Designing Collaborative Games for Children Education on Sustainable Development

Alysson Diniz Dos Santos[1,2(✉)], Francesco Strada[1], Andrea Martina[1], and Andrea Bottino[1]

[1] Dipartimento di Automatica e Informatica, Politecnico di Torino, Turin, Italy
[2] Instituto Universidade Virtual, Universidade Federal do Ceara, Fortaleza, Brazil
alysson@virtual.ufc.br

Abstract. Recent research in the digital learning game area strives for defining a solid grounding methodology, capable of driving the game design process towards the maximization of the intended educational results. In this work, we investigate the mix of tangible interaction, immersive environments, collaborative multiplay and validated theoretical background in the design of WaterOn!, an educational game focused on teaching water cycle contents for children. The paper presents the design decisions taken in light of the adopted methodologies, and discusses some open questions related to the use of these tools.

Keywords: Educational game · Tangible · Collaborative · Sustainable development · Water · Children

1 Introduction

Serious games have been used in several fields to convey training or learning [5]. When focused on learning, well designed games must provide an experience in which entertainment and instruction are seamlessly integrated. How to achieve such an ideal scenario is the research objective of an increasing number of publications [13]. In spite of the growing research interest, the digital learning area still lacks an overarching methodology capable of covering the whole development process, from design to evaluation [13]. Although some theoretical tools exist [7], they have not been extensively used yet [20].

The objective of this work is to investigate the use of practical and theoretical design background in the development of WaterOn!, a collaborative multiplayer game focused on teaching water cycle contents for 8–10 years old children. The game exploits tangible and multitouch interaction on mobile devices and a projected virtual environment in order to foster collaboration among co-located users, reinforce the emotional impact of the game [11], and improve the players feeling of immersion into the game story. The WaterOn! design is based on both the RETAIN framework [9] and the practical guidelines for collaborative games described in [1].

R. Poppe et al. (Eds.): INTETAIN 2016, LNICST 178, pp. 3–12, 2017.
DOI: 10.1007/978-3-319-49616-0_1

As for the related works, sustainability issues has already been approached in collaborative digital environments, like the game Futura [1,19] and the learning activity Youtopia [2]. Both works exploit tangibles as interaction tools, since they were found to be preferred by their audience, in comparison with purely graphic interaction. However, further investigation over the correlation of tangibles, collaboration, and educational games for children audience is needed. For example, [19] relates that collaborative activities are more influenced by group dynamics than by interaction modality and [17] argues that multi-touch interfaces do not always promote effective collaboration, since there is always the risk that players are engaged with their own task with little consideration for their nearby peers.

In this paper, we thoroughly discuss the choices taken in the design of WaterOn! and how the selected design models influenced them. We stress the fact that, to the best of our knowledge, our work is the first that exploits RETAIN as a design model rather than as a mere evaluation tool (like, for instance, in [4,9]). For this reason, although actually the implementation of WaterOn! is still in its preliminary phase and some instructional units are missing, we deemed interesting to share our initial results with the research community. We expect our contribution to rise a discussion on the use of these tools, hopefully providing answers to some of the questions arisen in our work.

The rest of the paper is organized as follows. In Sect. 2 we present the theoretical background related to the design of collaborative educational games. Then, we describe the WaterOn! game in Sect. 3 and we discuss our preliminary results in Sect. 4. Finally, we present the conclusions and outline future works in Sect. 5.

2 Theoretical Background

Recent researches proposed various methodological frameworks that offer structured principles to enhance game-based learning by coupling instructional theories and strategies with traditional game design aspects [12]. Among the possible options, we decided to base the design of WaterOn! on both the RETAIN framework [9] and the key design factors for collaborative games outlined in [1].

The reasons for choosing RETAIN were threefold: (i) it is both a design model and an evaluation tool; (ii) its theoretical bases are closely aligned with modern game design principles; and (iii) it is based on Piaget's theory of cognitive development [16] and, thus, well suited for a children game audience.

According to the RETAIN framework the game design should consider six key factors that can be summarized as follows. The learning materials should be *relevant* to the learners and their needs, the instructional units should be related to each another and the game should underline the relevance of the educational contents in the real life of the players. Then, the educational content should be seamlessly *embedded* into the game fantasy[1]. The game should also foster

[1] In this paper the term fantasy is used, as in [9], to encompass the game storyline, its narrative structure and the player experience.

the players' capabilities to use the acquired knowledge in other forms (*transfer*) or to *adapt* it to different contexts. Since an educational game is still a game, *immersion*, or the subjective sensation of "being there", is a key point for enhancing learner motivation. Gunter suggests a step ahead, that is reaching a "full immersion", where players are willing to intellectually invest in the learning situation. Finally, a game with high level of re-playability stimulates *naturalization* of the content, i.e., how well players develop automated or spontaneous use of the learned information.

A drawback of RETAIN is that, being based on the Piaget's theory of cognitive development [16], it offers little or no emphasis to the collaborative part of the learning process. To overcome this issue, we made explicit references in our design to the guidelines for collaborative game designs outlined in [1], which can be summarized in the following points:

- the use of spatially separate but shareable individual territories and resources to facilitate negotiation and learning from others;
- the prevention of a single player to take over the game; and
- the use of discrete world events to pause fast-paced interaction in order to facilitate reflection and self-regulation.

3 WaterOn!

The motivating factors for the choice of water as the educational focus of the WaterOn! game were two. First, education towards water in its different aspects, such as consumption, quality, supply and management, is the basis for understanding other knowledge needed by elementary school children (e.g., the life-cycle of plants and animals, natural disorders, energy production and so on [10]). Second, although being a fundamental topic, some studies show that there are still misconceptions in water education of school-age children [18].

The game design and the instructional units have been centered around the target audience, i.e. 8–10 years old children. This range corresponds to the center of concrete operational stage of children (7–11 years old according to Piaget [16]). The game mechanics have been defined taking into account that children at this age demonstrate logical and concrete reasoning and are more capable of taking part in cooperative activities, with respect to their younger peers [16].

With reference to both the national curriculum standards alignment developed by the water.org foundation [15] and the educational materials available from Project Wet [14], the following three instructional units were defined:

1. identifying the three states of the water and the transitions between them;
2. describing the movement of water within the water cycle;
3. recognizing solar energy as main driver of water movements on earth.

As for the development process, we actually completed the implementation of the first unit, which will be the focus of the rest of the paper. While the remaining units are still in their prototypical phase, we will provide in Sect. 5 hints on their mutual relationships.

3.1 The Game Design

WaterOn! is meant to foster collaboration among children since, in each level, it requires both communication and coordination between players to fulfil the objectives. In order to strengthen such cooperation, the game features a projected virtual environment (Fig. 1(a)). This screen shows the overall game scenario, where players are acting as individuals, and the game status, which is aimed at offering a shared understanding of what has been achieved and what has to be completed yet. Players interact with the game through a tablet (thus being free to move inside the physical game environment), exploiting both multitouch and tangible interaction. Each tablet displays a portion of the whole environment (Fig. 1(b)) and the system provides a direct feedback of players position on the projected scenario (Fig. 1(c)).

Unit 1: Level Design. The first three levels of the game are aimed at teaching children the states of water and the fact that the transition between them occur when heat energy is added or lost. The story of these three levels is played around a bunch of villains trying to plunder water resources while players are

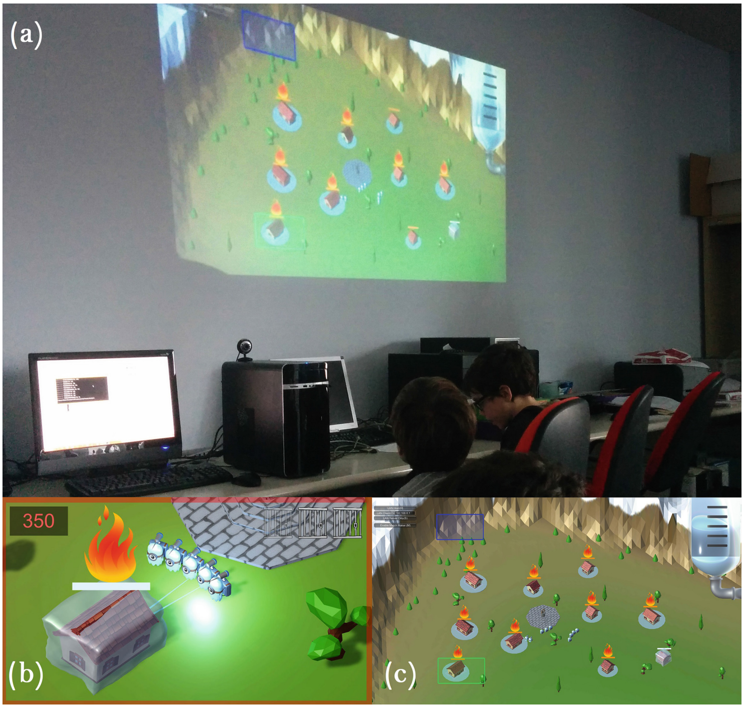

Fig. 1. (a) An image of the projected scenario; (b) View on the tablet screen; (c) Feedback of player positions (the coloured boxes) on the main screen. (Color figure online)

the village dwellers fighting the enemies. In the first level, *melting*, the villains have frozen all the available water to incorporate the village houses into giant ice cubes. Players have to melt the ice and fight against the enemies, which are trying to freeze again the water (Fig. 1). In the second level, *vaporization*, players have to blow up an air balloon, which is necessary to chase the (escaped) villain in chief, by transforming the collected water into steam. Players have to pour water into huge pots and to fuel the fire below them while enemies try to steal water from the pots (Fig. 2(a)). The last level, *deposition*, is preceded by an introductory scene showing that the air balloon has been attacked by enemies, which punched holes in it. The steam flowed out and condensed into clouds, while the air balloon crashed on a mountain top. The goal of the players is to move the clouds towards the mountain, cool them down to start snowing and create a snow ramp allowing to rescue the balloon passengers. Here the enemies use fans to hamper the cloud movements (Fig. 2(b)).

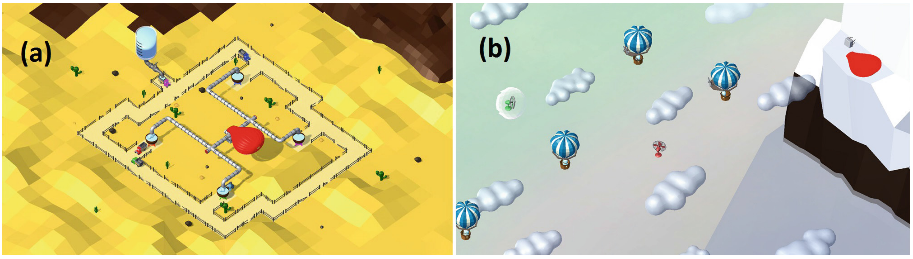

Fig. 2. Screenshots of vaporization (a) and deposition (b) levels.

In all three levels, the lose condition is associated with the extinction of the shared resources (i.e. the water in the desired state). The aim of aggregating win-lose conditions to the communal resources is to stimulate negotiation and players learning from others [1]. Another feature aimed at fostering cooperation is the absence of individual failure or success in-game, since it is only possible to win or lose in group.

3.2 Interaction Design

Players can move around the environment using either controls on the tablet screen or a map-based travel metaphor. As for the game interaction, players can use tangibles as tools to generate in-game actions. Examples are the *heat token* (the heat source used to melt the ice in the first level and evaporate the water in the second; both have effect only when placed in the proper position), the *cold token* (required to cool down the clouds and generate the deposition effect) and the *blower token* (used to move clouds in the third level; the position where the marker is placed around the cloud in the tablet screen determines the wind direction and force).

To enrich the game mechanics, direct touch interaction is also available. Besides enabling navigation, player touches can activate specific actions in the game. For instance, in all levels, each player can tap on an enemy to imprison it for some seconds. Each player has a limited number of cages, which can be unlocked according to the points acquired by the player. The choice for a limited amount of weapons is aimed at forcing a more "strategical" approach (i.e. requiring, again, collaboration). These touch interactions are not directly associated with the educational content of the game, but are meant to keep the player immersed by creating a more active gameplay and complexity progression among the levels.

Implementation Details. WaterOn! has been implemented into Unity 3D, a cross-platform game engine, which offers advanced lighting and rendering options, built-in support for spatialized audio, physics management, complex animations, multitasking, pipeline optimization and networking. Multiplayer collaborative interaction has been managed implementing a client-server architecture, where the server controls the primary screen and the clients are the players' tablets.

In order to enable the use of tangibles with devices equipped with commercial capacitive touch screens, we developed custom passive markers characterized by unique patterns of conductive touch points that encode both their position and ID [3]. Our markers use four contact points per marker, where three of them define an orthogonal Cartesian reference system capable of providing position and orientation information, and the fourth one, the data point, defines the marker ID. We experimentally found that the minimal size allowing a robust marker identification is 30 mm. With this size, the number of unique IDs that can be represented is 8, and a larger set of distinct markers can be obtained increasing the marker size. Since four touch points are required for a tangible, a maximum of two markers and two finger touches can be recognized at the same time on a standard tablet. Markers are 3D-printed, using conductive graphene filaments to create the contact points, which are attached to a common base and then enclosed in a plastic PLA shield (Fig. 3).

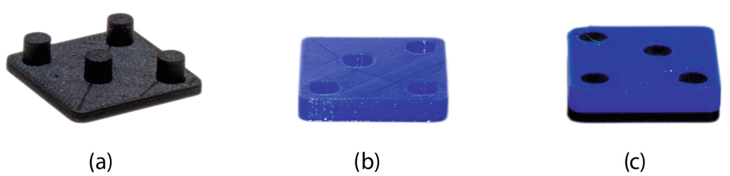

Fig. 3. The capacitive tangible (c) consists in a set of contact points (a) enclosed in a PLA shield (b).

4 Results and Discussion

The main goal of this study was to investigate the mix of tangible interaction, immersive environments, collaborative multiplay and pedagogical background in the design of an educational game for children. Based on this consideration, how can we assess the preliminary results of our research?

Beside defining the key elements to be considered in game-based learning design, the work of Gunter proposes as well an evaluation model that classifies each of these six aspects into four levels. However, we believe that the application of such evaluation scheme is too preliminary in our case, due to the fact that WaterOn! is still in its development stage and some instructional units are missing. Nevertheless, we think it is interesting to summarize how the RETAIN model and the principles expressed in [1] influenced our design and where we are planning to focus our future evaluation.

We underline that we actually tested our application with some volunteers (aged between 8 and 10). Although their number does not allow a systematic evaluation, we obtained positive feedbacks from our testers. Children expressed enjoyment and found challenging to progress in the game, which they commented was a factor increasing their fun. We observed that children rapidly find out they have to cooperate to successfully complete a level, although not instructed to do that. To this end, the shared scenario was effective in coordinating their efforts. Another positive finding was that all our testers enjoyed the use of tangibles as interaction tools.

WaterOn! and RETAIN. In the following we will discuss the influence to our design of each of the RETAIN aspects.

Relevance. The game mechanics (i.e., the use of simple interactions relying on previous knowledge on touchscreen devices and tangibles) were designed to match the developmental level of our target players. The learning objective is clearly defined (the three states of water and the transitions among them) and the game fantasy is intrinsically related to the educational goals, thus preventing the focus to shift away from the targeted contents.

Embedding. The educational content is endogenous to the fantasy context, i.e. the story and gameplay are tightly coupled with the information we want to transfer. We think that the level of engagement shown by our testers is a possible indicator of this fact. However, this point requires further investigation.

Transfer. The keys to progress in the game are mastering the instructional elements, which are introduced in a hierarchical manner, and using active problem solving approaches. The emulation of realistic scenarios intends to foster the transfer between the learned contents and real life. Gunter suggests reinforcing this transfer by introducing post acquisition events (e.g. by exploiting accessory educational material or reviews). We will investigate this aspect in our future work.

Adaptation. The first three game levels put forth the basis for adaptation, which will be necessary to progress in the following instruction units. Indeed, players will have to extend the learned state transition concepts in order to gain a clear understanding of the water cycle and, thus, advance in the game.

Immersion. The use of tangibles and the progressive presentation of mechanics (i.e., the introduction of new mechanics in each level) intend to maintain the cognitive immersion of the players. The game plot, the shared environment and animations aim to harness belief creation. Nevertheless, the achievement of a "fully involvement to invest in the belief", as referred by Gunter, needs to be further investigated.

Naturalization. In the preliminary tests, our users always asked us to replay the game. Beside being a positive indication of their attitude towards the game, replaying helps content retention and improves the speed of cognitive response. This, in turns, leads to positive effects in terms of naturalization, i.e. making it easier to use the acquired knowledge in novel scenarios. Clearly, further analyses are required to confirm this conjecture.

WaterOn! and the Guidelines for Collaborative Game Design. The guidelines described in Sect. 2 were adopted in WaterOn! as follows.

The use of spatially separate but shareable individual territories and resources is at the base of the game design. The tablets offer single manipulation over a common territory and allow to increase the number of simultaneous players, since they do not need to share the physical space over the same screen.

The prevention of a single player to take over the game is guaranteed mainly through game balancing. The quantity of enemies is adapted to the number of players and their power, when they act in group, overcome the capabilities of a single player. Therefore the artificial intelligence acts to group enemies and prevent a player to win alone.

The first three levels did not require the introduction of **discrete world events to pause fast-paced multi-touch interaction**. Indeed, the game design does not permit fast-paced interaction. The tools controlled by the tangible tokens have a limited speed of action, and the number of items to be used with direct touches is also limited. On the contrary, we plan to introduce such events in the extension of WaterOn! game. For instance, in the second instruction unit, the players will have to use the tokens presented in the first unit to re-stablish the balance of the water cycle, which was scrambled by the enemies. During the levels, periodic discrete events like precipitation, glaciation and transpiration will affect water states in the whole game scenario. This will change the natural balance, requiring players to collaboratively plan new actions, e.g. to decide which tool to use, where to use it in the scenario and how to face the enemies.

Open Questions. As we stated in the introduction, the RETAIN framework has been previously used to evaluate serious games [4,9], and our work is the first attempt to use it explicitly during the design process. As a result, some questions arose:

How to make the player interested in keep learning about the topic after the game experience? This point was not discussed in the work of Gunter. However, we think it would be necessary to develop in-game strategies capable of stimulating the children interest after the game finishes, although we have no clear suggestions yet on how to achieve this objective.

How to assess the fully involvement to invest in the belief (i.e. the full immersion)? Although Gunter links this requirement to the achievement of the highest level possible of content embedding, we found hard to detect which strategies can lead to this full immersion. We suggest that this feature can be re-modeled taking it account as well the flow concept [6].

Concerning the collaborative dimension, we found that the guidelines in [1] were clearly defined and useful. However, we think they do not completely enclose the collaborative design of the game. For example, we witnessed that during the first level played by all our groups of testers, although the majority of the players understood the need to collaborate, some of them initially attempted to simply complete their personal goals. Although this problem was readily solved, one possible solution to avoid it from the very beginning could be the introduction of challenges requiring multiple actions from different players. While this approach was successfully tested with young adults [8], further investigation on its adequacy to a children audience is needed.

5 Conclusions

In this work we described the preliminary implementation of an educational game for children. The game design has been based on solid and validated models and on sound guidelines that, according to our initial results, seem to provide: (i) a valuable contribution towards the achievement of the planned educational goals and (ii) a satisfactory level of engagement of our players.

As for future works, we will complete the implementation of WaterOn! with the introduction of the missing instruction units outlined in Sect. 3. Then, we will thoroughly evaluate our work exploiting both user surveys, panels of experts and the evaluation schema defined by the RETAIN model.

References

1. Antle, A.N., et al.: Futura: design for collaborative learning and game play on a multi-touch digital tabletop. In: Proceedings of the Fifth International Conference on Tangible, Embedded, and Embodied Interaction, pp. 93–100. ACM (2011)
2. Antle, A.N., et al.: Youtopia: a collaborative, tangible, multi-touch, sustainability learning activity. In: Proceedings of the 12th International Conference on Interaction Design and Children, pp. 565–568. ACM (2013)
3. Bottino, A., Martina, A., Toosi, A., Strada, F.: Gaine - a portable framework for the development of edutainment applications based on multitouch and tangible interaction. Entertainment Computing, pp. 207–216 (2016, to appear)
4. Campbell, L.O., Gunter, G., Braga, J.: Utilizing the retain model to evaluate mobile learning applications. In: Society for Information Technology & Teacher Education International Conference, vol. 2015, pp. 732–736 (2015)

5. Crookall, D.: Serious games, debriefing, and simulation/gaming as a discipline. Simul. Gaming **41**(6), 898–920 (2010)
6. Csikszentmihalyi, M.: Beyond Boredom and Anxiety. Jossey-Bass, New York (2000)
7. dos Santos, A.D., Fraternali, P.: A comparison of methodological frameworks for digital learning game design. In: De Gloria, A., Veltkamp, R. (eds.) GALA 2015. LNCS, vol. 9599, pp. 111–120. Springer, Heidelberg (2016). doi:10.1007/978-3-319-40216-1_12
8. Fan, M., et al.: Exploring how a co-dependent tangible tool design supports collaboration in a tabletop activity. In: Proceedings of the 18th International Conference on Supporting Group Work, pp. 81–90. ACM (2014)
9. Gunter, G.A., Kenny, R.F., Vick, E.H.: Taking educational games seriously: using the retain model to design endogenous fantasy into standalone educational games. Educ. Technol. Res. Dev. **56**(5–6), 511–537 (2008)
10. Hrennikoff, M.: Implementing an imaginative unit: wonders of the water cycle. Educ. Perspect. **39**(2), 27–33 (2006)
11. Iwata, T., et al.: Traditional games meet ICT: a case study on go game augmentation. In Proceedings of the Fourth International Conference on Tangible, Embedded, and Embodied Interaction, pp. 237–240. ACM (2010)
12. Kebritchi, M., et al.: Examining the pedagogical foundations of modern educational computer games. Comput. Educ. **51**(4), 1729–1743 (2008)
13. Mayer, I., et al.: The research and evaluation of serious games: toward a comprehensive methodology. Br. J. Educ. Technol. **45**(3), 502–527 (2014)
14. Online. Project wet's discover water, 02 2016
15. Online. Water.org foundation, 02 2016
16. Piaget, J., Cook, M., Norton, W.: The Origins of Intelligence in Children, vol. 8. International Universities Press, New York (1952)
17. Rick, J., et al.: Beyond one-size-fits-all: how interactive tabletops support collaborative learning. In: Proceedings of the 10th International Conference on Interaction Design and Children, pp. 109–117. ACM (2011)
18. Shepardson, D.P., Wee, B., Priddy, M., Schellenberger, L., Harbor, J.: Water transformation and storage in the mountains and at the coast: midwest students' disconnected conceptions of the hydrologic cycle. Int. J. Sci. Educ. **31**(11), 1447–1471 (2009)
19. 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). doi:10.1007/978-3-642-23771-3_45
20. Whitton, N.: Digital Games, Learning: Research and Theory. Routledge, Abingdon (2014)