# A Visual Thinking Skills Training in Support of STEM Education

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**Abstract**: In the "A me gli occhi" project, a virtual reality game addressing spatial perspective taking is used with a group of primary school children (ages 8-10) with the aim of supporting the development of visual thinking. Several studies have demonstrated a strong correlation between spatial reasoning and success in Science, Technology, Engineering, and Mathematics (STEM). Visual thinking skills predict a young person's achievement in STEM areas; people with good spatial abilities are more likely to engage in STEM studies and later in STEM related jobs. There are great differences among people in spatial reasoning abilities; nevertheless, they can be trained with long lasting improvements affecting STEM results. An intervention to increase spatial abilities at an early age may have positive effects on the person's future. We have developed a virtual reality game specifically designed to make the player feel as if the virtual world were real, with a special attention to its usability for all, including children with mild intellectual disabilities. The game is available in three different levels of immersion. The first phase of the project focused on the identification of the optimal level of immersion for the task and the definition of the best age group to be addressed. In the second phase, which is ongoing, the children, divided into balanced teams, will participate to a tournament using the same game. Specific moments when the stronger members of the team will teach the weaker ones will be organized. At the end of the experimental period, students' ability in spatial perspective taking will be measured again. Data will be correlated to their abilities with respect to STEM subjects and improvements will be compared to those of students who have not taken part to the training phase of the project.

**Keywords:** Spatial Reasoning; Spatial Perspective Taking; Immersive Virtual Reality; Head Mounted Display; STEM education.



## 1. Introduction

The Organisation for Economic Co-operation and Development (OECD) Programme for International Student Assessment (PISA, 2012) is a test for the evaluation of 15-year-olds students' skills in mathematics, science and language literacy. The most recent PISA test, which is delivered every three years, was done in 2012, involving 65 countries and more that 500 thousand students. Each PISA test has a specific subject it focuses on, and in 2012 the focus was on mathematics. In the 2012 PISA test, Europe is not among the best performers worldwide. These results show that there is the need to improve the teaching of Science, Technology, Engineering, and Mathematics (STEM) subjects all over Europe. Furthermore, The European Union's policy is to encourage STEM studies also to meet market requests.

Several studies have demonstrated that there is a strong correlation between spatial reasoning and success in STEM subjects. Furthermore, people who have good spatial abilities are more likely to engage in STEM studies and later in STEM related jobs (Newcombe, 2010; Sinclair & Bruce, 2015; Carlise et al., 2015; Uttal and Cohen, 2012).

This paper describes the "A me gli occhi" project (still ongoing), which is based on the use, in an experimental setting, of a virtual reality game, "In Your Eyes" addressing the Spatial Perspective Taking (SPT) skill. The game is used with a group of children in primary education (ages 8-10) with the aim of supporting the development of visual reasoning and assessing the resulting impact on their school results in mathematics and science.

In chapter 2, we discuss the relation between spatial reasoning, the Spatial Perspective Taking (SPT) ability and STEM subjects. Chapter 3 describes the "In Your Eyes" game and the three different levels of immersion in which it is available. Chapter 4 analyses the first phase of the project and presents some preliminary results. Finally, the second phase of the project is outlined.

## 2. STEM and Spatial Perspective Taking (SPT)

### 2.1 The SPT skill

Newcombe and Frick (2010) define SPT as the ability to identify correctly 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.
According to an experiment carried out by Surtees et al. (2013), SPT is an embodied process, in which the person actually imagines moving to the other person's place and then generates the new perspective from there, activating, while doing so, those parts of the brain that are involved with movements in space.
SPT and its development in children has been investigated by Piaget (1956), according to whom its complete development does not take place before the child is ten. Later studies (Newcombe, 1989) seem to demonstrate that the ability actually develops some years earlier. According to Surtees et al. (2013) 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 in 6-8 year olds, allows imagining how a given scene would look like from a different perspective. Success in the second level usually implies success the first level tasks (van den Heuvel-Panhuizen, 2015).
Egocentric errors occur when the participant chooses his own view instead of that of the other person, this is normal in young children and later is reduced as the child grows (Bernstein, 2004). Even in adults, there are great differences in performance and the tendency to choose one's own point of view instead of that of the other person is outstanding. According to Epley et al. (2004), SPT is a skill to be developed, adults and children share an automatic egocentric default in perspective taking, but adults, over time, become better at correcting when necessary. Corrections become more automatic with practice and experience, but are always incomplete and linked to motivation and attention: the more people are motivated, the fewer errors they make.
Furthermore, many spatial tasks require holding in working memory information such as the location of objects, their characteristics, etc. Working memory and attention are highly involved and they can improve with relevant training. Several studies have demonstrated that SPT, and, in general spatial skills are highly malleable, training is effective, durable and transferable (Mulligan, 2015; Uttal et al., 2013).

### 2.2 SPT and STEM

There is an extensive body of research that has accumulated over the past twenty years, which consistently shows a strong correlation between spatial reasoning and success in mathematics and science (Sinclair & Bruce, 2015). Newcombe (2010) reports several different longitudinal studies that started back in the fifties and followed the development of a large number of American children from nursery school to adulthood. These studies have shown that there is a strong correlation between spatial reasoning skills and results in STEM areas. Furthermore, having good spatial skills increases the probability to undertake STEM related jobs.
Several studies have shown that spatial skills can be improved with practice and are retained to have long-term effects on student learning (Carlise et al., 2015); research has shown that spatial training may be enough to significantly ''boost'' achievement in STEM disciplines at university level by helping students persist in early challenging course work (Uttal and Cohen, 2012). Also at an earlier age, enhancing children spatial skills can contribute to improving their mathematical skills (Newcombe, 2010).
Spatial capabilities of young children continue to receive inadequate attention in formal education, while the ability to manipulate quickly and efficiently spatial properties of objects and the spatial relations among them is a key skill in today's world. There is a worldwide need to encourage STEM studies to meet market requests and some individuals are harmed in their progression in mathematics due to lack of attention to spatial skills. Moreover, as Mulligan (2015) notices, interfaces are becoming less and less alphanumeric and more visuo-spatial, requiring people to be proficient in spatial management.

### 2.3 Virtual Reality and Spatial Immersion

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, spatial immersion refers to the feeling of being actually there, physically present in a non-real world. This perception is usually generated by surrounding the player with images, sounds and, sometimes, other perceptual stimuli that are perceived by the player as if they were genuine, making him feel as if the surrounding world was real.

When the brain recognizes the virtual world as authentic, learning transfer to real life becomes easier (Rose et al., 2000). Furthermore, in the virtual world the players can actually make the physical movements that are characteristic to the practiced abilities, supporting a kinaesthetic approach to learning.
Since SPT is an embodied skill, Immersive Virtual Reality (IVR) apparently offers a good environment to support its training and consolidation. Furthermore, an IVR game would also keep the players' interest high thus providing the conditions for a good performance. On the other hand, IVR can cause sickness to some players, and the use of a Head Mounted Display (HMD) isolates the player from the surrounding real world.

## 3. "In Your Eyes", a game to support the SPT skill

"In Your Eyes" takes place in a virtual living room (see Figure 1) where there is a table with some objects on it. On the wall, four screens show the table from the four sides, the coloured frames are used to identify them easily. In the room, an avatar (either a man or a woman) welcomes the players and helps them along the whole game. The goal is to train the players to recognize the screen that shows the table from avatar's perspective. The game is organized on five different levels that gradually move from the players' point of view to the avatar's. The gradual shift from the egocentric point of view to taking the other person's position is designed to support the learners to develop the abilities that are at the core of the playing activity (Bottino et al., 2009). Several scenes can be played at each level; each scene is automatically generated by placing randomly on the table a definite number of objects chosen from a pre-defined set. The players get points for each correct answer and, as the score reaches a threshold tailored to each single player's needs, the game goes to the following level.


**Figure 1:** The virtual living room of the "In Your Eyes" game

At any moment, the players are free to move, they can go beside the avatar to check what the table looks like from there. This allows them to decide autonomously how much help they need, nevertheless, the number of points given is decreased at every movement out of the play position. In this manner, as scaffolding theories state (Bottino et al., 2013), the players are provided with all the support they need to solve a problem that may be a little beyond their capabilities without any help. As their skills improve, the quantity of help they will ask will diminish up to the moment when they will be able to play autonomously.
At each mistake, the wrong answer is blackened and a brief hint is given. When the players cannot find the right answer, after the third error they have the possibility to move around the table and compare what they see with the correct image in the screens. They can take as much time as needed before continuing the game.
The number of objects on the table, as well as their positions and rotation, can be configured individually for each player and for each game level. A default configuration is given with 10 different levels, but it can be changed to match better the player's needs and capabilities.
Special attention has been paid to the instructions given to the players. It is possible to solve the given task in two different ways involving different skills: by imagining moving to the avatar's position and reconstructing the scene from there (SPT), or by imagining to turn the table around until the side where the avatar sits gets in front of us (object rotation). The two skills are different (Inagaki et al., 2002) and performance can vary a lot in the same person. Inagaki and his group have demonstrated through their experiment that just by giving different instructions it is possible to stimulate the subject to use one skill or the other with the same experimental setting. In order to promote the use the SPT skill, the avatar sits at the table looking at the

objects, offering the players a model to identify with, and tells them “imagine you are by my side and tell me what the table looks like from here”.
In a second part of the game, the players in the play position are given a picture of the room. They then have to move to the place where the picture has been taken. Again, each correct answer gives the players points and, hints are given at each error to help the players find the correct position. The avatar is always present and, when the players do not find the correct answer, he shows them the solution.
The game was originally developed as part of the Smart Angel project (Smart Angel, 2014). The goal of the project was to promote independent living and mobility in town for young adults with mild intellectual disabilities. Among the tools developed within the project, there was a set of games, including “In Your Eyes”, promoting the development of some basic abilities, needed for autonomous mobility. After the end of the original project, “In Your Eyes” has been refined and enriched with some new tasks.
“In Your Eyes” was developed in Unity 3D with Oculus Rift (Oculus VR, 2015). Unity 3D offers an easy way to implement Virtual Reality, and manages well 3D objects, allowing for good quality rendering. Oculus Rift, in its DK2 version was a good HMD, with an accessible price and easily connectable with Unity 3D. Since some users may have sickness issues while using a HMD, we decided to develop “In Your Eyes” so that it could also be played directly on the computer screen, without the headset.
A third, simplified version of the game was later developed for another project as a collective training tool for groups of people at the first stages of Alzheimer. In this version, the players have a fixed view of the room as if through a window, they can see all the important objects and the avatar, but without the possibility to move around.

## 4. The “A me gli occhi” Project

There appears not to be enough attention to the development of spatial reasoning skills in formal education. Since these skills get better with training, a specific project has been organized with the aim of supporting the acquisition and consolidation of the SPT skill in children at primary school level.

### 4.1 Research Method

The project has been divided into two phases: the first identified the best immersion level needed to maximise the players’ performance, taking into consideration usability issues, and the second will measure the actual impact of a game based training on results in STEM subjects. An experimental research with a between group design has been organized for phase one. In phase two, an experimental and a control group will be defined and a standardized math test will be used to assess children abilities before and after the training. The project is ongoing now; the first part has been completed while the second part is planned for the next school year.

### 4.2 Ethic Issues

The project has been organized with a local Italian school as part of their didactic activities. All the families have been informed with a written description of the project and the tools (Oculus Rift in particular), as well as the possible risks for the children health and links to allow them to get further information. A meeting has then been organized where parents had the possibility to try the game with the HMD and a researcher answered their questions. Only children whose families signed the informed consent participated to the project.
Play sessions were shorter than 10 minutes and before wearing Oculus Rift, the researcher informed the children that they could take the headset off at the first signs of sickness. Three players stopped the game before the end due to sickness (8.33% of players).

### 4.3 Phase 1: Assessing the impact of the immersion level in the game

The first aim of phase 1 experiment (Freina and Bottino, 2016) was to see if the different levels of immersion had an impact on performance and, consequently, which version of the software would be best suited for the following training.
Three versions of the software with different levels of spatial immersion are available:

- Complete immersion: using a HMD, the players feel as if they actually were inside the living room where they can move around freely.
- Semi-immersion: the players can still move freely, but they see the living room on a computer screen, they are not surrounded by the virtual 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 through a window.

A pool of 101 children from a local primary school in Genova (Italy) have been involved. They were from two grade 4 classes (aged 9-10) and four grade 3 classes (aged 8-9). Since men are statistically better in spatial tasks (Kaiser et al., 2008), the participants have been divided into balanced groups with respect to sex, age, and the results of a paper based pre-test similar to Frick's (Frick et al., 2014). Two groups had 33 participants. The third group, with 34 participants, was assigned to the immersive condition (using the HMD). Three players in this group stopped before the end of the session due to sickness, leaving 31 participants.

A preliminary analysis of the results shows that there is no significant difference with respect to the final score and the number of errors between the three versions of the game. The percentage of scenes where no error occurred ranges from 42.97% of the semi immersive game to 45.40% of the non-immersive one. Interestingly, in the non-immersive version the number of questions that get the correct answer without any error is higher than in the other cases. This may be because there are fewer distractions for the players.

Since the completely immersive game and the semi-immersive one offer the possibility to move behind the avatar to see what the table looks like, there are more participants with a higher score in these versions compared to the non-immersive one. In Figure 2, the graph shows the percentage of players for each score range. While for the immersive and the semi-immersive games, the highest percentage is in the range 70-89, in the case of the non-immersive game the maximum is in the 50-69 range.

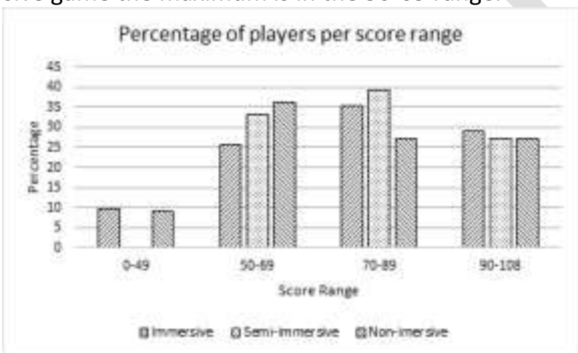


**Figure 2:** Percentage of players per score range. The maximum score is 108: 9 points for each of the 12 scenes.

Due to these results, it has been decided to use the semi-immersive version for the phase two training sessions. The immersive game gives similar results, with an even higher percentage in the top score range, but it has some drawbacks:

- Some players cannot use the HMD due to health or sickness issues;
- While playing, the HMD isolates the players from the real world, making it difficult to share observations or have group discussion during the game;
- The larger numbers of computers available in the school compared to the very limited number of HMD devices allows several players to play individually at the same time.

Another important outcome of phase 1 is related to the pre-test used to create the balanced groups. A significant number of participants did not understand the task when the paper-based test was given to them. As Bernstein (2013) states, there is a natural tendency to choose the egocentric point of view: regardless of the question, the participant selects the picture showing his/her own view of the scene. In out pre-test, this attitude could not be immediately corrected and some participants answered all the questions in an egocentric manner. When dealing with the game, the egocentric error was spotted and the participants were forced to correct their choice. As figure 3 shows, only 30% of the participants had equal performance between the pre-test and the game, while more than 62% had a better performance in the game compared to the pre-test. 5% of these went from a very low score in the pre-test to top score in the game.

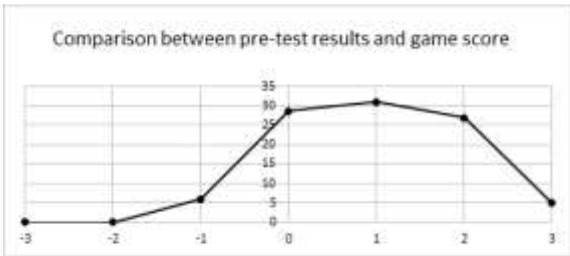


**Figure 3:** Performance in the pre-test and game score. In the positive area of the graph, game scores are higher than pre-test scores, while in the negative the opposite is true. Scores have been categorized into four ranges, and the graph shows the difference between the pre-test score range and the game one.

Due to these findings, a different pre-test has been organized to assess the initial abilities of participants with respect to the SPT ability. Using the same pictures, a computer-based test was developed and immediate feedback is given at each mistake allowing for a second choice. This allows those who did not understand the task to correct themselves and avoid a sequence of egocentric errors.

## 4.4 Phase 1: Assessing the chosen age group

Meyer's experiment (Meyer et al., 2010) shows that starting from grade 3 (8 year olds) the visuo-spatial representations in the working memory play an increasingly important role in predicting mathematical reasoning and numerical operations skills, while it is not so for younger children. For this reason, we believed that grade 3 would be just the right moment to consolidate and potentiate spatial reasoning, as well as exercising the visuo-spatial working memory.
Results from phase 1 support this choice. By dividing the participants into groups according to the score in the game (see figure 4), regardless of the game version, more than half scored in the middle ranges (from 50 to 89). About 32% reached the top scores, demonstrating a well-developed SPT skill, while a low percentage (6.26%) seems to be far from being able to apply the skill. As a conclusion, children of the chosen age in average have some SPT skills to be able to play the game, and many would take advantage from a specific training to potentiate the skill.

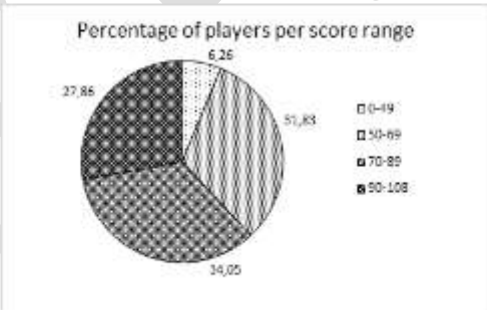


**Figure 4**: Percentage of players per score range.

## 4.5 Phase 2: The tournament

The second part of the experiment, which will take place in the next school year, will be based on a specific training of the SPT skill. The underlying idea is that by practising the SPT skill, the spatial reasoning abilities will improve and this will have a positive impact on the student's school performances in STEM related subjects, focusing on mathematics.
At the beginning of the experiment, all the participants from the grade 3 classes of the local public school will answer the previously described computer based pre-test for the SPT ability. Teams will then be defined as balanced as possible with respect to age, sex and pre-test results.
Before the tournament, the teams will meet to "heat up", try the game individually and discuss strategies used to solve the task. These meetings will be supervised and peer-to-peer teaching will be stimulated by pushing the stronger members of the team to help the weakest.

The tournament will then follow, during which each member of the teams will play individually at least three different times. At the end of the tournament, prices will be given to all participants; their learning will be celebrated regardless of their position in the final placement.
A standardized test to measure children's mathematic abilities will be used at the beginning of the project and at the end, including a control group who will not play with the game. Results from the test will be correlated with game scores and improvement will be measured and compared with that of the control group.

### 4.6 Expected Results

We expect that the increase in performance of the group of children participating to the training in the final mathematic standardized test will be in average higher than that of the control group. According to literature, those children who are weaker in spatial reasoning at the beginning should improve more that those who are already top performers, but also these should have some advantages from the training sessions.

## 5. Conclusions

There is a strong correlation between a person's ability in spatial reasoning and school results in STEM subjects, as well as the probability of a future job in STEM related areas. SPT is one of the components of spatial reasoning, it is, therefore, interesting to evaluate if developing the specific skill in primary school children will reflect upon their results in mathematic. The present paper describes an ongoing project aiming at such an intervention in a local Italian school.
Mathematic and, in general, STEM related subjects, need special attention since the European Community and OECSE report shortage of experts in STEM disciplines and they forecast a significant number of job openings in such areas in the next years. Early intervention is needed in order to promote interest towards scientific subjects from an early age.
In literature, several papers report a close correlation between spatial reasoning and performance in STEM subjects, furthermore, spatial skills appear to be augmentable, with long lasting results and a positive impact on school performance.
The present paper describes a wide ongoing project aiming at promoting spatial reasoning in 8-9 year olds. Phase one of the project has assessed the optimal level of immersion for the game to be used and the best target age group to be addressed. Phase two is planned in the next school year, lasting several months during which a game specifically developed to support the SPT skill will be used in a tournament. At the end of the project, participants' improvements will be compared to those of a control group. We expect that children who will have trained their spatial reasoning abilities will show a higher improvement in their mathematic results.

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