A VR Game to Teach Underwater Sustainability while Diving

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***Abstract*—We developed a game in virtual reality to make players experience an underwater environment and to increase their awareness towards a sustainable behaviour while diving. The game was tested with the Presence Questionnaire during a Science Festival in November 2016. The assumption was that a high degree of presence due to their immersion into the virtual environment would enhance players' empathy for the marine environment and, as a consequence, would make them more sensitive to sustainability and environmental issues related to diving. Our data show that players across various age categories did indeed feel immersed and involved in the game. However, we could not specifically test whether their level of environmental awareness had increased after playing this game.**

Keywords—marine education; environmental awareness; virtual reality games; presence; immersion

I. Introduction

In the past years, we have assisted at the widespread development of systems aimed at creating awareness in users towards a conscious sustainable environmental behaviour. The HCI community has been very active on this topic, exploring for example how social practices and digital technologies affect energy consumption or how persuasive technology can be used to promote behavioural change in these domains (for an overview of these projects, see in [6]).

Marine conservation and education have not been shy of this: the Aquatic Ecosystem prototype, for example, portrays life in water and is aimed to teach children to save water [3]. More often, though, technology is used to motivate people with little or no affinity with the sea, its challenges and opportunities to get closer to it: a computer-mediated experience is assumed to allow these users to understand the sea better. Diving, for example, has a huge educational and awareness rising potential, but is also linked to direct impacts on aquatic life if the needed skills are not properly mastered and/or divers are not adequately informed. Game technology is seen as having a huge potential in raising such awareness towards marine sustainability as recent games[1] applied to diving demonstrate. Infinite Scuba [5], for example, is a diving simulation game that allows non-professional divers to virtually explore underwater environments. The goal of this game is to increase awareness towards the marine environment through exploration. Players are rewarded if they find, identify, and photograph different species of fish and other sea life [1]. Planet3 [1] is also a virtual game and is targeted at students aged 10-14 in their school curriculum. Based on challenges classified by topic, students are triggered to solve the mission they are engaged in while exploring the underwater environment. DIVE, the game we developed, is also a virtual reality game. It is targeted at non-divers with the dual goal of making them experience diving and of making them aware about the consequences of a (non) sustainable diving behaviour. Therefore, it is ultimately meant to promote behavioural and attitudinal change. This is where it differs from the two games mentioned earlier: not just exploration of a underwater environment photorealistically recreated but also behavioural and attitudinal change through an increased awareness of what an underwater sustainable behaviour is. Our assumption was that the high sense of presence elicited by the virtual environment (VE) would make players develop a positive attitude towards the marine environment and therefore be a trigger for such behavioural changes. In order to measure whether this attitude was elicited, we needed to first measure the level of immersion experienced by the players in the game. This was done via a presence questionnaire administered after players had experienced the game (see under Methodology). However, the explorative nature of this study only allowed us to test how the game itself was experienced by the participants, and not their actual increased (or not) sustainable behaviour while diving.

[1] World of Diving: http://divegame.net/;
Infinite Scuba: https://www.infinitescuba.com/

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II. The DIVE Game

The DIVE game provides an immersive experience suitable for non-divers by enabling them to experience an underwater environment. The game allows the user to move around the seascape and among marine life using a virtual Diver Propulsion Vehicle (DPV, i.e., an underwater scooter). The user drives the DPV with one hand (one controller), while with the other hand (other controller) they can take pictures of the surrounding environment through a virtual photo-camera. The virtual reality dive simulation experience conveys a close-to-reality underwater diving experience based on real life data. In this open world environment, players are able to experience the sensations of diving in a completely safe environment, almost disregarding players' limitations (age, phobias and possible disabilities).

A. *VR Environment*

The VR environment was developed in direct collaboration with four professional diver instructors using a mixed approach, which combined auto-generated content based on real life underwater pictures and authored 3D models, textures and animations. An Italian underwater bio-cartography company, UBICA s.r.l., collected and created the morphological shape of the seabed, provided consulting on local marine life and insights on practical aspects of movement in an aquatic environment. All cartography data was collected in 2015 at the Techobanine reef, in Ponta do Ouro (Mozambique) through a series of photos by using an underwater DPV equipped with cameras and GPS (Global Positioning System). The referenced photo-samples were preliminarily processed using a photogrammetric software[2] to perform the photo-alignment and create a dense point cloud, which was converted into a 3D model. The mesh representing the morphological features of the Techobanine diving site was optimised and readjusted to be included in the VR environment. The aforementioned mesh represented the basis of the seascape where the virtual experience is set up. In addition, a biodiversity list of marine species (i.e., benthic, nektonic, sessile and vagile organisms) characterizing the reef of Ponta do Ouro was compiled. Photo-based information was also provided, which supported the authored composition step of the environmental modelling.

A game and VR scenes artist used the material described above and adapted the base mesh to create a UV map and textured of the environment according to the reference photos. A selected number of species were then 3D modeled and animated and included in the 3D scene (Figure 1).

[2] Agisoft Photoscan v1.3

Fig. 1. Example of wildlife, using a fish swarm and plant life.

Although the VR head mounted display (HMD) provides a large field of view, after experimenting and initial user testing, a virtual underwater mask outline was added. This actively reduces the field view of the participant (of roughly 5%), but it largely increases realism and it is supportive of the VR HMD device affordance (see in Figure 3 on next page). A specific graphical shader was developed to define the appropriate levels of light and color of the image. Volumetric fog was used to provide a realistic attenuation of distances (Figure 2).

Fig. 2. Underwater scene depicting the effects of a graphical shader attenuating reds and object distance.

Sound propagation and the human hearing are also largely affected underwater: sounds appear closer than they are in reality and their origin difficult to locate. However, since the game is being mainly designed for public usage, we kept the sound mainly on environmental water effects adding a calm and paced underwater breathing.

B. *Exploration*

The DIVE game was developed as an open and safe exploratory ground, that players can explore by means of an underwater DPV. This was intended to encourage free rooming in the 3D environment so that players could discover the different areas within it. This environment is around 60x80 meters by 15 meters depth (lowest point). The players' movement is however limited by the use of the graphical shader to reproduce the exact underwater visibility, which is greatly reduced due to both the presence of particulate matter in water and to the darker environment.

From the first iterations and tests we had with real users, it was clear that the locomotion mechanic was greatly appreciated, but also made players attempt to break the surface and see what is on the other side, above the sea water level. Necessarily, we had to develop a simple surface with appropriate props to satisfy their curiosity, with some flying seagulls and an anchored boat. Finally, other notable characteristics of the game experience worth reporting are the ease of losing one's bearings and the sense of direction as in real life. Players with diving experience reported to have really enjoyed the experience and to consider it very close to reality. Their suspension of disbelief was however negatively affected by the fact that they had to stand up while virtually diving (see Fig. 3).

C. The Experience

We designed and implemented an experience for a Science Festival. This experience consisted in teaching players how to dive safely, for both the divers and the environment. We triggered their motivations using the beauty of underwater life, the appeal of adventure, and the quest for peaceful sensations and unforgettable memories. In this way, we hoped to raise the players' awareness on how to behave underwater in an ecologically sustainable way.

Players had to wear a head mounted display, the HTC Vive (Figure 3), showing them stereo images of the underwater scenarios, which were also projected on the wall next to them for the audience around the players to watch them and follow the dive. Players could start and manage the experience using the handle joystick. The virtual representation of a human dive instructor would explain them all functions and control commands making large use of typical underwater signs to communicate between divers.

Fig. 3. A player experiencing the DIVE game with the virtual diving instructor and the experience projected on the wall.

III. THE METHODOLOGY

In this explorative study, we used an adapted[3] version of the Presence Questionnaire (PQ) developed by Witmer & Singer[4] [4, 7] to measure presence and immersion. We chose this questionnaire because it measures various factors that are considered as contributing to the feeling of presence in VR, such as control, sensory experience, realism and distraction factors, through 16 Likert-scale questions with seven response choices that range from "not at all" to "completely". Thus its focus is on the experience as a whole.

We distributed 100 questionnaires during the 14th Festival della Scienza held in Genoa, Italy, in November 2016. This festival represents a well-known annual event visited by schools, students and families from all over the country. Participants were given the questionnaire directly after they had experienced the VR game. There was no time constraint on this experience, although they played it for 3,8 minutes on average. Only 84 questionnaires were complete and could be ultimately considered valid for analysis. In order to make sense of the data, we decided to group players into four age categories, depending on their current school attendance:

- Category A: primary school kids, 0-10 years old (9 people)
- Category B: lower grade high school children, 11-13 years old (16 people)
- Category C: higher grade high school students, 14-19 years old (28 people)
- Category D: adults, 20 years and older (31 people).

IV. DATA ANALYSIS AND RESULTS

We performed some descriptive statistics on the variables from the Presence Questionnaire. From them, we can see that the VR game scored rather well among all age categories in terms of suspension of disbelief (the original question was Q3: "How real did the virtual world seem to you?"), consistency between virtual and real world (Q4: "How much did your experience in the virtual environment seem consistent with your real world experience?"), ability to control events (Q6: "How much were you able to control events?"), immediacy and responsiveness of the VE (Q8: "How responsive was the environment to actions that you initiated (or performed)?"), immersion and involvement in the VE (Q10: "How much did the visual aspects of the environment involve you?"), ease of movement in the VE (Q13: "How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?"), distraction of the visual display (Q14: "How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?"), and of the control devices (Q15: "How much did the control devices interfere with the performance of assigned tasks or with other activities?") and the level of influence of the game mechanics on task concentration (Q16: "How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?").

We also performed some comparative analysis over the various age groups. Looking at the means over the dependent variables, we can notice that the smaller children (category A) show a relatively different behaviour compared to all other age categories, in particular compared to the older players (category D). For example, the younger children played for significantly less time, namely around 2 mins on average, while all other players played for almost double this time (Kruskal-Wallis test: H (df = 3, N = 81) =9.96 p = 0.02). The

[3] This is an adapted version in that it was translated into Italian and in the Italian translation questions were phrased in such a way to make them easily comprehensible to the mainly younger audience of the festival.

[4] The original questionnaire can be found here: http://w3.uqo.ca/cyberpsy/docs/qaires/pres/PQ_va.pdf

children reported to experience the VE as extremely real (average score of 6), particularly in comparison with the oldest age category D (Mann-Whitney U test, $Z = 2.24$, $p = 0.02$). It is not surprising then that they found the consistency between the real and the virtual world to be rather high (mean: 5.8) in comparison with the oldest group (Mann-Whitney U test, $Z = 2.03$, $p = 0.04$). Finally, the children also scored significantly different concerning the distracting effect of both the visual display qualities (Mann-Whitney U test, $Z = 2.28121$, $p = 0.02$) and the control devices (Mann-Whitney U test, $Z = 0.88$; $p = 0.38$) on their performance. Almost no remarkable differences are found between categories A and B, both lower grade school children, while a few significant differences are found between categories A and C, the higher grade school students. These differences pertain the distracting effect of both the visual display quality (Mann-Whitney U test, $Z = 2.37$, $p = 0.02$) and the control devices (Mann-Whitney U test, $Z = 1.99$, $p = 0.049$) on the users' performance, with the younger group always scoring higher

V. Discussion

Overall, the VR game has been positively received throughout all age categories considered. It does not require much time to adapt to it and to understand how to behave in the VE. Players reported to be in control of their actions and of the events in the VE, to perceive their interactions in the VE as being natural and to feel involved and immersed in the VE. The majority of the players did not feel distracted by either the visual qualities of the display nor by the control devices, which could have prevented them from appreciating the content of the experience.

Although the main finding of a difference in experiencing the VR game between the youngest and the oldest age categories is not new, it is remarkable to notice how the youngest children behaved differently from all other age categories involved in this study and therefore represented an exception to the general trend just mentioned. They played for a significantly shorter amount of time compared to the other three categories of players. Nevertheless, they felt as immersed. They perceived the virtual world as real, although they remained quite aware of the real physical world around them with other people and noises and voices coming from it. This awareness however did not disrupt their suspension of disbelief and possibly also their feeling of immersion, despite the unnatural posture and the presence of an audience around them, which could have influenced the resulting experience. The lower time the younger children spent in the VE may be the reason why they were not able to adapt to the technological side of it and could not bypass the initial familiarisation period that is needed to forget about the goggles on their head and to concentrate completely on the content of the experience. This behaviour is visible only with this age category, and it differs significantly from all other players involved in this study. From the current results, we cannot however identify the reason for it, which might be either their more limited gaming experience, they getting bored faster or their parents putting a time limit on their experience of the game. Ultimately, as the DIVE game was not developed specifically for children of that age, but for a broad target group of non-divers, we had not considered their specific cognitive skills and abilities in processing information and in learning. A different way of presenting the content, one that does not "fail(s) to ignite lasting emotions" [2] may be a possible solution to this issue as well.

VI. Conclusion

The DIVE game was developed to simulate a diving experience in a virtual environment for non-divers with the purpose to create awareness in players about a conscious sustainable behaviour underwater that would maximise the benefits associated with diving while minimising its negative impacts on the environment. The results reported in this initial explorative study do not give any indication that this is the case. The results from the Presence Questionnaire discussed confirm that players felt immersed in the VE and developed a high sense of presence. However, we could not test whether this experience also increased their awareness and sensitivity towards environmental issues and if and how this is also actually translated into a more conscious sustainable behaviour while diving. This is something that we will have to investigate in a follow up study, with an *ad hoc* post-experience questionnaire.

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