How a Tangible User Interface Contributes to Desired Learning Outcomes of the Virtual River Serious Game

Robert-Jan den Haan[1](✉), Jelle van Dijk[1], Fedor Baart[2], Mascha van der Voort[1], and Suzanne Hulscher[3]

[1] Department of Design, Production and Management, Faculty of Engineering Technology, University of Twente, P.O. Box 217, 7500 AE, Enschede, The Netherlands
r.j.denhaan@utwente.nl

[2] Department of Software, Data and Innovation, Deltares, Boussinesqweg 1, 2629 HV, Delft, The Netherlands

[3] Department of Water Engineering and Management, Faculty of Engineering Technology, University of Twente, P.O. Box 217, 7500 AE, Enschede, The Netherlands

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.

Keywords: Serious gaming · Interaction design · Tangible user interface · River management

X. Fang (Ed.): HCII 2019, LNCS 11595, pp. 288–306, 2019.
https://doi.org/10.1007/978-3-030-22602-2_22

1 Introduction

Serious games are increasingly explored as tools to facilitate stakeholder discussion and collaboration in multidisciplinary settings [1–3]. Serious games are generally referred to as games designed with a purpose other than entertainment, such as training, educating or informing players [4, 5]. More specifically towards the use of games to facilitate discussion and collaboration in a policy-making setting, Mayer [6, 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 [6–8]. 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 [2, 6, 7].

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 [9–11]. 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 [12, 13] – 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 Sect. 2, we further introduce river management with a particular focus on the Netherlands and serious games in relation to river management. In Sect. 3, we present the theoretical framework in relation to both social learning and tangible interaction. In Sect. 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 Sect. 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 Sect. 6, we state some concluding remarks and explain our next steps in the development and evaluation of Virtual River and its tangible user interface.

2 Background and Related Work

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 [14, 15], concern inherent uncertainties [16, 17], and affect multiple stakeholders and agencies [18, 19]. 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 [20–23].

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 [24–26]. 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 [18, 19]. 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 [27]. 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' [28, 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 [8, 29].

2.2 Serious Gaming in River Management

Serious games that integrate scientific and political worlds are increasingly finding their way in the water domain [2, 30–32]. In relation to river management specifically, there are a number of examples of serious gaming approaches to facilitate stakeholder discussion and collaboration [33–40]. For example, Stefanska, Magnuszewski [34] 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, van der Brugge [35] 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, Mul [40] 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.

3 Theoretical Framework

3.1 Social Learning

Serious games—particularly the multiplayer and multi-role serious games following the definition by Mayer [6]—are recognized to offer the necessary collaborative and participative interactions needed to establish social learning [3, 30]. Social learning is considered to be a normative goals and prominent driver to manage natural systems in natural resources management [21, 41–43]. Scholars have yet to find a commonly shared definition for social learning (see [23, 41, 44, 45]), 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 [41, 42, 44, 46, 47]. Collaborative and deliberative interactions between stakeholders are required to achieve social learning, which should ultimately lead to collective action [45, 46, 48]. 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, Plummer [47] 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, Plummer [47] to distinguish between learning outcomes in connection to the literature on tangible interaction.

3.2 Tangible Interaction

Tangible interaction is a theoretically informed interaction design framework that combines physical object manipulation and digitally controlled interactive behavior [12, 13]. 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 [49]. 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 [50]. A tangible user interface can therefore be defined as an interface that provides physical forms to digital information [12]. 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 [51], and Illuminating Clay, where users apply landscape analysis directly by manipulating the clay model of a landscape [52].

Previous research suggests that tangible user interfaces offer qualities to facilitate learning and collaboration (see e.g. [53, 54] 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 [55–59], providing users with tools to engage in new ways of thinking [60]. Secondly, a tangible user interface invites trial-and-error behavior [61] and experiential learning through exploration, discovery, and reflection [56, 57, 62]. 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 [63], aiding users to grasp abstract concepts through the interaction with physical objects [64–66]. Lastly, tangible user interfaces also enable users to engage in collaborative activities [13, 62, 67] – a prerequisite to social learning – by offering a multi-user interface where control is shared [59, 61] and making the actions and activities of other users visible [68, 69]. Specifically, the social-collaborative value of tangible interaction has been emphasized since its initial formulation (see [70]), focusing on how users working with tangible objects in social settings may contribute to creating a shared understanding of the problem at hand [71].

4 Virtual River

As part of the RiverCare research programme [72], 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 [27]. 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.

4.1 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.

Fig. 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.

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 [73] (Fig. 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 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.

4.2 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.

Fig. 2. SandBox setup and interface (photo from [74]). 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 beamer projects the model's output back on the box of sand.

As a basis for the interface, we are using an existing framework called the SandBox, an augmented reality collaborative modeling tool [74]. Inspired by the LakeViz project [75], the SandBox consists of a box of sand, a color and depth camera (RGBD, Kinect), the relevant hydrodynamic model, and a projector (Fig. 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 [76] 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.

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

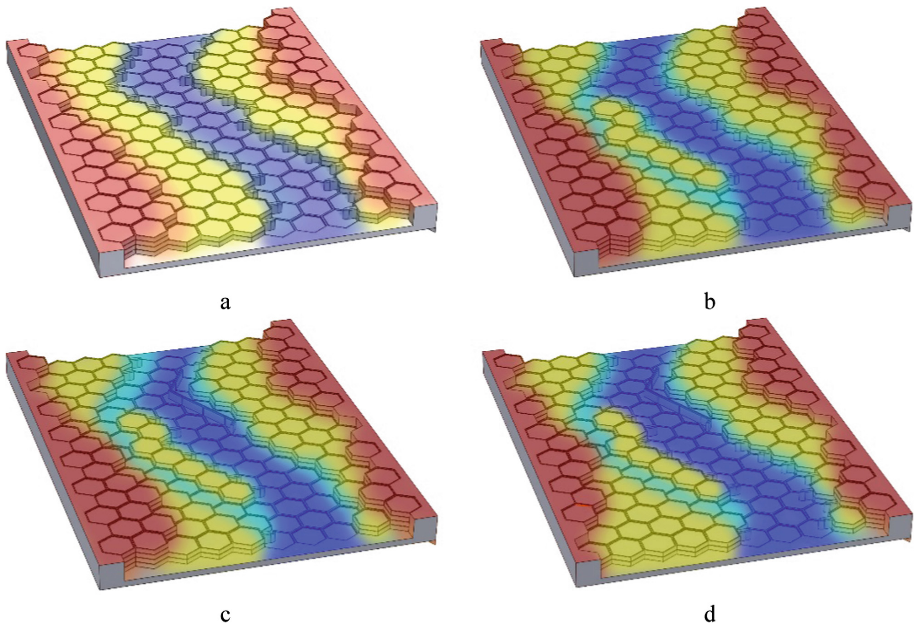
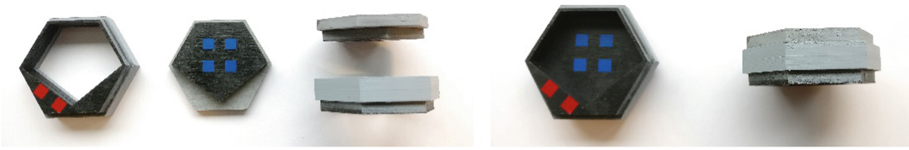


Fig. 3. Game board impression with (a) an initial river basin, in a typical Dutch layout, and elevation projection; (b) game board after the construction of a side-channel, a secondary channel next to the main river channel; (c) game board after constructing a longitudinal training dam, a dam constructed 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.

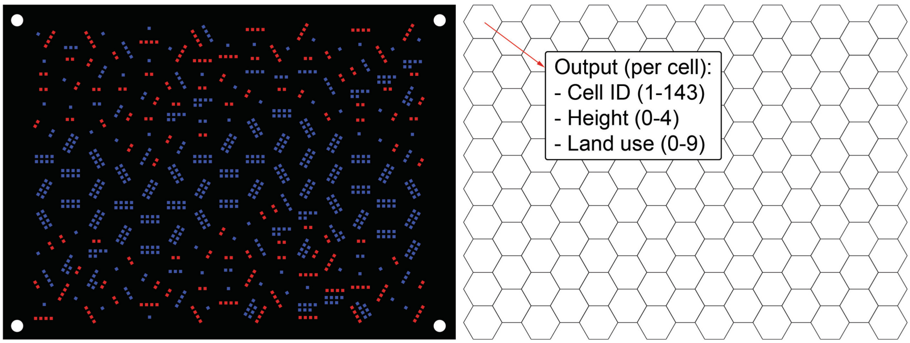
transforming the board from the paper prototype into a 3D game board, where the shape of the game board, based on hexagon game pieces of different heights, correspond to the geometrical shape of a river stretch. The geometrical shape is used as input for a hydrodynamic model and the output of the hydrodynamic model is projected back on the 3D game board (see Fig. 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 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 (Fig. 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 (Fig. 5).



a b

Fig. 4. The geometry and land use type of game pieces (a), which combined (b) make up the position of one cell.



a b

Fig. 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. (Color figure online)

We are currently developing a prototype for the Virtual River's tangible user interface (Fig. 6). At the time of writing, the physical part of prototype is built 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 Fig. 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 Fig. 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.

a b

Fig. 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.

5 Discussion

Tangible user interfaces have been applied in other tabletop (serious) game settings. Bakker, Vorstenbosch [77] 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, Antle [78] 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, Haller [79] 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 [12], 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 Sect. 3.1 and [47]). 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 [80].

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. This is 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' [81]. 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 [82]. In other words, in line with the tradition of Distributed Cognition [83], 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 [84].

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 qualitive insights into how the tangible user interface enabled learning about the functioning of a river system.

Hypothesis 2: Using a Tangible User Interface in 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 [85], 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 [49, 70]. 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 [70, 71]. 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 [86, 87].

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.

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 [71], people engaging in collaborative efforts in itself creates a dimension of relationship building and trust formation. Moreover, as Van Dijk and Van der Lugt [87] 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 [88] 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.

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.

Acknowledgments. This research is part of the research programme RiverCare: towards self-sustaining multifunctional rivers, supported by the Netherlands Organization for Scientific Research (NWO) and partly funded by the Ministry of Economic Affairs under grant number P12-14 (Perspective Programme).

References

1. Furber, A., Medema, W., Adamowski, J.: Assessing the benefits of serious games to support sustainable decision-making for transboundary watershed governance. Can. Water Resour. J./Revue canadienne des ressources hydriques **43**, 401–415 (2018)
2. Marini, D., Medema, W., Adamowski, J., et al.: Socio-psychological perspectives on the potential for serious games to promote transcendental values in IWRM decision-making. Water **10**(8), 1097 (2018)
3. Ampatzidou, C., Gugerell, K., Constantinescu, T., et al.: All work and no play? Facilitating serious games and gamified applications in participatory urban planning and governance. Urban Plan. **3**(1), 34–46 (2018)
4. Susi, T., Johannesson, M., Backlund, P.: Serious games: An overview. Institutionen för kommunikation och information (2007)
5. Michael, D.R., Chen, S.L.: Serious Games: Games That Educate, Train, and Inform. Muska & Lipman/Premier-Trade, Cincinnati (2005)
6. Mayer, I.: The gaming of policy and the politics of gaming: a review. Simul. Gaming **40**(6), 825–862 (2009)
7. Bekebrede, G.: Experiencing complexity: a gaming approach for understanding infrastructure systems. TU Delft, Delft University of Technology (2010)
8. Barreteau, O., Le Page, C., Perez, P.: Contribution of simulation and gaming to natural resource management issues: an introduction. Simul. Gaming **38**, 185–194 (2007)
9. Ritterfeld, U., Cody, M., Vorderer, P.: Serious Games: Mechanisms and Effects. Routledge, Abingdon (2009)
10. Harteveld, C.: Triadic Game Design: Balancing Reality, Meaning and Play. Springer Science & Business Media, London (2011). https://doi.org/10.1007/978-1-84996-157-8
11. Salen, K., Tekinbaş, K.S., Zimmerman, E.: Rules of Play: Game Design Fundamentals. MIT press, Cambridge (2004)
12. Ishii, H.: Tangible bits: beyond pixels. In: Proceedings of the 2nd International Conference on Tangible and Embedded Interaction. ACM (2008)
13. Hornecker, E., Buur, J.: Getting a grip on tangible interaction: a framework on physical space and social interaction. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM (2006)
14. Vreugdenhil, H., Slinger, J., Kater, E., Thissen, W.: The influence of scale preferences on the design of a water innovation: a case in Dutch river management. Environ. Manag. **46**(1), 29–43 (2010)
15. Gurnell, A., Rinaldi, M., Belletti, B., et al.: A multi-scale hierarchical framework for developing understanding of river behaviour to support river management. Aquat. Sci. **78**(1), 1–16 (2016)
16. Berends, K.D., Warmink, J.J., Hulscher, S.J.M.H.: Efficient uncertainty quantification for impact analysis of human interventions in rivers. Environ. Model Softw. **107**, 50–58 (2018)
17. Warmink, J.J., Van der Klis, H., Booij, M.J., Hulscher, S.J.M.H.: Identification and quantification of uncertainties in a hydrodynamic river model using expert opinions. Water Resour. Manag. **25**(2), 601–622 (2011)

18. Wiering, M., Arts, B.: Discursive shifts in Dutch river management: ‘deep’ institutional change or adaptation strategy? Hydrobiologia **565**(1), 327–338 (2006)
19. Wolsink, M.: River basin approach and integrated water management: governance pitfalls for the Dutch space-water-adjustment management principle. Geoforum **37**(4), 473–487 (2006)
20. Armitage, D., Berkes, F., Doubleday, N.: Adaptive Co-Management: Collaboration, Learning, and Multi-Level Governance. UBC Press, Vancouver (2007)
21. Berkes, F.: Evolution of co-management: role of knowledge generation, bridging organizations and social learning. J. Environ. Manag. **90**(5), 1692–1702 (2009)
22. Pahl-Wostl, C.: The implications of complexity for integrated resources management. Environ. Model Softw. **22**(5), 561–569 (2007)
23. Rodela, R.: Social learning and natural resource management: the emergence of three research perspectives. Ecol. Soc. **16**(4), 30–41 (2011)
24. Klijn, F., de Bruin, D., de Hoog, M.C., Jansen, S., Sijmons, D.F.: Design quality of room-for-the-river measures in the Netherlands: role and assessment of the quality team (Q-team). Int. J. River Basin Manag. **11**(3), 287–299 (2013)
25. van Herk, S., Rijke, J., Zevenbergen, C., Ashley, R.: Governance of integrated flood risk management to deliver large scale investment programmes: delivery focused social learning in the Netherlands. In: Floodrisk 2012—2nd European Conference on Flood Risk Management, Rotterdam, Netherlands (2012)
26. Rijke, J., van Herk, S., Zevenbergen, C., Ashley, R.: Room for the river: delivering integrated river basin management in the Netherlands. Int. J. River Basin Manag. **10**(4), 369–382 (2012)
27. den Haan, R.-J., Fliervoet, J.M., van der Voort, M.C., Cortes Arevalo, V.J., Hulscher, S.J.M.H.: Understanding actor perspectives regarding challenges for integrated river basin management. Int. J. River Basin Manag. **17**, 1–14 (2018)
28. Star, S.L., Griesemer, J.R.: Institutional ecology, translations’ and boundary objects: Amateurs and professionals in Berkeley’s museum of vertebrate zoology, 1907–39. Soc. Stud. Sci. **19**(3), 387–420 (1989)
29. White, D.D., Wutich, A., Larson, K.L., et al.: Credibility, salience, and legitimacy of boundary objects: water managers’ assessment of a simulation model in an immersive decision theater. Sci. Public Policy **37**(3), 219–232 (2010)
30. Medema, W., Furber, A., Adamowski, J., Zhou, Q., Mayer, I.: Exploring the potential impact of serious games on social learning and stakeholder collaborations for transboundary watershed management of the St. Lawrence river basin. Water **8**(5), 175 (2016)
31. Magnuszewski, P., Królikowska, K., Koch, A., et al.: Exploring the role of relational practices in water governance using a game-based approach. Water **10**(3), 346 (2018)
32. Aubert, A.H., Bauer, R., Lienert, J.: A review of water-related serious games to specify use in environmental multi-criteria decision analysis. Environ. Model Softw. **105**, 64–78 (2018)
33. Lankford, B., Watson, D.: Metaphor in natural resource gaming: insights from the RIVER BASIN GAME. Simul. Gaming **38**(3), 421–442 (2007)
34. Stefanska, J., Magnuszewski, P., Sendzimir, J., et al.: A gaming exercise to explore problem-solving versus relational activities for river floodplain management. Environ. Policy Gov. **21** (6), 454–471 (2011)
35. Valkering, P., van der Brugge, R., Offermans, A., Haasnoot, M., Vreugdenhil, H.: A perspective-based simulation game to explore future pathways of a water-society system under climate change. Simul. Gaming **44**(2–3), 366–390 (2012)
36. Rusca, M., Heun, J., Schwartz, K.: Water management simulation games and the construction of knowledge. Hydrol. Earth Syst. Sci. **16**(8), 2749–2757 (2012)

37. Hill, H., Hadarits, M., Rieger, R., et al.: The invitational drought tournament: what is it and why is it a useful tool for drought preparedness and adaptation? Weather Clim. Extremes **3**, 107–116 (2014)
38. Savic, D.A., Morley, M.S., Khoury, M.: Serious gaming for water systems planning and management. Water **8**(10), 456 (2016)
39. Onencan, A.M., Van de Walle, B.: From Paris agreement to action: enhancing climate change familiarity and situation awareness. Sustainability **10**(6), 1929 (2018). (2071-1050)
40. Douven, W., Mul, M.L., Son, L., et al.: Games to create awareness and design policies for transboundary cooperation in river basins: lessons from the shariva game of the mekong river commission. Water Resour. Manag. **28**(5), 1431–1447 (2014)
41. Reed, M.S., Evely, A.C., Cundill, G., et al.: What is social learning? Ecol. Soc. **15**(4), r1 (2010)
42. Pahl-Wostl, C., Craps, M., Dewulf, A., et al.: Social learning and water resources management. Ecol. Soc. **12**(2), 5 (2007)
43. Armitage, D., Marschke, M., Plummer, R.: Adaptive co-management and the paradox of learning. Glob. Environ. Change **18**(1), 86–98 (2008)
44. Muro, M., Jeffrey, P.: A critical review of the theory and application of social learning in participatory natural resource management processes. J. Environ. Plan. Manag. **51**(3), 325–344 (2008)
45. Cundill, G., Rodela, R.: A review of assertions about the processes and outcomes of social learning in natural resource management. J. Environ. Manag. **113**, 7–14 (2012)
46. Keen, M., Brown, V.A., Dyball, R.: Social Learning in Environmental Management: Towards a Sustainable Future. Routledge, Abingdon (2005)
47. Baird, J., Plummer, R., Haug, C., Huitema, D.: Learning effects of interactive decision-making processes for climate change adaptation. Glob. Environ. Change **27**, 51–63 (2014)
48. Pahl-Wostl, C., Tàbara, D., Bouwen, R., et al.: The importance of social learning and culture for sustainable water management. Ecol. Econ. **64**(3), 484–495 (2008)
49. Klemmer, S.R., Hartmann, B., Takayama, L.: How bodies matter: five themes for interaction design. In: Proceedings of the 6th Conference on Designing Interactive Systems. ACM (2006)
50. Jetter, H.-C., Reiterer, H., Geyer, F.: Blended interaction: understanding natural human—computer interaction in post-WIMP interactive spaces. Pers. Ubiquit. Comput. **18**(5), 1139–1158 (2014)
51. Jordà, S., Geiger, G., Alonso, M., Kaltenbrunner, M.: The reacTable: exploring the synergy between live music performance and tabletop tangible interfaces. In: Proceedings of the 1st International Conference on Tangible and Embedded Interaction. ACM (2007)
52. Piper, B., Ratti, C., Ishii, H.: Illuminating clay: a 3-D tangible interface for landscape analysis. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM (2002)
53. Antle, A.N., Wise, A.F.J.I.w.C.: Getting down to details: using theories of cognition and learning to inform tangible user interface design. Interact. Comput. **25**(1), 1–20 (2013)
54. Marshall, P.: Do tangible interfaces enhance learning? In: Proceedings of the 1st International Conference on Tangible and Embedded Interaction. ACM (2007)
55. Resnick, M.: Technologies for lifelong kindergarten. Educ. Technol. Res. Dev. **46**(4), 43–55 (1998)
56. Marshall, P., Price, S., Rogers, Y.: Conceptualising tangibles to support learning. In: Proceedings of the 2003 Conference on Interaction Design and Children. ACM (2003)
57. Price, S., Rogers, Y., Scaife, M., Stanton, D., Neale, H.: Using 'tangibles' to promote novel forms of playful learning. Interact. Comput. **15**(2), 169–185 (2003)

58. Price, S., Sheridan, J., Pontual Falcao, T., Roussos, G.: Towards a framework for investigating tangible environments for learning. Int. J. Arts Technol. **1**(3/4), 351–368 (2008)
59. Zuckerman, O., Arida, S., Resnick, M.: Extending tangible interfaces for education: digital montessori-inspired manipulatives. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM (2005)
60. Resnick, M., Martin, F., Berg, R., et al.: Digital manipulatives: new toys to think with. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM Press/Addison-Wesley Publishing Co. (1998)
61. Xu, D.: Tangible user interface for children-an overview. In: Proceedings of the UCLAN Department of Computing Conference (2005)
62. Price, S., Falcão, T.P., Sheridan, J.G., Roussos, G.: The effect of representation location on interaction in a tangible learning environment. In: Proceedings of the 3rd International Conference on Tangible and Embedded Interaction. ACM (2009)
63. Zhang, J., Norman, D.A.: Representations in distributed cognitive tasks. Cogn. Sci. **18**(1), 87–122 (1994)
64. Antle, A.N.: The CTI framework: informing the design of tangible systems for children. In: Proceedings of the 1st International Conference on Tangible and Embedded Interaction. ACM (2007)
65. O'Malley, C., Fraser, D.S.: Literature review in learning with tangible technologies (2004)
66. Clements, D.H.: 'Concrete' manipulatives, concrete ideas. Contemp. Issues Early Child. **1** (1), 45–60 (2000)
67. Fernaeus, Y., Tholander, J.: "Looking at the computer but doing it on land": children's interactions in a tangible programming space. In: McEwan, T., Gulliksen, J., Benyon, D. (eds.) People and Computers XIX—The Bigger Picture, pp. 3–18. Springer, London (2006). https://doi.org/10.1007/1-84628-249-7_1
68. Suzuki, H., Kato, H.: Interaction-level support for collaborative learning: AlgoBlock—an open programming language. In: The First International Conference on Computer Support For Collaborative Learning. L. Erlbaum Associates Inc. (1995)
69. Stanton, D., Bayon, V., Neale, H., et al.: Classroom collaboration in the design of tangible interfaces for storytelling. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM (2001)
70. Dourish, P.: Where the Action Is: The Foundations of Embodied Interaction. MIT Press, Cambridge (2004)
71. Arias, E., Eden, H., Fischer, G., Gorman, A., Scharff, E.: Transcending the individual human mind—creating shared understanding through collaborative design. ACM Trans. Comput.-Hum. Interact. **7**(1), 84–113 (2000)
72. Hulscher, S.J.M.H., Schielen, R.M.J., Augustijn, D.C.M., et al.: Rivercare: towards self-sustaining multifunctional rivers. In: Netherlands Centre for River Studies Conference, pp. 13–14, Netherlands Centre for River Studies, Delft (2014)
73. den Haan, R.-J., Cortes Arevalo, V.J., Van der Voort, M.C., Hulscher, S.J.M.H.: Prototyping virtual river. In: NCR DAYS, p. 76, Netherlands Centre for River Studies, Delft (2018)
74. Ottevanger, W., Den Haan, R.-J., Baart, F., et al.: SandBox-FM: augmented reality CFD. In: Hydro 17, Rotterdam, the Netherlands (2017)
75. Reed, S., et al.: Augmented reality turns a sandbox into a geoscience lesson. EOS **97** (2016). https://doi.org/10.1029/2016EO056135
76. Peckham, S.D., Hutton, E.W., Norris, B.J.C.: A component-based approach to integrated modeling in the geosciences: the design of CSDMS. Comput. Geosci. **53**, 3–12 (2013)

77. Bakker, S., Vorstenbosch, D., van den Hoven, E., Hollemans, G., Bergman, T.: Tangible interaction in tabletop games: studying iconic and symbolic play pieces. In: Proceedings of the International Conference on Advances in Computer Entertainment Technology. ACM (2007)
78. Speelpenning, T., Antle, A.N., Doering, T., van den Hoven, E.: Exploring how tangible tools enable collaboration in a multi-touch tabletop game. In: Campos, P., Graham, N., Jorge, J., Nunes, N., Palanque, P., Winckler, M. (eds.) INTERACT 2011. LNCS, vol. 6947, pp. 605–621. Springer, Heidelberg (2011). https://doi.org/10.1007/978-3-642-23771-3_45
79. Leitner, J., Haller, M., Yun, K., et al.: IncreTable, a mixed reality tabletop game experience. In: Proceedings of the 2008 International Conference on Advances in Computer Entertainment Technology. ACM (2008)
80. den Haan, R.-J., van der Voort, M.C.: On evaluating social learning outcomes of serious games to collaboratively address sustainability problems: a literature review. Sustainability **10**(12), 4529 (2018)
81. Norman, D.: The design of everyday things: Revised and expanded edition. Constellation (2013)
82. Kirsh, D.J.A.: Thinking with external representations. AI Soc. **25**(4), 441–454 (2010)
83. Hutchins, E.: Cognition in the Wild. MIT Press, Cambridge (1995)
84. Van Dijk, J.: Designing for embodied being-in-the-world: a critical analysis of the concept of embodiment in the design of hybrids. Multimodal Technol. Interact. **2**(1), 7 (2018)
85. Suchman, L.: Human-Machine Reconfigurations: Plans and Situated Actions. Cambridge University Press, Cambridge (2007)
86. Ehn, P.: Design things: drawing things together and making things public. TECNOSCIENZA Ital. J. Sci. Technol. Stud. **1**(2), 31–52 (2011)
87. Van Dijk, J., Van der Lugt, R.: Scaffolds for design communication: research through design of shared understanding in design meetings. AI EDAM **27**(2), 121–131 (2013)
88. Jordan, B., Henderson, A.: Interaction analysis: foundations and practice. J. Learn. Sci. **4**(1), 39–103 (1995)