SAVR – Design and evaluation of an immersive virtual reality serious game on hazard perception in technical and vocational education

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***Abstract*—Technical and vocational secondary school students take internships in enterprises as part of their training. As such, they are often confronted with hazardous situations, such as contact with chemical substances, operating specialist machinery or in potentially dangerous working conditions. Students therefore need to be prepared in the school setting, prior to their internship experience. To address this challenge an immersive virtual reality serious game was developed. Students' perceptions of the effectiveness of the game were assessed using a survey. Targeted variables were presence, design, interest and usefulness. Students positively evaluated all measures, suggesting an immersive virtual reality serious game is a useful instrument in teaching hazard perception in technical and vocational secondary education.**

Index terms—serious game, hazard perception, secondary education, design research, safety education

I. Introduction

Immersive virtual reality (iVR) is increasingly being used in educational settings as VR headsets have become more affordable and user friendly [1]. Several authors point to the affordances of iVR for learning, such as authentic learning environments, visualizing what is otherwise invisible and creating learning experiences which are in real-life not possible, too expensive or too dangerous [1]-[4]. Providing students with authentic learning experiences which would be too dangerous in real life, was the main incentive for the design of the SAVR project. Previous research has shown iVR to be an effective tool for teaching safety procedures in an interactive and engaging way [5]-[8] and outperforming more traditional or 2D-approaches [9], [10]. Although these safety trainings often are designed as serious games, results from research on iVR serious games are not consistent [11], [12]. Building on the existing literature, we designed an immersive virtual reality serious game to teach hazard perception to students in technical and vocational secondary education in Flanders. Hazard perception, sometimes called hazard identification [13], refers to one's ability to perceive situations as dangerous, including the perceived level of risk [14].

II. Methodology

We adopted the methodological framework of Educational Design Research as developed by McKenney and Reeves [15]. This approach consists of three main stages: analysis and exploration; design and construction; evaluation and reflection.

Both students and teachers from five Flemish technical and vocational secondary schools, were engaged during the development of SAVR in an approach of collaborative design and co-creation. An informed consent prior to the start of the whole SAVR project was obtained by all students, parents, teachers and the principal.

A. Analysis and exploration

In this first stage, we conducted separate interviews and focus group interviews with all stakeholders from the project team who were involved with safety education. They were asked for their current needs, what regulations they had to adhere to, how the SAVR game should be integrated into their current courses and so on. These interviews included 15 teachers, 28 students, 7 members of three organizations concerned with developing curriculum materials for safety education in Flanders, 2 persons from 2 organizations monitoring safety procedures at work and 2 pedagogical advisory board members.

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All interviews were held online using *Microsoft Teams* due to Covid-19 safety regulations and were recorded. The recordings were downloaded as MP4-files and converted to MP3-files for further analysis.

B. Design and construction

Based on the existing materials and outcomes of the interviews a first prototype was developed. This prototype was then tested for usability by all stakeholders. They were all provided with one or more Meta Quest 2 iVR headsets. Prior to the testing phase a member of the developer agency organized an online webinar explaining how to operate the virtual reality headset and how to port the software to the device. The developer agency used their own management software to be able to push updates to the device and to live monitor the testing sessions. The first prototype was then tested by all stakeholders while being observed by the developer agency and the research team. All observations were written down via an observation protocol and discussed in an online meeting with all members of the developer agency and the research team. The findings were then categorized in codes, such as usability, software bug, playfulness… which gave rise to suggestions for the next prototype. The design suggestions were first presented to the project team as a whole and confirmed or adapted according to needs and desires which were identified in the first stage of analysis and exploration. Over a timespan of five months, a total of four prototypes were designed, developed and tested in an iterative approach (see Fig. 1): results from observations of each formative test session were used to improve the design of the next prototype.

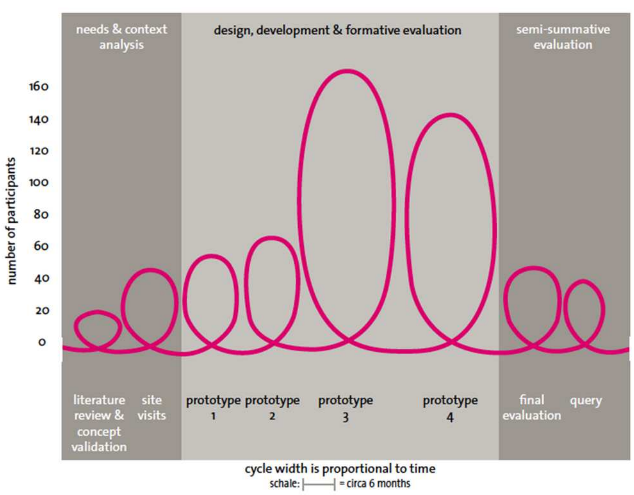

Fig. 1. Process display of a design study, adapted from McKenney, 2001.

C. Evaluation and reflection

Finally, the last version was tested (Fig. 2). 51 students from 5 schools in vocational and technical secondary education in Flanders participated in the summative testing of the application.

48 students were male, 3 were female; and their age ranged between 14 and 18. Following safety regulations by the iVR headset manufacturer Meta [16], iVR players under the age of 13 were excluded from this study. Most students (76,5%) had quite a lot of gaming experience, but only a minority (31,4%) had experience with immersive virtual reality.

The participants tested the full version of the game, which takes approximately 14 minutes. Then, they were asked to complete an online questionnaire using Qualtrics survey software, starting with some demographic elements such as age, gender, prior VR experience and prior gaming experience. Part two of the survey consisted of 26 items on a 7-point Likert scale. Presence was measured using 8 items from the Presence Questionnaire of Schubert, Friedman and Regenbrecht [17]: 4 items on spatial presence and 4 items on involvement. Next, usability was measured using 4 items from the design scale of Web Based Learning Tools survey [18]. We were also interested in whether the game had an effect on students' motivation for safety education, so we added 7 items measuring interest/enjoyment and 7 items on value/usefulness, both from the Intrinsic Motivation Inventory by Deci and Ryan [19].

Fig. 2. Students engaged in user testing sessions of SAVR

III. RESULTS

A. Analysis and exploration

Results from the focus group interviews with students indicate current safety education practices lack authenticity. Often students are referred to books on safety regulations, which they have to study on their own. Sometimes a visit to a conference on safety is organized. The main problem for students, is the lack of real-life experiences, due to the limitations within formal education. They expected the immersive virtual reality learning experience to tackle that gap and to provide for ample training opportunities. Teachers expressed a similar concern, but also asked for a learning experience which would be easy to use in their classes, which could be integrated in their existing course materials and is curriculum aligned. This was also expressed by the pedagogical advisory members. Furthermore, teachers indicated a lack of educational materials on safety, aimed at secondary education. Most safety education materials address a professional market or are in most cases focused on safety instructions when operating specific machinery. Teachers and pedagogical advisory members asked for training hazard perception as an attitude. This was confirmed by the organizations concerned with developing these materials. The SAVR project tries to address the gaps identified by the several stakeholders.

The development of SAVR was partially funded through the InnoVET program by the Flemish Department of Education, stimulating innovation in Vocational Education and Training (VET) [20]. Only a small budget was provided, limiting the development of the game. Hence, several design decisions had to be taken.

B. Design and construction

First, we provide a short overview of the game design of SAVR. The game starts with a tutorial to get students familiar with how to interact with the virtual environment. They learn how to move by teleporting and how to take photographs. This is explained in a prerecorded 2D-video by a member of the research team dressed as a construction site manager. Students are asked to perform a last-minute risk analysis as a rationale for the game. The tutorial is set in a container at the virtual construction site. Next, students move over to the site itself where 23 construction workers are engaged in welding, drilling, climbing scaffolds… Students need to find the hazardous working situations and take a photograph of it. When such a danger is spotted correctly, short audio feedback is provided and the dangerous situation is corrected. When students spot a situation which is not hazardous, they are told there is no danger in that situation. Students get a maximum of 15 pictures to find 10 hazards within a total of 23 construction situations. Both the number of photos taken and identified hazards are always shown to the students on the virtual smartphone. The game ends when 15 pictures are taken. Finally, students are teleported back to each hazardous situation in the game automatically. The construction site manager then shows the students whether they had identified the hazard, why the situation can be seen as dangerous and how it should be done properly.

Fig. 3. Screenshot of SAVR showing user interaction via smart device

As ease of use was one of the major concerns of teachers, we chose to develop for a standalone VR setup. Meta Quest 2 served as our best option, as it fitted within the constraints of the budget and Meta Quest 2 also allowed for running other educational applications which are available within education and training in Flanders.

Standalone VR setups, such as Meta Quest 2, are limited in GPU-power. Therefore, graphic detail must be reduced in order to maintain performance and limit motion sickness resulting from latency issues.

Another concession resulting from the limited budget, was the design choice of downsizing the amount of interactivity. Instead of having machines operated by the players themselves and testing whether safety procedures were taken into account, virtual avatars and a virtual construction site were created. The avatars perform all operating actions on this site, sometimes in a safe way, sometimes not. Players have to take a picture of dangerous working conditions with a virtual smart device. This design choice was in line with teachers' emphasis on detecting hazardous situations rather than training specific operations procedures.

All stakeholders expressed the desire for ample training opportunities. First, we defined a list of 23 hazardous situations which students had to be able to detect. As was explicitly expressed by all stakeholders during the analysis phase, these situations align with the curriculum standards, meeting several learning goals of students' hazard perception training. The situations were then designed in both a safe and an unsafe version. All 23 situations were then saved in a repository of which the SAVR game randomly chooses 10 situations which are presented in an unsafe condition. The remaining 13 situations are carried out in a safe way by the virtual avatars. This randomization allows for multiple learning opportunities, as each time different hazards have to be found.

Observing students during the prototype testing sessions brought forth some new design elements. Students initially took as many photos as they could, shooting almost everything there was to see. As a result, they eventually succeeded in finding all hazardous situations, but mainly by coincidence. Therefore, we limited the number of photos they could take to 15. This is indicated by a symbol on their smart device, next to a symbol showing how many hazards they have already found (Fig. 3).

Another design element resulting from observation was that students took a wide-angle picture, once again being lucky to have the hazard on the picture. In the final prototype a picture was therefore only valid when students were close enough to the hazardous situation, excluding the factor of luck.

Due to an initial lack of system feedback, some users kept on taking photos from different angles to be sure the system registered the photo taken correctly. To address this, the hazard is now automatically corrected into the safe version when a user captures the hazardous situation, accompanied by short audio feedback by the virtual trainer. Doing so, a combination of both system feedback and content-related feedback is established.

Observations also made clear that after the initial tutorial on how to interact with the virtual environment, not every student was able to teleport or to take a picture in a fluent way. As such, it seemed the tutorial did not present enough learning opportunities, resulting in the game being too complex for first time SAVR players. To tackle this issue, we chose to add a validation element to the tutorial. Users must perform the actions, needed for the training itself later on, three times, each within a timing of 5 seconds. When users were not successful in doing this, they needed to restart the first exercise. In doing so, users got familiar enough with the control instruments, allowing them to fully focus on the training content on hazard perception instead of thinking about which controller button to use.

Although the range of teleporting was already limited, some users were disoriented after transporting to another location in the tutorial scene. To mitigate this effect, users were automatically turned into the direction of the next hazard or the virtual construction site manager.

C. Evaluation and reflection

We first tested the unidimensionality of the instrument via exploratory factor analysis using SPSS28. All items had satisfactory factor loadings. Next, Cronbach's alpha was calculated for each scale to test reliability. To test the effect of SAVR we calculated the means and standard deviation. All items were scored on a 7-point Likert scale. Results are presented in Table 1.

TABLE I. RESULTS OF RELIABILITY TESTS AND SUMMATIVE ASSESSMENT OF SAVR BY STUDENTS

Scale	Cronbach's Alpha	Means	Standard Deviation
Spatial presence (IPQ)	.526	5.47	.844
Involvement (IPQ)	.690	4.47	1.27
Design (WBLT)	.774	5.95	.853
Interest/enjoyment (IMI)	.912	5.75	.937
Value/usefulness (IMI)	.935	5.48	1.052

Next, we looked for significant differences in variance between groups. Due to the skewed distribution for gender (only 3 female, less than 5%), the effect of gender was not further investigated. For age, we made a distinction between students from different grades. In Flanders, Belgium, secondary education is divided in 3 grades. Students in year 3 and 4 belong to grade 2, year 5 and 6 belong to the third grade. Scores for each scale were calculated using Mann-Whitney U tests. Comparison for design (WBLT) proved to be significant in favor for the second grade (mean rank 29,72) over the third grade (mean rank 21,09) with a p-value of .037 and an effect size of -.291 which is considered to be low to medium. A similar significant difference was found for interest/enjoyment (IMI) with a mean rank of 31.90 for the second grade and 18,23 for the third grade at a p-level of .001. This time the effect size was medium to large ($r = -.46$). We also investigated the effect of gaming experience and created three groups: few, moderate, a lot. This time we used Kruskal-Wallis test as we had three groups. Comparison of groups showed no significant difference for any measure. The final effect under investigation was prior experience with virtual reality. Again, three groups were created and Kruskal-Wallis tests were run. No significant differences could be found.

IV. DISCUSSION

In this study we designed, developed and tested an immersive virtual reality serious game on hazard perception, called SAVR. This game was developed to be used in courses on safety in the second and third grade of technical and vocational secondary schools in Flanders.

Results from the interviews during the analysis stage indicated a need for such materials as all stakeholders expressed the lack of authentic learning experiences. One of the affordances of immersive virtual reality is that it can recreate such authentic, real-life environments, due to its immersion, presence and interactivity [21], [22]. Test results for spatial presence and involvement indicate students felt highly immersed in SAVR. They also valued the iVR game in terms of interest/enjoyment and value/usefulness, indicating SAVR is a useful instrument for safety education on hazard perception in vocational and technical secondary schools.

We could not retrieve any difference of significance between subgroups, apart from the grade. Students from the second grade scored both Design [18] and interest/enjoyment [19] significantly higher than students from the third grade. A plausible explanation could be that older students had already more iVR experience, hence are more critical about new iVR experiences. However, no correlation could be found between age or grade and prior iVR experience. Our results apparently suggest that SAVR is more fit for younger students. A sound explanation cannot be provided for and should be investigated in more detail in future studies.

We were successful in attaining both goals of our project. First, we developed a useful tool to teach hazard perception in technical and vocational secondary education. The game is now used in several schools in Flanders and the Netherlands. The second goal of Educational Design Research [15] is adding to the theory, in this case on hazard perception. Some design guidelines were identified, such as randomization of hazards, taking photographs as a test base and avoiding the factor of coincidence via iVR interaction settings. This adds to the understanding of how immersive virtual reality games can help to teach hazard perception in technical and vocational secondary education. Especially within the constraints of limited budget, concerns of ease of use in a classroom and demands for sustainability in terms of ample learning opportunities.

Although successful, this study was also confronted with some limitations. First of all the results should be interpreted carefully and not be generalized as our sample was limited to 51 students. Secondly, this paper includes only students' perceptions. Analysis of teachers' and other stakeholders' perspectives would complement our findings. Next, design guidelines were identified during observations. They cannot yet be taken for granted and need to be validated in future studies involving larger groups and in quantitative research designs. We were also not able to test whether SAVR has a real life impact, i.e. whether students will show a transfer of attitude of hazard perception to real working conditions.

V. CONCLUSION

To address the lack of authentic learning experiences on hazard perception in technical and vocational secondary schools, we designed, developed and tested an immersive virtual reality serious game. Test results indicate SAVR can be considered as a useful instrument to be used for safety education. In line with the methodological framework of Educational Design Research our work has both practical and theoretical implications.

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