve stakeholders in a game's design process.

Core of the human centered design philosophy is acknowledging the use related expertise of prospective users and recognizing that prospective users should therefore be involved in a product's design process in order to develop a product that meets their needs and wishes (Kujala, 2003; Sanders, 2002; Sanders and Stappers, 2008). To design the Virtual River Game, we gradually increased our understanding of the real needs and desires by facilitating stakeholder involvement. Explicitly, the interviews enabled us to gain an initial understanding the needs and desires of stakeholders (Chapter 2) and the iteratively developed prototypes facilitated stakeholder involvement to further increase that understanding (Chapter 4). Implicitly, understanding the stakeholder needs and desires went beyond the formal studies and was also shaped by having one-on-one conversations, reading articles and visiting conferences. We critically reflected on the game's design based on the evolving understanding of needs and desires throughout the design process. As a result, we explored new avenues for the game's design as we increasingly understood how the game could fulfill the needs and desires of stakeholders. Only through the involvement of stakeholders did we understand that hydrodynamic models, which are used in Dutch river management to substantiate decision-making, are perceived as black boxes to some (Chapter 4). In other words, without facilitating the involvement of stakeholders in the design process, we would have likely not realized or fully understood the stakeholders' need to make hydrodynamic models more accessible and transparent. Consequently, without critically reflecting on if and how the game's design met the stakeholders' needs and desires, we would have likely not looked beyond designing a computer game nor explored new interaction designs. To conclude, by developing the Virtual River Game, we showed how a human centered

design approach can lead to more in depth identification of the meaning and value a serious game can offer to stakeholders.

6.1.2 *Making models accessible and transparent*

Models and model-based tools are used in environmental management to predict effects of interventions and thereby support decision-making (Ascough II et al., 2008; Liu et al., 2008; Schmolke et al., 2010). For example, hydrodynamic models are used in Dutch river management to anticipate the effects of interventions to the water levels in the river for specific discharges (Berends et al., 2019; Straatsma and Kleinhans, 2018; van Vuren et al., 2005). As discussed in the previous subsection, we set out to make such models accessible in the game and to increase their transparency. In general, serious games are recognized as a method to enable stakeholders to interact with models (Bots and van Daalen, 2007; Mayer, 2009; Voinov et al., 2016). Therefore, we first looked at other water and river management related serious games as a source of inspiration. Some games include an interaction layer to a hydrodynamic (meta) model based on a graphical user interface and provide insights into effects based on the model (Becu et al., 2017; Craven et al., 2017; Douven et al., 2014; Valkering et al., 2013). Other serious games that include water related computer models also use a graphical user interface as an interaction layer (Chew et al., 2013; Hill et al., 2014; Jean et al., 2018; Learmonth et al., 2011; Onencan and van de Walle, 2018; Rusca et al., 2012). Exception to this approach are Stefanska et al. (2011) and Magnuszewski et al. (2018), who designed a game board that players use to provide input to models. The interface to the models in their implementation was however controlled by a facilitator who processed the player decisions. Although all these approaches provide stakeholder with an interaction layer to computer models, these do not show how the models function or calculate effects. In other words, something goes in and something comes out. To make a model truly transparent requires that players are able to experience how the input to a model is related to its output.

We therefore looked beyond serious games to make a hydrodynamic model accessible and transparent (Chapter 4). We found inspiration in the SandBox-FM (Ottevanger et al., 2017), a tangible user interface to the Delft3D Flexible Mesh hydrodynamic model developed by Deltares. Tangible interaction is rooted in linking physical forms to digital information (Hornecker and Buur, 2006; Ishii, 2008). Similar tangible user interfaces as the SandBox-FM have been used in connection with environmental models before (Piper et al., 2002; Reed et al., 2016). In the SandBox-FM, users shape a literal sandbox as the geometry of, for example, a river bed. The geometry of the sand is turned into a digital elevation model by a Kinect that can be used by the hydrodynamic model. The model subsequently returns the water flow

pattern and uses the pattern to project and visualize how water would flow in the river geometry on the sand. Results of using the SandBox-FM showed that it provided an easily understandable, accessible and interactive interface to the hydrodynamic model, especially to those without a relevant background (Ottevanger et al., 2017). This property in particular was of interest for the Virtual River Game and the main reason we explored the use of a tangible user interface for the game (Chapter 4). The results of the Virtual River Game's evaluation showed that the interface enables domain experts and non-experts to engage in shared exploration of river management strategies (Chapter 5). By using the interface, non-experts gained insights about the functioning of hydrodynamic models and their use to make decisions. Moreover, we saw that experts could enhance this learning by contributing their background knowledge to further explain the visualized model output. In addition, the interface makes the views of both experts and non-experts explicit to others as they point to and make changes to the game board.

To our knowledge, using a physical game board as a tangible user interface for serious games, at least in the type of games as the Virtual River Game, has not been explored before. Tangible user interfaces have been applied in (serious) game design, but only in combination between tangible objects and a digital surface (Bakker et al., 2007; Leitner et al., 2008; Speelpenning et al., 2011). In turn, non-digital game boards as a representation of a river system or segment have been used before (Lankford and Watson, 2007; Magnuszewski et al., 2018; Rajabu, 2007; Stefanska et al., 2011), but not in (direct) connection to computer models or with model output visualized on the board. The tangible user interface described in this thesis is therefore a novel approach of combining the accessibility of a board game to the power of computer models. As a result, players interact with computer models by rearranging game pieces and are in full control of the interaction without intermediary facilitation. By visualizing model output back on the board, players observe the effects of changing game pieces on the location where they made them. Combined, based on our results, tangible user interfaces can make computer models such as hydrodynamic models accessible and transparent to stakeholders, regardless of their background.

Tangible interaction has intrinsic benefits to make models accessible and transparent (Chapter 4). First, tangible interaction makes use of people's ability to grab, move and change physical objects as an easy, intuitive and low-threshold way to interact with digital information (Hornecker and Buur, 2006; Ishii, 2008; Jetter et al., 2014). Second, by using physical objects as external representations reduces the cognitive load needed for problem solving. As external representations are physical, these can be inspected in the world (Zhang and Norman, 1994) and thereby enable people to more easily gain an understanding of abstract concepts (Antle, 2007; Clem-

ents, 2000; O'Malley and Fraser, 2004). Third, tangible user interfaces enable people to engage in collaborative activities. The control of the interface is shared (Xu, 2005; Zuckerman et al., 2005) and taking actions with the interface (or even pointing to an object) is visible to other people (Stanton et al., 2001; Suzuki and Kato, 1995). To summarize, the use of tangible user interfaces is of value to serious games that include digital models as they provide domain experts and non-experts with a shared object that: (1) enables players to collaboratively work with models; (2) provides an easy to use and low-threshold interface to models; (3) reduces the cognitive load for problem-solving; and (4) makes actions in the game visible to other players.

6.1.3 *Experimenting with interventions*

Serious games are designed to be environments in which it is safe to experiment (Bekebrede, 2010; Duke and Geurts, 2004; Geurts et al., 2007; Mayer, 2009; Zhou, 2014). Decisions inside the game are only valid within the context of playing the game and therefore stimulate as well as provide safety to experiment. In serious games to collaboratively explore complexity, players apply interventions in order to pursue their objectives or improve their scores. As serious games are representations of reality, these interventions are representations of management interventions applied in practice. In games where players manage a spatial area, interventions are generally included as binary options that can be turned on or off for defined locations in the game (Bathke et al., 2019; Bonté et al., 2019; Carson et al., 2018; Craven et al., 2017; Hill et al., 2014; Rusca et al., 2012). Sometimes games include multiple options of the same intervention on the same location, such as including small, medium and large versions (Onencan et al., 2016; Savic et al., 2016; Valkering et al., 2013). After selecting and applying one or more interventions, players can inspect the interventions' effects based on the game's integrated models. As a result, players gain insights into the combined effects of the predefined interventions and therefore learn about the techno-physical complexity of the environmental system through experimentation (Bathke et al., 2019; Carson et al., 2018; Hill et al., 2014; Onencan et al., 2016; Valkering et al., 2013).

Whereas most similar serious games enable experimentation with combinations of predefined interventions, the Virtual River Game adds the design of interventions (Chapter 5). Moreover, the interventions are not hardcoded in the Virtual River Game's software, but are implemented based on game rules defined outside the software. Players apply measures by replacing pieces on the game board. Therefore, players determine the location, direction, shape and size of the intervention. This in turn allows players to engage in new forms of collaborative experimentation in the game. Players learn about how and when interventions are effective by thinking

of, trying and evaluating different implementations of interventions. Subsequently, the new insights can be used by players to think of, try and evaluate more effective implementations of the intervention. In effect, this trial and error experimentation is a form of experiential learning (Kolb, 1984), where players move through the circle of an experience, reflection on the experience, develop new ideas based on the experience, and apply the new ideas to gain a new experience. We showed through the evaluation of the Virtual River Game that the ability to collaboratively experiment with interventions contributed to establishing learning outcomes by playing the game (Chapter 5). For serious games in general, adding the ability to design interventions over selecting predefined interventions is valuable to trigger experimentation and (social) learning.

6.1.4 *Platform for developing serious games*

In environmental management, serious games are typically tailor made to a specific environmental system, its physical location, its unique policy-making setting and its cultural contexts (Bots and van Daalen, 2007; de Caluwé et al., 2012; Duke and Geurts, 2004; Geurts et al., 2007; Toth, 1988b). Researching, designing and developing serious games in this context is therefore time consuming and the resulting game is not easily transferable to other systems or locations. The Virtual River Game is tailor made to Dutch river management. Its development has indeed been time consuming, from understanding the field of river management and its policy-making setting to eliciting the real stakeholder needs to developing and testing game prototypes. To develop the game, we created the hybrid, tangible interface as a platform (Chapter 5). Although serious games will still need to be tailor made, the platform and its customization options can be used to transfer the Virtual River Game more easily to other locations and settings and to develop new spatial serious games.

The developed platform can be summarized as a game table setup comprising a physical game board and hardware components in combination with a software package to process the physical board and link it to computer models and a game engine (Chapter 5). Rather than base the design of a game on specific models, the platform uses the generic link to models that are used in practice, creates schematizations based on the physical pieces that form the game board, and uses the schematizations as model input. This way, the game pieces combined form an abstract representation of a stretch of a Dutch river in the Virtual River Game. The developed version of the Virtual River Game is therefore not immediately applicable to the management of rivers in the United States, Colombia, Bangladesh or other countries. To transfer the Virtual River Game, game designers can design game pieces that represent elevation levels and land uses found in other countries. In addition,

the number and shape of the pieces can be changed to match the game board to a desired resolution for the stretch of a river. Tailoring the pieces may therefore be used to create schematizations that serve as abstract representations of stretches of a river that are found in other countries. Such changes would require only minor changes in the platform's software. Beyond the game pieces, the rules, roles and interventions of the Virtual River Game would also need to be tailored to the specific setting, but these are defined outside the game's software. In addition, the game designers would need to consider linking models that are used in practice in other countries to the platform, which is supported as long as the models have an interface option available such as the Basic Model Interface (Peckham et al., 2013). Other software components such as the visualizations of model output are fully customizable. As for the hardware, the game table can be manufactured with readily available materials and all hardware components are off-the-shelf. The designs for the game table are available.

Next to tailoring the Virtual River Game to new locations, the platform can also be used to develop entirely new games with a spatial component. The platform converts the physical board to a digital board and processes the digital board into a digital elevation model and land use distribution. This principle is valuable for developing serious games in river management and other environmental systems. Apart from serious games on flood safety of rivers, the platform can be used to develop serious games on water resources (Craven et al., 2017; Jean et al., 2018), such as on irrigation management (Lankford and Watson, 2007; Rajabu, 2007) and for considering constructing hydropower plants (Douven et al., 2014). It can be used for serious games around coastal management, such as on delta management (Bonté et al., 2019), flood safety management (Becu et al., 2017) or marine spatial planning (Keijser et al., 2018; Mayer et al., 2013). Beyond water, the platform can be used for serious games on for example land use management (Schulze et al., 2015; Sušnik et al., 2018), agriculture management (Farrie et al., 2015; Sausse et al., 2013; Speelman et al., 2014) and biodiversity conservation (Vasconcelos et al., 2009). Beyond environmental management, the platform is expected to be valuable to develop serious games for urban planning (Ampatzidou et al., 2018; Mayer et al., 2005; Zhou et al., 2013).

To conclude, the developed hybrid, tangible interface offers potential value as a platform to be used in environmental management and beyond to transfer the Virtual River Game and develop new serious games with a spatial component. The platform cannot overcome the overall weakness that such serious games need to be tailor made, but it does provide a proven basis. In context of the argument to not make technical aspects a driving force in the design of serious games, the platform value proposition may sound as a paradox. To clarify, game designers should first determine why using the platform helps to achieve the designers' intended purpose

and adds meaning and value for stakeholders. Only afterwards should game designers seek to determine how the platform can be used and customized to the environmental domain, physical location and policy-making context. In other words, the questions: (1) what are the stakeholders' actual needs; and (2) why to use the platform, should be answered before answering how to use the platform.

6.2 Reflection

Below, we reflect on the overall research conducted and presented in this thesis. We do so by reflecting on the overall research approach, the research as part of the River-Care research program and the limitations of the research.

6.2.1 *Research approach*

In this thesis, we explored applying human centered design to serious games to collaboratively explore complexity. We therefore took the stakeholders' actual needs and wishes as the starting point of the Virtual River Game's design. We showed that the identification of the actual stakeholder needs and wishes led to exploring the use of tangible interaction in the game. In turn, the use of tangible interaction proved effective to develop an interface that makes hydrodynamic models both accessible and transparent to stakeholders. In that regard, human centered design has shown its value to apply in the design and research of serious games to collaboratively explore complexity. At the same time, it was also time consuming to apply the approach.

Besides designing a serious game, we were designing ways to facilitate stakeholder involvement in the game's design process. We used interviews as a method to elicit stakeholder needs and wishes ([Chapter 2](#)). Interviews may not be considered a core human centered design method. However, in accordance with the human centered design philosophy, we developed an interview method, informed by Sense-making and Cultural Theory, to facilitate river management stakeholders to structurally reflect on a self-introduced, challenging situation and subsequently imagine how they would like to address the situation. The method proved effective to gain a deeper understanding of the challenges and stakeholder perspectives, while allowing to generalize the understanding to derive needs and desires. The developed interview method may therefore be used to gain an understanding of how stakeholders frame issues and solutions in contested policy areas. Developing the method took time, as did the analysis of the interviews themselves. A method that would have engaged multiple stakeholders at once, e.g. a focus group, may have taken less time to execute and analyze, but would not have enabled us to explicitly explore and

understand the “worlds” of individual river management stakeholders. We iteratively developed prototypes of the Virtual River Game and evaluated these together with stakeholders (Chapters 4 and 5). We deliberately evolved the prototypes from rough and low-fi to the final stylized and high-fi prototype in order to match the prototypes’ completeness, presentation and aesthetics with the state of the design process and the type of feedback that we sought from stakeholders. Although developing the prototypes took time, iteratively developing and evaluating the prototypes together with stakeholders was both effective and efficient to determine possible improvements and design steps.

Moreover, designing the prototypes enabled us to involve stakeholders in the design of the Virtual River Game as well as to shape our own design ideas. However, the most important value of the intermediate prototypes was its use as a form of communication of our design ideas. Based on our experience developing the Virtual River Game, communicating game design ideas through means such as presentations on interface designs or concept maps of qualitative models works poorly to both get the desired message across and facilitate stakeholders to provide meaningful feedback. Serious games have to be experienced in order to properly determine if the design is on the right path. In essence, playing and evaluating the game prototypes ensured that we and the stakeholders spoke the same language. Subsequently informing stakeholders how we intended to use their feedback led to further discussions on the game’s design and generated interest to be involved in the design process at a later stage. To conclude, after developing an initial idea and scope for a game, designing rough, but playable prototypes is most helpful as a form of design communication to gain further insights into next steps in the game’s design. Our advice to designers is therefore to overcome their inherent (or natural) reluctance to showcase unfinished or, in their view, poor quality designs and to start the communication early.

6.2.2 *Research as part of RiverCare*

The research presented in this thesis was executed as part of the RiverCare research program (Hulscher et al., 2014). The RiverCare program is a large research program comprising five Dutch universities and around twenty governmental and industrial partners. Embedding the research in RiverCare defined the focus on developing a serious game on river management. Moreover, the large number of researches, supervisors and partners involved in the program equaled the number of different expectations on the serious game’s development. Most notably, the serious game was envisioned as a tool to integrate research results of RiverCare projects as a form of science communication and decision support.

As the purpose of the game was leading for all design decisions, we were looking to integrate RiverCare research results relevant to that purpose. We made attempts to generalize results of researchers to so called rules of thumb; simplified, cause-effect relationships that we could embed in the game. We tried to find such rules of thumbs in both workshops and one-on-one meetings with RiverCare researchers. However, it proved difficult to: (1) take researchers out of their comfort zone to generalize their results to rules of thumbs; and (2) explain exactly what we were looking for as game designers. Only after also playing game prototypes with researchers did it become easier to discuss their potential contributions and build on their expertise. The lesson learned here is that game prototypes should not only be considered as a form of external communication to involve stakeholders in the design process, but also as internal communication to convey design ideas in the research program.

To perform design research in a large, interdisciplinary research program therefore has its challenges, but the struggles that it may bring do not outweigh the benefits. The points outlined above should therefore be seen as helpful reflections for future design and game researchers taking part in larger research programs. Designing a serious game is inherently an interdisciplinary effort ([Harteveld, 2011](#); [Ritterfeld et al., 2009](#)). The RiverCare program included the needed interdisciplinary from the start. The main benefit of conducting the research in RiverCare was therefore to involve researchers and form an interdisciplinary team to contribute to the Virtual River Game's design, reflected by the number and diversity of co-authors of [Chapters 2, 4 and 5](#).

6.2.3 *Limitations*

All research has its limitations. The first limitation to this research relates to developing the Virtual River Game as a RiverCare communication tool. As described in the previous subsection, the expectation was that RiverCare results could be easily integrated in the game and that the game would function as a decision support system. As we developed the game as a generic experimentation environment following the research on stakeholder needs and wishes ([Chapter 2](#)), meeting those expectations proved difficult. The knowledge and models generated as RiverCare results were specific, while the knowledge and models sought for the game were more generic. Moreover, as this research was executed in parallel with other RiverCare projects, not all knowledge and models were readily available when we had to make design choices. As a result, the game is a result of the interdisciplinary work of RiverCare researchers and includes general messages that reflect RiverCare results such as the ecologic value of spatial measures, but does not include the specific results of the RiverCare program as initially envisioned.

As a second limitation to the research, we developed the Virtual River Game without a real world case study in the form of a river management project. As the RiverCare program was launched in response to the new type of interventions applied in the Room for the River management program, most of the Room for the River projects were (nearly) finished by the time it started. On-going river management projects that included spatial intervention measures were few and sensitive among local residents (During et al., 2016; Van Buuren et al., 2016). We attempted to develop and apply the Virtual River Game in an on-going project, but the project managers were not eager to introduce experimentation given the project's sensitive nature. As a result, the Virtual River Game has not been applied in a real policy-making setting. We therefore have not been able to study if the game provides a safe experimentation environment when applied in a real project nor if playing the game has a positive contribution to a project, i.e. if the game's social learning outcomes are transferred to and applied in reality.

A third limitation of the research relates to the extent of stakeholder involvement in the Virtual River Game's design. As part of the human centered design approach, we organized co-design workshops with stakeholders early in the design process. The workshops aimed to facilitate stakeholders to participate in the game's design and as such to create a sense of ownership of the game. These workshops were helpful to us to gain a better understanding of the stakeholders' needs and desires, but were not successful to create the sense of ownership. The human centered design approach could be further improved by informing the workshop set-up with techniques from companion modelling (Barreteau et al., 2003; Étienne, 2013) and participatory modelling (Voinov and Bousquet, 2010; Voinov et al., 2016). These approaches are already applied in environmental management and could therefore facilitate more active participation in the design of serious games to collaboratively explore complexity, fitting with the human centered design philosophy. Moreover, in order to develop a sense of ownership of the game among stakeholders, the availability of a real world case study would have been crucial.

Concluding, it would have been beneficial to have a real world case both to apply human centered design and to develop the Virtual River Game. Although we designed the game to be a generic representation of Dutch river management, the availability of a real world case in early game development phases would have better facilitated stakeholders to contribute to the game's development. Without this case, it proved difficult to convince stakeholders of the value to participate in co-design workshops. Moreover, from a practical point of view, stakeholders had difficulty to justify spending significant time on the game's design without the co-design workshops being organized in relation to an existing project that they or their organi-

zation were involved in. These two barriers were easier to overcome once we had developed game prototypes and we could both explain and show to stakeholders what we saw as the game's potential added value.

Chapter 7

Conclusions and recommendations

Our objective was to explore how a human centered design of serious games contributes to foster exploring complexity, facilitating stakeholder participation and stimulating social learning in environmental management. In this thesis, we therefore applied a human centered design approach to the Virtual River Game by: (1) researching the actual needs and wishes of Dutch river management stakeholders; (2) exploring how the game's design can meet these needs; and (3) evaluating to what extent the game was successful to meet these needs. Based on the results, we are able to determine how applying a human centered design approach enriches the design of serious games to collaboratively explore complexity. Below, we first draw conclusions on the thesis' research objective. Afterwards, we draw conclusions on the research questions. We end with recommendations for both future research and in regard to the outcomes of this thesis.

7.1 Conclusion to the research objective

From the outset, we proposed that applying a human centered design approach to serious games may enrich their design and enhance their abilities to foster: (1) exploring complexity; (2) facilitating stakeholder participation; and (3) stimulating social learning in environmental management. Based on the research, design and evaluation of the Virtual River Game, we draw the following conclusions on each of these three aspects. On the first aspect of the research objective, the results from the five evaluation sessions show that game was successful to explore complexity in river management. To explore the techno-physical complexity, players rearranged pieces on the game board to apply river management interventions such as side channels, longitudinal training dams and dike relocations. Players could subsequently inspect the effects of these interventions on the flood safety, biodiversity and costs indicators based on computer models widely used in practice. Players explored the socio-political complexity by playing the role of flood safety, nature or budget manager in the game. In these roles, players pursued different objectives and had protest abilities that guided how players might propose or block certain implementations of interventions. By using a physical game board, players were provided with an environment that stimulated exploration and experimentation. In comparison with existing serious games, the Virtual River Game's design increased the experimentation potential as the game enabled players to design interventions over selecting predefined interventions.

On the second aspect of facilitating stakeholder participation, the Virtual River Game was successful to engage both domain experts and non-experts and in particular to enable them to work together. The game expands on existing serious games by providing players with a tangible user interface to collaboratively work with environmental models, regardless of players' background and expertise. For experts, it was important to include models as these form a basis for discussions and decision-making in practice. For non-experts, it was important to be able to work with these models to increase their understanding of how these models are used in decision-making. Moreover, players used visible actions such as moving pieces or pointing to locations on the game board to support discussions, making their views on both the problem and possible solutions explicit to each other. As a limitation however, the game was evaluated in sessions that were not related to a real world policy context. We therefore cannot conclude that the game is also successful to facilitate stakeholder participation when applied in an actual river management project.

On the third aspect of the research objective, the results indicate that the Virtual River Game was successful to stimulate social learning. By playing the game, both domain experts and non-experts gained insights through the shared explora-

tion and experimentation with interventions as well as from discussions with other players. Non-experts indicated, mostly with strong agreement, that they gained both cognitive and relational learning outcomes, and emphasized outcomes associated exclusively with cognitive learning as their main insights. Experts reported more mixed results, with many statements associated with cognitive and relation learning rated positively and some rated neutrally to negatively. Experts emphasized main insights associated with both cognitive and relational learning. Based on the evaluation, we discussed how the game's hybrid, tangible interface enhances social learning by combining strengths of board and computer games. First, by using the physical game board as a tangible user interface, the players shared control of the game and were not dependent on a facilitator or one player using an input device. Second, the interface enabled players to collaboratively work with environmental models without the need to have expertise with these models. Third, enabling players to experiment with the design of interventions contributed to triggering learning.

Central to the objective was to investigate how human centered design contributed to enriching the design of the Virtual River Game. By applying human centered design, we gradually gained an understanding of an actual need of river management stakeholders: To open up the black box of hydrodynamic models that are used in Dutch river management practice. We therefore aimed to make these models accessible and transparent in the game. We did not find satisfying design solutions in existing serious games to do so and therefore looked for inspiration to develop design concepts that went beyond existing solutions. Finding that inspiration in tangible interaction, we developed the novel interface design that links a physical game board to digital models. The interface design makes the hydrodynamic model accessible as it enables players to work with these models by rearranging game pieces on the game board. The model's output is subsequently projected and visualized on the game board. As such, the interface design makes the hydrodynamic model transparent as the game board is the location for both the model's input – the changes made by players – and its output – the projected visualizations. Evaluation of the game showed that Virtual River Game was successful to make the hydrodynamic model both accessible and transparent. The human centered design of the Virtual River Game therefore made the stakeholder needs and desires leading in the game's design, placing the game's technical aspects second. Moreover, the human centered design approach led to a game design that, as discussed above, contributes to exploring complexity, facilitating stakeholder participation and stimulating social learning in environmental management.

In conclusion, human centered design fits recent calls to make the stakeholders, the policy context and the (social) processes of the problem at hand the driving

force in the design of serious games to collaboratively explore complexity (Aubert et al., 2019; Rodela et al., 2019). Applying a human centered design approach by explicitly researching actual needs and wishes of stakeholders can enrich the design of a serious game to collaboratively explore complexity in environmental management. Specifically, applying a human centered design approach may lead to looking beyond existing solutions and therefore lead to novel game designs that provide meaning and value to stakeholders.

7.2 Conclusions to the research questions

7.2.1 RQ1: *What are the challenges, needs and stakeholder perspectives needed to collaboratively explore river management complexity?*

To design the Virtual River Game, we considered the stakeholder needs and desires as the prominent drivers. We developed an interview method that follows the human centered design philosophy. Using the method, we interviewed stakeholders to elicit their needs and desires. From these, we determined that stakeholders should be able to explore the cost-effectiveness of river management interventions such as dike reinforcement and spatial measures to both increase flood safety levels and pursue secondary objectives. In addition, stakeholders should be able to experiment with floodplain land use planning to experience the spatial explicitness of floodplain vegetation. These needs and desires relate to the identified challenges of (1) formulating future river management policies to adapt to climate change, and (2) creating flexibility to allow natural dynamics in a controlled river system respectively (Chapter 2). We subsequently analyzed the stakeholder perspectives on these challenges. The perspectives served as input to game design by further understanding what players should experience and explore while playing the game. On the first challenge, we found only one perspective that focused on defining specifications for both: (1) the distribution between the contribution of spatial measures and dike reinforcement to reach flood safety norms; and (2) the inclusion of secondary objectives next to reaching flood safety norms. We identified two stakeholder perspectives in regard to the second challenge: (1) to create clear boundaries on the extent that natural dynamics in nature areas may take place (the control perspective); and (2) to develop the river system following natural processes (the flexibility perspective). In addition, we identified a third challenge in sustaining the integrated river management approach in the maintenance of floodplains. We also found two stakeholder perspectives on this challenge: (1) to accept public tendering, focusing on each own's responsibilities and developing public tendering strategies together to pursue integrated objectives; and

(2) to reject public tendering, reducing its negative effects or removing the mechanism altogether as it obstructs long-term planning. As this challenge focused on the governance aspect of river management rather than the new spatial interventions, we did not aim to design the Virtual River Game to explore this challenge.

7.2.2 RQ2: How can social learning through the serious games be evaluated and how can the evaluation approach be used to distill game design guidelines for collaboratively exploring complexity?

For the first part of the question, we looked at the assessment of three types of social learning outcomes: (1) acquiring new or restructuring existing knowledge (cognitive learning); (2) shifting viewpoints, values or paradigms (normative learning); and (3) improving the understanding of the other stakeholders' views and mind-sets as well as enhancing their ability to cooperate (relational learning) (Baird et al., 2014). Based on a systematic literature review (Chapter 3), we identified three evaluation strategies to assess each type of learning outcome: (1) measuring participants' knowledge before and after playing a game (measured learning); (2) participants self-reporting on learning after playing a game (self-reporting learning); and (3) observing learning by participants during a game (observed learning). We discussed how all three strategies are suitable for assessing cognitive learning outcomes. For normative learning outcomes, the use of the measured and self-reported learning evaluation strategies are suitable. For assessing relational learning outcomes, the self-reported and observed learning strategies are applicable. We further provide an overview of methods applicable to each evaluation strategy to assess each type of social learning outcome.

For the second part of the question, we showed how considering the evaluation of social learning outcomes as a design question is beneficial to designing a serious game to collaboratively explore complexity. Explicitly including the evaluation of social learning outcomes as a design question created an objective that we aimed to both attain and assess. This goal therefore served not only to determine how the game's social learning outcomes can be evaluated, but also to emphasize how the game can be designed to enhance social learning. On a practical level, considering the evaluation as a design question meant that the required data collection was included in the game's design requirements. As such, developing the evaluation approach did not become a retrospective activity. Combined, we conclude that considering the game's evaluation as a design question increases the quality of both the game and its evaluation as well as saves time. We further conclude that considering the game's evaluation as a design question contributes to more systematically assess the effectiveness of using serious games to stimulate social learning.

7.2.3 RQ3: How can the intended serious game be designed to meet the identified stakeholder needs and intended social learning outcomes?

We showed that involving stakeholders throughout the design process of a serious game is a necessity to meet their needs and desires. We discussed how game designers therefore need to not only design the game, but also use design to facilitate stakeholder involvement. To do so, we explained how game prototypes – from rough, non-playable and low-fi prototypes to stylized, playable and high-fi prototypes – should be considered as a form of design communication. We showed that developing prototypes and facilitating stakeholder involvement led to the design of the novel interface design that links a physical game board to digital environmental models (Chapter 4). We conclude that game designers need to therefore balance completeness, presentation and aesthetics of the prototypes to reflect the state of the design process and the type of feedback sought for. We stress the importance to clearly communicate both the state of the design process and type of feedback sought for to stakeholders. We further emphasize the importance and benefits for game designers to communicate how they intend to use the feedback to stakeholders that participated in a prototype's evaluation.

7.2.4 RQ4: How and to what extent does the Virtual River Game enable stakeholders to collaboratively explore river management complexity and stimulate social learning?

We showed that the Virtual River Game was successful to explore Dutch river management complexity (Chapter 5). In particular, we showed that the game enabled domain experts and non-experts to collaboratively experiment with river interventions. We conclude that the game was therefore also successful in facilitating participation of diverse types of stakeholders. In the game's evaluation, both domain experts and non-experts indicated that they gained insights by playing the game, albeit to a different extent, through self-reporting. Non-experts mostly agreed or strongly agreed with statements that they gained insights in relation to topics such as the functioning of the river system, the trade-offs between interventions, the use of hydrodynamic models, and the views and perspectives of other players. In their comments, non-experts emphasized insights that are exclusively associated with cognitive learning. Experts rated the statements in a more mixed way, with some statements rated positively but some statements, such as on the use of hydrodynamic models, neutrally to negatively. In their comments, experts emphasized insights related to both cognitive and relational learning. We conclude that playing the game led to establishing social learning outcomes and that the Virtual River Game's interface design contributed to enhancing social learning by combining three

strengths of board and computer games. First, the developed tangible user interface gave the players shared control of the game. Players were therefore not dependent on a facilitator or another player using an input device. Second, the interface enabled players to collaboratively work with environmental models regardless of them having expertise with these models. Third, the game increased the level of experimentation by enabling players to design river management interventions using tangible game pieces over selecting predefined interventions.

7.3 Recommendations and next steps

Serious games are increasingly used in environmental management as tools to foster the collaborative exploration of complexity and to stimulate social learning. Through the research presented in this thesis, we have explored how human centered design can enrich serious games to collaboratively explore complexity. Of course, research is never finished. Below, we present recommendations and possible next steps for future research as well as for the Virtual River Game and its hybrid, tangible interface.

7.3.1 Research

Transfer of social learning outcomes

Serious games are designed with learning objectives in mind. Lessons learned by playing the game should be useful in the world outside the game. Therefore, applying serious games is based on the assumption that learning through games is transferable to reality (Chin et al., 2009; Crookall and Thorngate, 2009; de Caluwé et al., 2012; Duke and Geurts, 2004; Geurts et al., 2007; Mayer, 2009; Mayer et al., 2014). To reuse an excerpt from the introduction: “Proving that simulation games work reminds us of high school math in which one had to build a complicated argument to prove that two triangles had the same shape when one glance at the figure sufficed to confirm that they did. The effectiveness of simulation games is evident to those who work with them (players and facilitators)” (Hofstede et al., 2010, p. 825). As both players and facilitators, we indeed see the effectiveness of serious games and this thesis adds additional evidence to this claim. However, to prove that learning through games is transferred to the real world continues to be a challenge (Chin et al., 2009; Hofstede et al., 2010; Mayer, 2009; Mayer et al., 2014).

Initially, we had set out to contribute to this knowledge gap, but this proved incompatible with both researching and designing the Virtual River Game. Specifically, to evaluate if and to what extent learning through a game is transferred to the world outside the game requires analyzing the long-term effects of playing the

game in a real policy-making setting. Moreover, it may require stakeholders to play the game more than once during a period of time. In a project that aims to design a serious game, the final, tested, and validated prototype is likely going to be finished towards the end of the project, leaving (too) little time to conduct such evaluations. For research, a next step is to conduct more research on the transfer of in-game learning to reality. [Chapter 3](#), the literature review on assessment of social learning outcomes, may serve as a resource to do so. We recommend to do such research as a next step with the Virtual River Game.

Human centered design of serious games

Based on the results of this thesis, we recommend to apply human centered design in the development of serious games to collaboratively explore complexity. Doing so puts emphasis on designing games that meet the actual needs and desires of stakeholders. As a possible next step, the value of applying human centered design to serious games can be further explored. In particular, future research could explore how stakeholders can not just be included in the design process, but can become part of the design team. In other words, a possible next step is to explore how stakeholders can be involved and facilitated to co-design serious games to collaboratively explore complexity and thereby create a feeling of ownership of the game. To do so, such research would benefit from developing a game in a real policy-making setting. This way, the game development would relate to a real project or policy implementation that affects involved stakeholders. Such research could moreover explore to merge the human centered design approach with techniques such as companion modeling ([Barreteau et al., 2003](#); [Étienne, 2013](#)) and participatory modelling ([Voinov and Bousquet, 2010](#); [Voinov et al., 2016](#)) that already look at games as a way to collaboratively develop and use environmental models in participatory settings.

7.3.2 Virtual River Game and platform

Reconsider roles

Considering the Virtual River Game as a product, there are some improvements and next steps to consider. An important outcome of this research is the recommendation to reconsider the roles in the game. Specifically, as the game evaluation showed, a more direct representation of the interest of agriculture in the floodplains should be considered ([Chapter 5](#)). In development of the game, we had considered the inclusion of a fourth role, the economic manager, that would represent the interest of agriculture and could also include the interest of river navigation. Currently,

agriculture is represented indirectly through financial penalties to acquire farms and agricultural land as well as by providing the budget manager with a veto for these acquisitions. When presented with the economic manager proposal in the evaluation of the game's external validity, domain experts stated that the current game setup was very effective to demonstrate the effects of interventions in the river system. Adding the role would improve the socio-political representation of the game, but the experts feared that it would change the type of discussions and make the game far more complex.

Additional game levels

As discussed above, the inclusion of the roles in the game should be revisited, but another option worth exploring would be to create a second, more complicated game level where additional roles, objectives, interventions and indicators are introduced. This way, the current game could serve as an introductory level to river management and the economic manager role would be added in a second level. An option to further consider including in this second level is to not only look at possible flooding, but also at droughts, i.e. low river discharge situations which are becoming more common in the Netherlands (de Wit et al., 2007; Lenderink et al., 2007; van Vliet and Zwolsman, 2008). Including low river discharges would, in turn, make it logical to also include the interest of river navigation as part of the economic manager role. RiverCare results related to floodplain vegetation (Harezlak et al., 2020; van Iersel et al., 2018) and morphodynamics of both the main channel and spatial measures (Chavarrías et al., 2019; de Ruijscher et al., 2018; Duró et al., 2018; Van Denderen et al., 2019) could be relevant to include in this level as well.

Another direction for an additional level could be to specifically address the third challenge identified in RQ1: Sustaining the integrated river management approach in the maintenance of floodplains. We did not focus on this challenge in the design of the Virtual River Game as it relates to river governance rather than river interventions. The Virtual River Game as presented in this thesis could however serve as an introductory game to river management and the additional level to subsequently explore river governance. In the design of this level, the focus would be on the roles to include in the level and place more emphasis on their interaction rules. For example, the level could allow the exploration of how players, based on their in-game roles, can collaboratively develop plans in relation to the Dutch public tendering process around managing floodplain areas. For this level, RiverCare results in regard to the governance of floodplain management (Fliervoet et al., 2017), public participation (Verbrugge and van Den Born, 2018) and public procurement strategies (Bout et al., 2019) would be relevant to consider.

General improvements

Next to reconsidering the in-game roles and additional levels, the evaluation showed that there are some potential improvements to the Virtual River Game's design (Chapter 5). First, missing from the game was a go back option when players wanted to undo an intervention implementation. This meant that players had to remember what the previous board state was to go back, which is not in line with the notion that the interface reduces cognitive load. The proposed solution is creating a visualization of the board state before an update that players can switch to when desired, which has since been added. Second, the information panel for the costs of different interventions requires a redesign as some players found it difficult to interpret the table. In the current table, players first look which cost types are linked to which interventions and then look up what the costs are. The redesign should merge these two cognitive steps to make the actual costs associated with interventions immediately clear. Third, players indicated that the biodiversity information panel was very helpful and that they would appreciate a similar information panel for how different land uses affect hydraulic roughness. Fourth, although updating the board state stops the water flow visualization on the board, the software did not provide players with direct feedback that the system is updating on the touchscreen monitor. At times, players therefore did not realize that the system was updating after initiating the update on the touch screen. As a result, players sometimes pressed the update button a second time, causing the system to update twice. The solution is to make a popup window appear after pressing the update button, which has since been applied. The popup window could be further improved by including information on the status of the update or with an indication of how much longer the update is expected to take. Last, the aesthetics of the Virtual River Game's GUI, the window on the touchscreen that players use to trigger updates and switch visualizations, reflect its prototype status and should be redesigned to match that it is a finished product.

Linking game tables to increase spatial scale

Beyond these improvements of the game design, one possible next step to consider is to develop a larger Virtual River Game by connecting two game tables, transforming the game to manage a larger river section with two playable stretches of a river. The game would work similarly as its current implementation, with all the roles played at both game tables, but choices on one board affect the other. Interventions implemented on the downstream game table would have effects on the upstream one and vice versa. Moreover, the decisions on both game tables would influence the indicator scores, meaning that negotiations between the managers of the two stretches of river are required. Adding an option to support the negotiations in the game – e.g.

enabling the exchange of budgets – would stimulate the players to collaboratively balance their performance in the stretch of river they are responsible for as well as in the larger river section. The Virtual River Game described in this thesis enables players to experiment with river interventions and to inspect their effects. By connecting two game tables, the Virtual River Game would add that players also experience how interventions in one river location affect another and how therefore river management encompasses different spatial scales (Gurnell et al., 2016; Vreugdenhil et al., 2010). Consequently, players would also experience the need for collaboration on different spatial scales.

Transferring and developing serious games

Considering the developed hybrid, tangible interface as one of the thesis' main contribution, a possible next step would be to further explore its use as a platform to transfer or develop serious games in environmental management. Of interest would be to use the platform to tailor the Virtual River Game to river management in other countries with different spatial properties and policy contexts. Beyond river management, the platform can serve as a basis to develop games on other environmental systems. Staying close to the Virtual River Game, such applications could be in other water systems, e.g. coastal, delta or urban water management. Other application areas could be land use management and urban planning. Of initial interest would be to research how well the platform serves the design and transfer of serious games. Next, exploring how the platform can be used to develop games in other application areas would determine additional functionality and requirements for the platform. Further development of the platform should thereby increase its value proposition.

7.4 Closing

Supported by the results of this thesis, we strongly believe in the value of serious games to collaboratively explore complexity in environmental management. As we show in this thesis, serious games can provide a simplified yet accurate representation of reality where stakeholders can engage in a shared exploration of environmental complexity. Moreover, we show how human centered design can contribute to designing serious games that cater to the actual needs and wishes of stakeholders. As a result, the four main contributions of this thesis are: (1) applying a human centered design process to the design of serious games; (2) developing a novel interface design that uses a physical game board linked to environmental models to make the models accessible and transparent; (3) adding the ability to experiment with the design of interventions as a game mechanic over selecting predefined interventions; and (4) creating a platform to customize existing or develop new serious games with

a spatial component. There is work to be done to further explore to use and potential of serious games and we provide recommendations for both research in general and towards the outcomes of this thesis specifically. We hope that this thesis encourages and inspires both design researchers and game designers to continue exploring how the design of serious games to collaboratively explore complexity in environmental management can add meaning and value to stakeholders.

List of publications

Peer reviewed articles

- Cortes Arevalo, V.J., Verbrugge, L.N., den Haan, R.J., Baart, F., van der Voort, M.C., & Hulscher, S.J.M.H. (2018). Users' perspectives about the potential usefulness of online storylines to communicate river research to a multi-disciplinary audience. *Environmental Communication* 13(7) 909-925. <https://doi.org/10.1080/15715124.2018.1503186>.
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