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Immersion or Non-Immersion? That is the Question. Is Immersion Useful in a Spatial Perspective Taking Task?

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Abstract: Results in literature suggest that immersion and presence in virtual reality facilitates spatial reasoning, but is it really so? The present paper describes a methodology and the set-up of an experiment aimed at assessing the relation between immersion in virtual reality, presence and performance in spatial reasoning. "In Your Eyes" is a virtual reality game to support the development of the spatial perspective taking skill, which is one of the basic abilities in spatial reasoning. The game has been developed in three different versions: one in complete immersion, using a Head Mounted Display; one in semi-immersion in which all movements are still possible but the room is seen from a computer monitor; and a non-immersive one with a fixed view on the virtual room. A wide test with children from 8 to 10 years of age was planned with the aim of assessing whether the use of immersion impacts on reported presence and on performance in the perspective taking task. Six elementary classes are involved in playing with the three versions of the game. The data collected will be the basis for a deeper research on spatial immersion, presence and their impact on performance and learning of visual reasoning skills.

One Sentence Summary: A methodology to investigate the relation between immersion in virtual reality, presence and performance in spatial reasoning.

1. Introduction

Virtual worlds are recognized by the brain as if they were real, and this facilitates both the acquisition and the transfer of several abilities. Virtual worlds can offer different levels of "immersion", in other words they can surround the user to make him feel as if he was really there. We organized an experiment with the aim of assessing if and how different levels of immersion impact on a specific ability: Spatial Perspective Taking (SPT).

SPT is the ability of imagining how the world looks like from another person's point of view. It is one of the basic skills needed for orientation in space and it is correlated with good results in STEM subjects. According to Newcombe [1], it completes its development in the first years of primary school.

"In Your Eyes" is a game that takes place in a virtual room where an avatar sits at one of the four sides of a table that has some objects on it. Four pictures on the wall show the table from the four sides and the player has to pick the one that shows the scene from the avatar's point of view. The game can be used both for training (where the scenes are randomly generated and the player goes through a sequence of different levels of difficulty) and for assessment (a pre-defined sequence of scenes is presented to each player). It has been developed in three versions with different levels of immersion: completely immersive using a Head Mounted Display (HMD), a semi-immersive where the virtual world is seen through a computer screen and a non-immersive with a fixed view on the virtual room.

An experiment has been set up to test the three versions of the game with a group of children between the age of 8 and 10. A repeated measures design has been chosen for the experiment, so that each child will use all the three versions of the game with a fixed sequence of scenes. Balanced groups have been made with a simple paper based pre-test in order to counterbalance results and avoid order effects.

In our hypothesis, better performance should be measured in the complete immersive version of the game since having the possibility to "dive" into the virtual world allows the player to:

- Better build a mental model of the scene and the involved objects by freely moving around the table and examining the objects from all the possible perspectives;
- Manage by himself the amount of help needed: it is always possible to move to the other side of the table and see what the scene looks like;
- Increase his involvement in the game by exploring the virtual world as he pleases.

On the other hand, using a HMD can be tiring, it can cause sickness to some players and it may need more effort in managing an interface the player is not used to. Furthermore, the presence of a complete environment in which to move and explore, can draw the attention away from the main task and therefore influence learning negatively.

The experiment is running at the present time, data collection is planned to finish within the next month and by June the first results will be available. Furthermore, performance in the game will be correlated with school results in STEM subjects.

Spatial Perspective Taking

Newcombe and Frick [2] define SPT as the ability to correctly identify the position and rotation of a person in space and understand that their perspective can be different from ours. It is the ability to imagine ourselves in the place of the other person and be able to predict what will be seen after the corresponding movement in space. It involves occupying the place of the other person and understanding the relative position of objects.

SPT and its development in children has been investigated by Piaget [3], according to whom its complete development does not take place before the child is ten. Later studies [4] seem to demonstrate that the ability actually develops some years earlier. According to Surtees et al. [5] there are two different levels of SPT skills: the first level, which usually develops in children when they are about five, allows understanding if a given object can be seen from a different point of view. The second level, which usually develops some years later, between six and eight, makes it possible to imagine how a given scene would look like from a different perspective.

According to an experiment carried out by Surtees et al. [5], SPT is an embodied process, in other words when people are asked to state what another person would see, they actually imagine moving to the new position in space and then reconstruct the view from there, activating, while doing so, those parts of the brain that are involved with movements in space.

SPT is one of the basic abilities that is part of spatial reasoning, it is important for orientation in space and it can get better with a specific training. Furthermore, it has positive effects on school results, especially in STEM related subjects. Newcombe [1] reports several different longitudinal studies that started back in the fifties by following the development of a large number of American children for a long period of time (starting from nursery school all the way to adulthood). These studies have shown that there is a correlation between spatial reasoning skills and results in STEM areas. Having good spatial skills increases also the probability to undertake STEM related jobs.

Immersive Virtual Reality and Presence

Virtual reality is defined as an artificial environment that is experienced by the player through sensory stimuli and with which it is possible to interact in a natural manner using electronic tools. In virtual reality, the concepts of “spatial immersion” and “presence” are often used and sometimes there is confusion between the two. While “spatial immersion” is usually defined as an objective property that refers to the technical capability of the system to deliver a surrounding and convincing environment, many authors define “presence” as the human response to such an environment. Presence is therefore the extent to which participants believe they are somewhere different from their actual physical location [6].

When interacting with the surroundings, we create a mental simulation of the world we are in, based on previous experience. The simulated world and previous experience determine expectations and predictions [7], therefore when we pick up a pencil we expect it to have a certain weight, to be hard, to feel the wood it is made of, etc. Presence is possible when perceptions pair with expectations: it is not so important that the simulated reality actually matches completely with the real world, but rather that it matches with the player’s expectations.

Presence is related to feeling physically in the subjective mental reality that is simulated in the brain. It involves the commitment of the person’s entire neurology to the “suspension of disbelief” that they are somewhere else rather than where their physical body really is [8]. Furthermore, it is grounded into the ability to do something in the virtual environment [9]. Presence is closely connected to attention: while waiting for a bus we may be daydreaming and lose contact with the surroundings, therefore we are not “present” at the bus stop. The same may happen in a IVR where the user may be thinking about something different while immersed in the virtual world.

Presence is then linked to the mental simulation we make of the surrounding world and it depends largely on the absence of events that will “break the illusion”. Also when dealing with the real world, there are always prediction errors, according to which the mental model is refined to be adapted to them. It is important that these errors are not too big or it becomes impossible to adapt the model. These errors are useful because they attract the person’s attention: it has been demonstrated that when the world is entirely familiar and predictable presence diminishes. In the same way, the virtual world has to have some unexpected events to maximise presence, but not such as to invalidate the whole mental model.

Presence in an IVR world in children has been studied by Baumgartner et al. [10] through the analysis of brain activation in adults compared to children between six and eleven. Their studies show that the children are more susceptible to the arousing impact of the visual and auditory spatial stimuli and are thus less able to regulate and control the experience of presence during arousing VE. Jäncke et al. [11] also find that virtual reality causes different brain activation in children and adults, suggesting that children react more to immersive visual and auditory stimuli.

An IVR world to practice SPT skills

Due to the embodied component of the SPT ability, an IVR environment is probably the best environment to practice the skill. As Dalgarno says, “3-D Virtual Learning Environments can be used to facilitate learning tasks that lead to the development of enhanced spatial knowledge representation of the explored domain." [12].

However, immersion alone is not enough; a good level of presence is needed to make the learner feel that the surrounding world is real. Learning in a virtual world that is recognized as real by the learner makes learning transfer to the real world easier [13]. Furthermore, in the virtual world the player can actually make the physical movements that are characteristic to the abilities that he is practising, supporting a kinaesthetic approach to learning.

IVR offers several other advantages: the player can practise in many different scenarios, widening the range of his experiences; his interest is kept high by the gaming situation, which usually guarantees a better performance; the player is motivated and therefore will play enough time to gather all the needed experience [14]. On the other hand, the tutor can supervise several different players at the same time optimizing his effort; finally, researchers have the possibility to replicate experiments made in the virtual world several times avoiding unintentional changes in the settings.

Description of the game "In Your Eyes"

The game "In Your Eyes" [15] is a virtual reality game to support the development of the spatial perspective taking skill, which is one of the basic abilities in spatial reasoning.

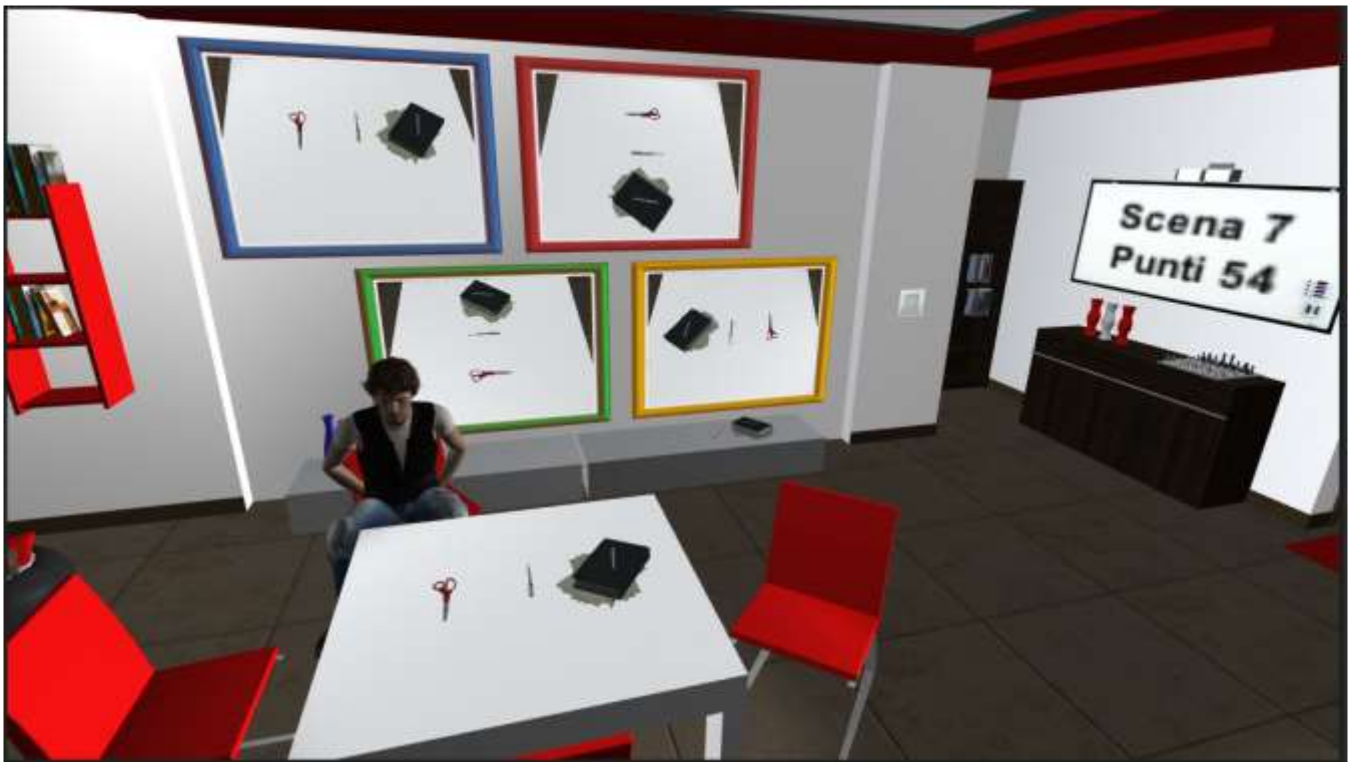

Figure 1. The Virtual Room of the "In Your Eyes" game.

The game takes place in a virtual home environment. The player is in a living room, where there is a table with some objects on it and four screens on the wall showing the table from the four sides. In the room, a virtual friend welcomes the player and helps him along the whole game. Before starting, the player is free to move in the room so that he can see the table and the objects on it from every possible perspective. The room has been designed so that it is appealing and engaging for the player, with enough details to make it look as if it was a real living room so that the feeling of presence in the virtual world is stimulated. At the same time, attention has been paid not to overload and distract the player from the relevant task [16].

The goal of the game is to train the player to recognize the screen that shows the table from the avatar's perspective. The game is organized on five different levels that gradually move from the player's personal point of view to the avatar's. The gradual shift from the egocentric point of view to the other person's position is designed to support the learner to gradually develop the abilities that are at the core of the playing activity [17]. At each level, several scenes can be played, each of which is automatically generated by placing randomly on the table a definite number of objects chosen from a pre-defined set. The player gets points for each correct answer and as the score reaches a threshold (that can be tailored to each single player's needs) the game goes to the following level.

At any moment of the game, the player is free to move, he can go beside the avatar check what the table looks like from there. In this manner, as scaffolding theories state [18], the player can decide autonomously how much help he needs to solve a problem that may be a little beyond his capabilities without any help. As his skills improve, the quantity of help he will ask will diminish up to the moment when he will be able to play by himself.

At each mistake, the wrong answer is blackened (the screen is switched off) and a brief hint is given to help the player. If the player cannot find the right answer, after the third error he has the possibility to move around the table and compare the view he sees with the correct image in the screen. He can take as much time as he needs before continuing the game.

The number of objects that are present on the table, as well as their positions and rotation, can be configured individually for each player and for each level. A default configuration is given with 10 different levels, but it can be changed to match better the player's needs and capabilities.

Implementation choices

The game has been developed using Unity 3D [19] and, since in literature it appears that presence is higher when wearing a HMD [6], Oculus Rift [20] has been chosen.

The first release of the game was specifically designed to minimize any clue in the surrounding environment that would probably not match with the player's previous experience of the real world. In order not to break the feeling of presence, the player was asked to turn around when the scene changed, while he was not looking, the avatar would go back to the start position and the objects on the table would be changed, then the following scene would be played.

Nevertheless, immersion was not complete. The avatar's face was not animated, so that when he was speaking the mouth would not move. Furthermore, it has been decided not to give the player a virtual body for the following reasons:

- If the player had a virtual body, he would expect it to move just as the real body. To implement this, a more complex technical environment would be needed which would make the game less easy to move around and more difficult to be adapted quickly to different users.
- We did not want the player to be able to interact physically with then given scene since he is not supposed to move the objects on the table. Furthermore, touching an object would require to have a haptic feedback.

Moreover, since wearing the Oculus Rift headset is not very comfortable for our end users, we avoided the use of earphones. Even if Nichols' studies [6] demonstrate that the audio source is not so important in the generation of a feeling of presence, this reduces the match with the real world. Using the earphones, for example, would have given the feeling that the voice of the avatar actually came from the avatar's position in space, while in our configuration the voice just comes from the computer's position.

A very first trial we made with few target users demonstrated that presence was actually guaranteed and rather high: a boy started walking on the spot, stimulated by the sight of the floor moving under him. While doing so, he tripped over a virtual object, demonstrating how his physical behaviour matched what he was seeing in the HMD. This matches with the fact that more than 50% of our brain is involved in visual processing, therefore information that comes through the sight has a greater influence than that coming from other senses, allowing for presence even when the other senses are not completely fulfilled.

Since some users have sickness issues when wearing virtual reality headsets, we decided to make the game playable also without the use of the HMD. In this case, the virtual world is seen on a normal computer screen and the mouse is used to move in the room.

The "A Me Gli Occhi" experiment

"In Your Eyes" was originally developed as part of the Smart Angel project [21], to foster the acquisition and consolidation of the SPT skill in young adults with mild intellectual disabilities, with the aim of supporting their independent mobility in town. SPT is one of the basic skills for orientation in space and in people with intellectual disabilities, it tends to develop some years later.

"In Your Eyes" was initially tested with a limited number of target users and their tutors for a two-month period. Even if this was not a complete experiment due to lack of time and a limited number of available end users, some interesting results were obtained. Interestingly, most users were enthusiastic at their first impact with the HMD, but most of them, after the first few play sessions, preferred to play without it [22]. In order to assess if, and to what extent, presence actually supports better performance in the SPT task, a specific experiment has been set up.

A newer version of the game was developed with three different levels of immersion:

- Complete immersion: using a HMD, the player feels as if he actually is inside the living room where he can freely move around as he wishes.
- Semi-immersion: the player can still move freely, but he sees the virtual world on a normal computer screen, he can explore but does not feel as part of the environment.
- Non-immersion: there is a fixed view on the living room showing the table, the avatar and the pictures on the wall as if they were seen through a window.

Some small changes have been made to the game to make it easier to interact with and to maximize presence. As described previously, small unexpected events are useful to draw the player's attention and increase presence. Keeping this in mind, since moving in the virtual room is not so easy for most players, we decided to simplify the game by letting the scene change under the player's eyes.

The game has then been adapted so that a fixed sequence of scenes will be presented to the player: all the participants to the experiment will play exactly the same scenes and in the same order. Since it is recommended to keep the play sessions rather short, a ten-minute limit has been fixed [6] to keep sickness and tiredness as low as possible, and a sequence of 12 scenes has been defined.

Special attention has been paid to the instructions given to the player. It is possible to solve the given task in two different ways, involving different skills: either imagining moving to the avatar's position and reconstructing the scene from there (SPT) or imagining turning the table round until the side of the table where the avatar sits gets in front of us (Object Rotation). The two skills are different [23] and performance can vary a lot in the same subjects. Inagaki et al. have demonstrated that with the same experimental setting it is possible to stimulate the subject to use one skill or the other by changing instructions. We wanted the children to use the SPT skill, therefore, we instructed the player to "imagine you are by my side and tell me what the table looks like from here". Furthermore, the avatar's body sitting at the table and looking at the scene offers the player something to identify with, supporting the use the SPT skill.

A third, simplified version of the game has then been developed in which the virtual room is seen on the computer screen as if through a window. The player has a fixed view of the room, where he can see all the important objects and the avatar, but without the possibility to move around.

Recruitment

Since there is the possibility that people with intellectual disability may get more tired and badly stand the HMD, we decided to involve in the project children from a local primary school in Genova (Italy). Due to the age in which the ability develops, we recruited children aged between 8 and 10.

Six elementary classes have been chosen, four grade 3 classes (8-9 year olds) and two grade 4 classes (9-10 year olds). All the families have been invited to a meeting in which the project has been described and the possibility to try the game in its completely immersive version was given. Informed consent was then signed and the authorized children were enrolled in the experiment. The game was not shown to the children before the start of the project in order not to influence them.

The participants were 101, 60 boys and 41 girls aged from 8 years and 2 months to 10 years and 7 months, with an average age of 9 years and 1 month at the beginning of the experiment. Six children had some kind of assessed cognitive disability and one had previous light episodes of epilepsy so could not use HMD. Data from these children will not be considered in the final data analysis, leaving 94 participants.

A repeated measures design was chosen, each child will use all the three versions of the game with the same fixed sequence of scenes. Balanced groups are needed in order to counterbalance results and avoid order effects.

Paper based pre-test and participant groups

A simple paper based pre-test has been defined to assess the participant competence with respect to the SPT ability. The paper based pre-test was made of 15 questions created by our researchers following the lines of Frick [24]. Figure 2 shows an example of the questions: in the upper part of the test sheet, a bigger picture shows a toy ghost looking at a scene with one, two or three objects. In the lower part of the sheet, four smaller pictures show the same objects seen from the four sides (at 0°, 90°, 180° and 270°). The participant is asked to choose the little picture that shows what the ghost sees. After explaining the project and the specific task to the whole class, three example sheets were solved collectively and then each child did the test individually. No time limit was given. The same test will be given again at the end of the project in order to assess if there is any difference in performance after the three play sessions.

Results from the pre-test have been rather surprising: the ability in the involved children was less developed that we believed and the egocentric error was outstanding. Egocentric errors occur when the participant chooses his own view instead of that of the avatar, which is normal in young children and is later reduced as the child's abilities grows. The participants have been divided into 6 groups, balanced with respect to age, sex (men are statistically better than women in spatial tasks [25]) and performance.

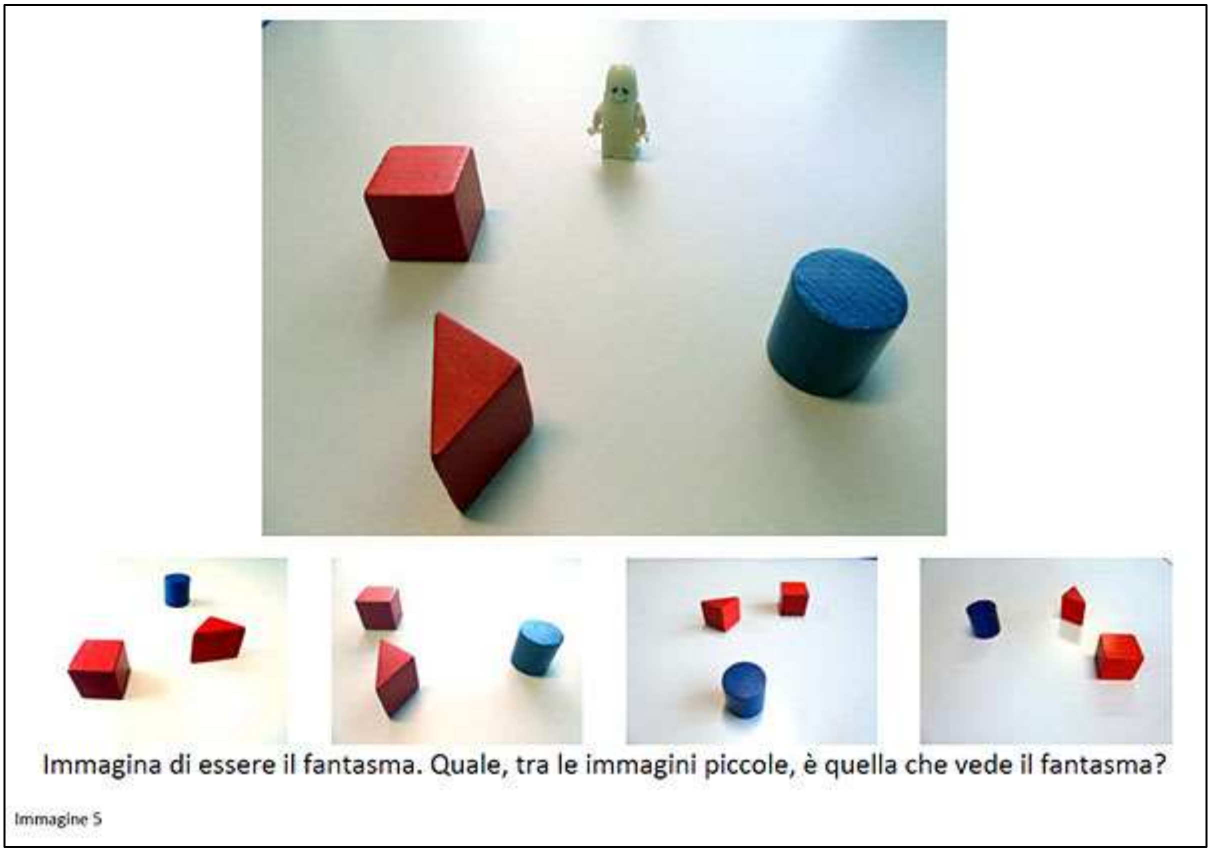

Figure 2. An example of the perspective-taking task in the pre-test. Instructions: “Imagine you are the ghost. Which of the small pictures shows what the ghost sees?”

Expected results

Individual play sessions have started; each participant will use the game three times, one for each level of immersion available. To minimize the memorization of the sequence of scenes, the three sessions will be separated by at least two weeks and the assignment of the correct answer to a coloured screen on the wall has been kept random so that it changes each time the same scene is played.

A short questionnaire with the three questions used by Slater [26] is used to measure a self-reported subjective feeling of presence in the virtual world. The questions have been translated into Italian and answers are given on a seven-point rating scale. The overall score of presence is computed by adding the score of all the question, unlike Slater who only considered questions rated 6 or 7. Presence score ranges from 3 (no presence) to 21 (maximum presence).

Each participant is taken out of the class for ten minutes and plays with the game individually, with the presence of the experimenter. At the end of each session, the questionnaire is filled in and the child returns to class. After the last play session, the pre-test will be given again to assess if there are improvements in the SPT skill after 30 minutes of play with the game.

During the data analysis, correlations will be assessed with respect to the immersion level of the game and self-reported feeling of presence, the immersion level of the game and participants’ performance and participants’ performance and self-reported feeling of presence.

In our hypothesis, a higher level of self-reported feeling of presence should increment performance in the SPT task. Furthermore, self-reported feeling of presence should positively correlate with the immersion level of the game. Finally, the comparison between the pre-test results and those coming from the repetition of the same test at the end of the last play session, will tell us if there has been any improvement after the three play sessions.

The correlation between the participants' performance and their school results with respect to STEM subjects will also be investigated, a positive correlation is expected. If such a correlation is found, since the SPT skill can be trained and this may have a positive impact on school STEM performances we plan to organize more focused specific interventions during the next school year.

Conclusions

An experiment has been organized with the aim of assessing if a complete immersion in a virtual world has a positive impact on a SPT task, which refers to the ability to imagine how the world would look like when seen from another person's point of view. Our hypothesis is that performing a SPT task in a virtual world that is felt as if it was a real world is easier than other less immersive conditions. If that is the case, participants will make fewer errors and take less time to answer when playing in an IVR world rather than other less immersive conditions.

In the experiment, a game with three different levels of immersion is tested with a group of elementary children. A repeated measures design has been chosen for the experiment, balanced groups have been defined based on a paper based pre-test, age and sex in order to avoid order effects. Results will be available by the month of June.

Correlation between the participants' performance in the SPT task and their school level in STEM subjects will be analysed and future intervention may be planned to potentiate the SPT ability in those students who show more weaknesses, using the game as a training tool, in the hope that a greater ability in spatial reasoning will have a positive impact on achievements in STEM subjects.

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