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PhD Thesis

Virtual Worlds for education:
methodology, interaction and evaluation

Stefania Cuccurullo

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Chair:
Patrizia Longobardi

Supervisor:
Genny Tortora

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The life of every man is a fairy tale written by the hand of God.

(H. C. Andersen)

My family, but especially to my princesses ...
are my fairy tale.

Abstract

When students arrive in the classroom they expect to be involved in immersive, fun and challenging learning experiences. There is a high risk that they become quickly bored by the traditional instructional methods. The technological evolution offers a great variety of sophisticated interactive devices and applications that can be combined with innovative learning approaches to enhance study efficiency during the learning process.

3D immersive multi-user Virtual Worlds (VWs) are increasingly becoming popular and accessible to wide public due to the advances in computational power graphics and network bandwidth also connected with reduced costs. As a consequence, it is possible to offer more engaging user experiences. This is particularly true in the learning sector, where an increasing interest is worldwide rising towards three-dimensional (3D) VWs and new interaction modalities to which young digital native people are accustomed to. Researches on the educational value of VWs have revealed their potential as learning platforms. However, further studies are always needed in order to assess their effectiveness, satisfactorily and social engagement not only in the general didactic use of the environment, but also for each specific learning subjects, activities and modality. The main challenge is to well exploit VW features and determine learning approaches and interaction modalities in which the didactic actions present added value with respect to traditional education. Indeed, educational VW activities are evolving from the early ones based only on information displaying towards simulated laboratories and new interaction modalities.

The main objective of this thesis is to propose new learning methodologies in Virtual Worlds, also experimenting new interaction modalities and evaluating the effectiveness of the support provided.

To this aim we first investigate how effectively a 3D city-building game supports the learning of the waste disposal practice and promotes behavior change. The game is one of the results of a research project funded by Regione Campania and is addressed to primary school children. A deep analysis of the didactic methodologies adopted worldwide has been performed to propose a reputation-based learning approach based on collaborative, competitive and individual activities. Also, the effectiveness of the proposed approach has been evaluated.

The didactic opportunities offered by VWs when considering new interaction approaches are also investigated. Indeed, if for the last four decades keyboard and mouse have been the primary means for interacting with computers, recently, the availability of greater processing power, wider memories, cameras, and sensors make it possible to introduce new interaction modalities in commonly used software. Gestural interfaces offer new interaction modalities that the primary school children known well and may result accepted also for higher students. To assess the potentiality of this new interaction approach during learning activities we selected Geography as subject, since there is a decreasing interest of the students towards this topic. To this aim the GeoFly system supporting the Geography learning based on a Virtual Globe and on the interaction modalities offered by Microsoft Kinect has been developed. GeoFly is designed for elementary school level Geography students. It enables the exploration of the World by flying, adopting the bird (or aeroplane) metaphor. It also enables the teacher to create learning trips by associating to specific places images, text and videos, to develop learning activities concerning geographically situated scenarios. The proposed approach has been evaluated through a controlled experiment aiming at assessing the effect of the adoption of GeoFly on both the students' attitude towards learning Geography and also on their knowledge.

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"Sappiamo bene che ciò che facciamo non è che una goccia nell'oceano. Ma se questa goccia non ci fosse, all'oceano mancherebbe." (Madre Teresa di Calcutta)

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Chapter 1: Introduction

1.1 Research context and motivation

In the last two decades many things changed in the areas of communication and networking. The new paradigms introduced by web 2.0 shift the IT users from a simply "reader" role to an active and "author" one. These changes significantly influence today's students that already exhibit characteristics of "digital native" [100] that are very different from the ones of twenty years ago: the student 2.0 go to class equipped by smartphones, laptop and iPads and expect a multimedial, involving and creative didactic practice.

Different trends are emerging in this era of computing and communications. The web has evolved from a medium for publishing information to a medium for building massive online communities around all conceivable spheres of interest. According to this new scenario, the web has become the infrastructure for business collaboration and the associated technologies are driving significant changes in other institutions like government and education. Based on this development, parts of education and teaching switched from the real world into Virtual Worlds to use the innovations and new opportunities for improving the level of teaching and learning. Considering the actual e-learning scenarios embedded in a fully technological enabled environment it is crucial to take advantage of this kind of capabilities to let learning process gain best results. Online degree programs and distance learning are commonly available in daily routine of universities. Thus, e-learning, for the delivery of educational content, has rapidly become mainstream, creating wider access to education, new markets for content and new revenue opportunities for academic institutions. According to the constructivists learning theories of Vygotsky [99][78], learning approaches should encourage students providing active

learning experiences, cooperation, and collaboration. Virtual environments, with their ubiquitous and social nature, let these aspects become possible.

Even if there are still persons convinced that learning only takes place at school, educators have to recognize that schools are just part of a broader learning ecosystem. In general, the question about where and when students learn should be answered with one line: anywhere at anytime. The new didactic paradigms free the learning activities that are no longer limited by a building with its walls.

Virtual World learning experiences are fun: learning activities can be held on the beach, in another country, in outer space, or in any simulated setting. Students do not need to be confined into a traditional class setting, with chairs facing forward. On the contrary, they can move within the learning environment, communicate via text or voice, offer information or ask questions whenever they like and correspond with classmates and friends via private messaging. However, Virtual Worlds are not only a fun place for alternative didactic activities, since they provide new ways to study, discuss, create, and express the course subject under the supervision and support of the instructor. Virtual environments offer stimulating, creative landscapes and, when the didactic setting is populated with the right mix of content and discovery, students remain long after class ends.

As the web 2.0 has changed the way of studying, also the traditional interaction techniques designed for desktop scenarios are facing great challenges related to "technology power users" [41]. The different scenarios and requirements of innovative Human-Computer Interaction (HCI) need novel, gesture-based and multimodal interaction techniques. By "gesture" we mean any intentional human movement that conveys meaningful information for interaction. People use gestures in everyday life to facilitate communications, to command other people, and to control

physical tools. A computer that can perceive and respond to the user's gestures could provide an intuitive interface. On the other hand, computing devices became increasingly accessible for various people. The different intellectual and physical capabilities of potential users (e.g. seniors, children or people with disabilities) require human-computer interfaces that are easily learnable and usable in different circumstances, instead of traditional interaction devices such as the mouse and the keyboard, which require a certain kind of skills, and restrict the physical posture of the user. The gesture-based interaction modality should overcome these constraints, since gestures are one of the most common skills of people. In addition, since 3D information becomes graphic and realistic, traditional input devices designed for operating on text and 2D content become inconvenient and cumbersome. Gesture-based interaction may provide a way of direct hand-on control of high-dimensional information by exploiting human interaction skills related to the physical world. Consequently, the adoption of gesture-based interaction to support learning in Virtual Worlds is going to be an increasingly interesting research topic.

1.2 Research problem and question

"To utilize VWs as a simple tool is like using a boat without paddles on the sea". Nelson [76]

The potential of e-Learning to support individual learning processes and life-long-learning is well known. Nowadays, the issue is to find pedagogical concepts and application domains that fully exploit this potential. This requires high quality structured information and a modification of the traditional teacher and student roles into the roles of assistant and knowledge seeker, respectively.

A major question in using VWs in education is finding appropriate value-added educational applications. In this thesis two challenges have been identified. First, determining situations in

which learning in VWs presents added value that goes beyond what traditional education these settings can provide. Second, verifying the effectiveness of the adoption of gesture-based interface for supporting learning. As a consequence, it appears natural to exploit this feeling for amplifying the perceived quality of individual didactic experiences and to verify whether the VW setting influences user perceptions.

At this aim, the following research question has been formulated (and evaluated):

RQ *Do Virtual Worlds satisfactorily and effectively support learning activities?*

In particular, we refer to the environmental education domain, considering the need of enforcing Environmental Education at worldwide level according to what asserted in Tbilisi Intergovernmental Conference on Environmental Education (1977):

"The main objectives of such an education program should build awareness of ecological issues, increase the sensitivity to these matters, and developing values and attitudes which motivate action and change"

According to Worldwide, EU and national direction there is the need of involving the youngest citizens, also proposing an **Edutainment approach.** To this aim we investigated *how to induct a responsible environmental behavior*. In particular, we adopted city-building games based on Virtual Worlds to enhance children environmental knowledge and behavior. Thus, the previous RQ has been split in two more specific ones, one for the city-building didactic setting and one on the gestural interfaces proposed.

RQ₁ *Do city-building games based on Virtual Worlds effectively supports learning?*

RQ₂ *Are gestural interfaces an effective interaction modality to support to Learning activities in Virtual Worlds?*

RQ_2, has been introduced since there is a high risk that children become quickly bored by the traditional instructional methods. Indeed, at school students expect to be involved in immersive, fun and challenging learning experiences. Thus, there is the need of taking into account the development of new habits of young people with digital technology, specifically w.r.t. gesture interfaces and Virtual Worlds. In particular, there is a decreasing interest of the students towards Geography [77]. Thus, we specialized the RQ_2 for investigating this direction in the Geography learning application domain.

1.3 Research contribution

This section presents the research contributions of this thesis derived from the analysis of the research question defined above.

RQ$_1$ has been formulated to verify the potentiality of Virtual Worlds for supporting individual and collaborative learning activities. In particular, we propose and evaluate a 3D Virtual World serious game named Pappi World [46], designed according to pedagogical theories and to the Italian Environmental Ministry guidelines. This game aims at helping children to learn how to dispose waste and to understand that waste can become a relevant resource when correctly managed. The game proposes individual and collaborative activities and exploits the city evolution mechanism proper of city-building games to involve the students. In particular, we evaluate *Pappi World* 1) considering the learning efficacy and the student perceptions and 2) collecting the teachers opinions related to the game usability, fun, engagement, mechanism and metaphor adequateness as well as expected learning outcomes.

RQ₂: we propose and evaluate innovative learning activities by combining sophisticated interactive devices and applications with innovative learning approaches to enhance study efficiency during learning process. In particular, we assess the effectiveness of the adoption of gesture-based interfaces for interacting with Virtual Worlds. To this aim, we present the GeoFly system for supporting the Geography learning based on a Virtual Globe and on the interaction modalities offered by Microsoft Kinect [98]. The system is designed for primary school level Geography students that explore the World by flying. GeoFly adopts the bird (or airplane) metaphor and customizes on it the gestures associated to the various commands (go up, down, turn left, right and stop). It also enables the teacher to develop learning activities concerning geographically situated scenarios by associating images, text and videos to specific places. GeoFly has been evaluated through a controlled experiment aiming at assessing the effect of GeoFly on both the participants' knowledge and their attitude towards learning Geography.

1.4 Thesis organization

This thesis is composed of 5 chapters, including this one. The rest of this thesis is organized as follows: Chapter 2 discusses the state-of-art concerning Virtual Worlds and their application to Education field. Also Learning experiences exploiting Gestural Interfaces are discussed. Chapter 3 and 4 answer to the research questions **RQ₁** and **RQ₂** by presenting and evaluating the learning approaches offered by Pappi World and GeoFly, respectively. Finally, Chapter 5 gives conclusion remarks and directions for future work.

Chapter 2: State-of-the-Art

This chapter introduces the most important concepts of this thesis. The discussion begins with an overview of Virtual Worlds and their adoption for supporting education. We then concentrate on the state-of-the-art concerning the adoption of gesture-based interface for supporting learning.

2.1 Virtual Worlds and Education

This section gives an overview of Virtual environments and Virtual Worlds in general, and of previous work related to their application in the educational field. By starting with defining these terms and their differences, the origins and developments of Virtual Worlds and Virtual environments will be covered.

2.1.1 Virtual environment

There are many definitions for the expression "Virtual environment". Some authors are very restrictive, defining Virtual environments as "three-dimensional, multi-sensorial, immersive, real time and interactive simulations of a space that can be experienced by users via three-dimensional input and output devices." [8]

Schroeder [17] described a Virtual environment as "a computer generated display that allows or compels the user (or users) to have a sense of being present in an environment other than the one they are actually in, and to interact with that environment." In short, a more abstract definition can be provided by using the phrase "being there". In [15] the author expanded his idea of Virtual environments with an additional term and used the phrase "being there together",

for a multi-user, collaborative, shared environment where users are present at the same time in the environment, interacting with other participants.

The sense of being there together may also occur in reading a book or dreaming or other similar phenomena. Just the feeling of being at a different place with others is not the only requirement for calling something a Virtual environment. Schroeder [16] wrote that his definition "focuses on sensory experience. If the sensory element of experiencing a place or space other than the one you are physically in, or of experiencing other people as being there with you, is taken away, then anything goes and definitions become meaningless".

In [16] the author defined Virtual Worlds as a persistent Virtual environment "in which people experience others as being there with them - and where they can interact with them". Thus the difference between Virtual environments and Virtual Worlds is that "the latter term has been applied to persistent online social spaces; that is, Virtual environments where the people experience as ongoing over time and that have large populations socially interacting as in a real world". Steinkuehler & Williams [18] expanded the concept of a social interaction: Virtual Worlds can therefore be distinguished from online gaming and massively multiplayer online role-playing games (MMORPGs) in that "they are third spaces, online places for socializing".

Altogether there are three aspects defining Virtual Worlds:

- being present
- persistence
- social interaction

Castronova [2] made a summary about the features of a Virtual World: it is a computer program with three aspects: physicality, persistence and interactivity. Prentice [12] put one additional point on his list of essential elements of a Virtual World. The interaction with others

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in the world implicates "the representation of our online persona via an avatar". These four aspects are explained in more detail in the following.

Physicality

People access the program through an interface that simulates a first-person's physical environment on their computer screen. The environment is generally ruled by the same natural laws like on Earth and is characterized by scarcity of resources. Therefore a chat room "would not be a Virtual World because it has no physics." [1] It can only be a part of a Virtual World used as another communication channel similar like voice or video.

Persistence

The program has to have at least an option to continue running no matter if anyone is using it or not. It remembers the location of people and things as well as the ownership of objects. Therefore the Virtual World is running separately but in real time parallel to the real world. As one can see in Second Life[1] a person in the real world co-exists with the persona in the Virtual World which represents the real person.

According to this, a first-person shooter is not persistent. [1] The character of the user who will play this game will not 'live' all over the time. The persona will only exist level by level and game by game.

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[1] Official website of Second Life - http://www.secondlife.com

Interactivity

A Virtual world may exist or be managed on one computer system but can be accessed remotely (i.e. by an internet connection) and simultaneously by a large number of people, with the command inputs of one person affecting the command results of other people. Therefore the interaction with the world takes place in real time. [12] Every action one does "in-world" (a term that Bruce Damer coined in 1995 to describe the act of being, "in a world") Damer [5] gives a response to other people. Interactivity is one main aspect for using Virtual Worlds for collaboration, education and training of social skills.

Representation

The only possibility of displaying the first-person-view on the computer screen of each user is still not sufficient, but it rather has to be possible to distinguish each user from another by his custom avatar.

Avatars were first introduced in 1985 to describe users' visual embodiment in cyberspace that is to say in the Virtual World "Habitat". Originally the term avatar came from Hindu mythology and is the name for the temporary body which a god inhabits while visiting Earth. Other synonyms for Avatars are: characters, players, Virtual actors, icons or Virtual humans.[4]

In reality the body language of a human is very important for getting more information about ones feelings. If one sees a person talking about something but does not hear anything, he or she can still guess if this person is talking about something positive or negative and if the person is happy or sad. As a result if one gets in contact with this person he or she has some information about the well-being in advance and is able to react on that. The body language also intensifies the spoken language and makes the communication more expressive.

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To provide such information in Virtual space avatars are needed. In times of social worlds and increasing computer and graphical performance, avatars got more and more realistic. Now they are able to express themselves through their body language like making gestures or by their facial expressions. Perlin [11] described a set of tools and techniques developed at the New York University in the late 1990s. He also pointed out the importance "to create applications involving animated agents that behave, interact and respond to user in ways that convey mood and emotion".

2.1.2 Virtual World application domain

Steve Prentice, the vice president of Gartner, Inc, [12] addressed the issue of the purpose of Virtual Worlds and their target markets. "Virtual Worlds encompass a wide range of environments, for distinctly different purposes". They includes:

Consumer focused Virtual Worlds : they enable to reach a wide number of people, specifically youngest.

Education focused Virtual Worlds: they are very versatile. Indeed they can support a wide range of learning approaches, ranging from simulating realistic environments for training, role playing and scenario playing, Typical examples include military exercises, emergency services and disaster scenarios. [12] The advantages are low costs, safety and the ability to repeat scenarios again and again. It is easy to play different roles and scenarios by creating a manifold of episodes and adapt them to particular situations [10]. As a consequence, many teaching organizations adopts Virtual environments for supporting distance learning. In his report, Steve Prentice agreed that "Virtual Worlds are increasingly being used for teaching at all education levels from primary through to tertiary level education and beyond". [12]

Enterprise focused Virtual Worlds: a wide range of well known global brands established a Virtual subsidiary in Second Life. A growing number of organizations either formally closed their subsidiaries, significantly downgraded their involvement or simply abandoned the environment – leading to the 'ghost town' syndrome of commercial presences with nobody around". [12]

"As a result, enterprise involvement in Virtual Worlds has declined significantly" in 2007, Prentice continued, "enterprises seek safety in proven solutions and well established channels of communications".

Enterprises Virtual environments can be adopted for training the employees by considering the scenario based role playing which is largely adopted in the business world and the public sector. In this way risks are calculable (military training and emergency evacuations), low costs (civil defense scenarios) and complex environments "where the outcomes are non-trivial (such as disaster of famine relief) or take a long time to play through (such as aid programs). Virtual Worlds can also be exploited to hold Virtual meetings, since big companies have employees scattered throughout the whole world.

2.1.3 Teaching and learning

Wendy Shapiro and Lev Gonick [13] pointed out that within the last two decades many things changed in the areas of communication and networking. These changes influence today's students in a significant way. Today's students are very different from twenty years ago students [7]. While a notebook and pen may have formed the tool kit of prior generations, today's students come to class armed with smart phones, laptop and iPods.

"The web has evolved from a medium for publishing information to a medium for building massive online communities around all conceivable spheres of interest. The web has become the infrastructure for business collaboration and increasing collaboration technologies are driving significant changes in other institutions like government and education". [13]

Based on this development, parts of education and teaching switched from the real world into Virtual Worlds to use the innovations and new opportunities for improved level of teaching and learning [6]. Encouraging students for active learning, cooperation, and collaboration are main aspects on how students should learn. With Virtual environments these aspects become possible. Some people think that learning – as people are aware of it – only takes place in school or at colleges. But even educators have to recognize that schools "are just part of a broader learning ecosystem. In the digital age, learning can and must become a daylong and lifelong experience". [9]

Cynthia M. Calongne, Professor of Computer Science at Colorado Technical University, taught nine university courses with the aid of Second Life as an educational classroom till fall 2008. From the experiences she gained during these courses, she came to the conclusion that "successful Virtual class experiences require a blend of technology, tools, content, student ownership, identity, engagement, course structure, risk management, mentoring, feedback, and a good orientation to using the tool" [3].

The focus should always be kept on the main goal which is to acquire new competencies and not to handle the avatar in-world. On the other hand, students should also obtain the perception that learning in a Virtual World is connected with fun. Classes may be held all over the world, while students can create content and commit their creative potential by using built-in tools. This way they can take on an active role which helps to enrich the class' experience in terms of social

networks, interaction and liveliness. When Virtual Worlds are populated with the right mix of content and discovery, students remain long after class ends". [3] VWs can also be used to set up experiences which help learners to understand phenomena not visible to the human eye and to relate them to the physical world. For instance, the Virtual Labs described by the authors of [14] allows a student to visualize using augmented reality techniques the magnetic and/or electric field lines around a small magnet.

2.1.4 Serious Virtual World

In the last decade, video games have become a pastime for the new generation youth. Developers have created a set of design principles that capture and persistently engage the participants, promoting learning. Many researchers have tried to understand how these principles can be used to make education more effective, in fact, games can be a useful and attractive learning method [30]. Great interest is, in particular, facing the Serious Game, programs that follow the principles of game development, but with the aim of forming as well as entertain. Serious games and Games-Based-Learning (GBL) are sometimes considered synonymous, even though the former have a wider objective of supporting training and behavior change not only in the education sector, but also in different areas, such as business, industry, healthcare and marketing [31]. One of the advantages of adopting GBL is that the game activities are near to the modern psychological and educational theories on effective learning [32]. Indeed, they suggest that the most effective learning is reached when the learning experience is active, experiential, situated, problem-based and provides immediate feedback [32]. The didactic model adopted in a game-based learning approach is a learner-centered model that puts the learner into a more active role, shifting from the learning-by listening to the learning-by-doing approach. In addition, the

game should appropriately embed feature knowledge and skill acquisition mechanisms that should be integrated in a meaningful and homogeneous way [33].

City-building games

City-building are games where the player is the leader of a city and is responsible for its growth and management. The first city game was The Sumer Game[2], presented in 1968 and based on keyboard input. Since then a lot of City Games have been proposed with different settings (i.e., historical, contemporaneous, fantastic, scientific)[3]. As an example, the Sims and SimCity games allow the users to play by creating and managing simulated communities and worlds, using an isometric representation. In particular, SimCity does not use individual game avatars as representations of the player and the environment is uninhabited.

Some investigators have even thought it was possible to develop GBL using existing games without the need to create new ones, for example, Yang [36] in her work, adopted a City-Building game for assessing the effectiveness of a Digital Game-Based-Learning approach for teaching daily economics. She assessed that GBL improves learner motivation and problem-solving skills, while no improvement was detected in academic achievement. Other examples of previous work on city building games proposed in literature are:

Math-City [34], providing a city-simulation environment in which students can build and maintain a city with residential, commercial, and industrial buildings, as well as renewable and non-renewable power sources. The game incorporates many elements of a real city, using a simplified interface designed to be intuitive for young students. As in real life, "city developers"

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[2] http://en.wikipedia.org/wiki/The Sumer Game
[3] http://en.wikipedia.org/wiki/Chronology of city-building video games

in the game need money to pay for buildings and resources, and a successful city should include roads, houses, places for people to work, and essential services such as police and fire departments and hospitals. All buildings in the city require energy to operate, so they must be connected to a power source (e.g., wind turbines, solar panels, or coal plants) by power lines.

The game begins with an empty grid on which the city can be built and a small amount of money available to start building the city. Throughout the game players can answer different mathematics questions to earn additional money. A toolbar that provides all the necessary construction items (e.g., different kinds of buildings, power sources, power lines, roads, etc.) and game information (e.g., money available) is available throughout the game (see Figure 1). Each item available for the city is associated with a specific cost and students need to have the necessary funds available to add an item to their city.

The main goal of the game is to create a city that maximizes the happiness of its residents. Currently, the game includes five happiness factors: Pollution, Police, Fire, Health, and Big Buildings. For example, when the pollution in the city is too high or when there is not enough police or fire or health coverage, the residents are not happy and they move out of the city. To assist students in reaching the goal of developing a city with happy residents, the game provides constant feedback through the city happiness indicators which are available on the game's main toolbar (see Figure 1).

In addition, the game exposes an Info button available which provides players with information on individual houses, such as the number of residents, the negative and positive factors affecting the happiness of those residents, and if applicable, a hint as to what actions the player can take to improve the happiness factors affecting the desirability of the house.

Differently from them, in Pappi World we add to the city-building mechanisms also social features (based on collaboration, competition and reputation).

Figure 1: A screen of Math-City

Recycle City [35], providing a web application for teaching environmental education through the presentation of educational concepts in this area. Students learn about recycling processes, how to reduce waste and use less energy. The website of Recycle City includes several parts of the city: Recycle, the game Dumptown, activities and resources. A map of the city encourages students to explore its four sections. Within each section of the city, students can click on various businesses and homes to learn about how the people who live and work there improve their local environment (see Figure 2)

Figure 2: Web Game Recycle City

In the game Dumptown, students assume the role of city manager. This section is shown first that the city seems to have no programs and sustainable practices. They visit the town hall to learn about ten programs (composting, recycling, and so on). The students select the program you would like to implement and then display how the program has improved their city.

The Activities section of the site includes ideas for teachers and students, an activity book, downloadable resources and tips to get involved in their community.

This game does not adopt social learning approaches. In addition the exploration is limited.

Social Virtual Worlds for supporting learning

A well designed game can effectively induct cognitive processes providing explicit and implicit information, stimulating deductive and inductive reasoning, proposing problem-solving situations requiring players to make deductions [37]. When the learning activity is embedded in an on-line Virtual World, these features are integrated with social interaction, presence and

awareness perception which can contribute to improve involvement and to maintain the learners interest over time [38][39]. The social dimension is a key factor for learning and for this reason the adoption of Massively Multiplayer Online Games (MMOGs) to support learning has been widely investigated. As an example, De Lucia et al. [41] experiment a Second Life setting for supporting synchronous direct instruction, while in [42] and in [40], [43] Second Life has been adopted to conduct Virtual lab experiences and collaborative activities, respectively.

Several research works have been addressed to the development and evaluation of social serious games in Virtual Worlds ([44] [45]). In the following we report the details of the main ones.

The Geoworlds Project. One way to quickly get a low-cost environment for collaborative learning experience can be found by adopting an existing Virtual World such as Second Life (SL) [47][48][49]. The interaction model proposed by SL are based on video games and metaphors typical of web communities. The Geoworlds Project (see Figure 3) consists of a set of "worlds" or more precisely of thematic areas set up on Second Life. In each area students receive information in different formats (text, sound, video) and can interact with pedagogical agents, designed to be guides to help in moving through the worlds. Each area is divided into several worlds (levels) linked together by portals. To activate a portal, students are asked to pass tests to assess the knowledge acquired. For example Terra World is one level of the Geoworlds. It is designed to learn information on the origin and evolution of the Earth. The learning metaconcepts include the geologic time scale and how it relates to the history of the earth, fossils and their documentation of the transitions of life. Using the fossil record and its journey through geologic time as the platform for one of the Geoworlds's Problem-based scenarios provides a

natural connection between: 1) what teachers must teach and test in high school earth science classrooms and 2) what many students have already been introduced to through their informal science experiences.
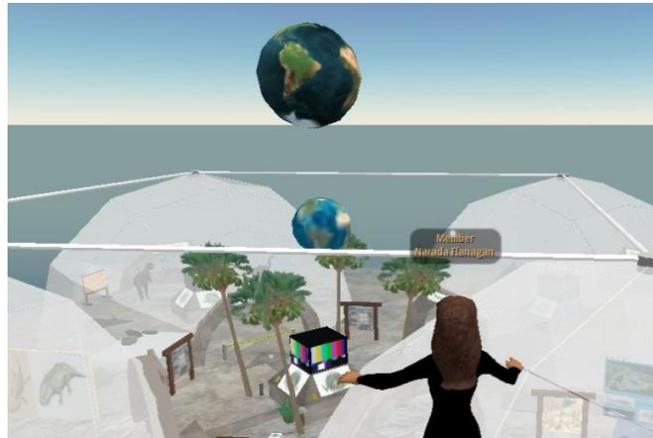
Figure 3: Geoworlds main area

SeaGame (see Figure 4) is a *3D immersive* game whose setting is the coastal area with lots of harbor, beach and different types of equipment (umbrellas, jet skis, boats moving, etc.) to educate young people to take correct behavior at sea, with respect to both of human life and the environment. SeaGame uses the graphics capabilities and simulation of typical video games to build learning experiences. Every experience can be done alone or shared with other people. The educational approach is a *collateral learning*, where the training content is learned in the same way you learn the "tricks" in video games, if the player breaks the rules, he does best in the game.

Figure 4: SeaGame

E-Junior is a serious Virtual World (SVW) that conforms to the Spanish natural science and environment curriculum as well as to specific pedagogical theories. The goal of E-Junior is to introduce students to the basic notions of natural science and ecology, and more particularly, to one of the ecosystem of the Mediterranean Sea: Posidonia oceanica. The Mediterranean Sea was chosen as a topic for the project because of its close geographical, social, and economical relationship to the Valencian community (Spain). The E-Junior was placed in L'Oceanogràfic of Valencia, Spain (one of the largest aquariums in Europe). Its purpose is to encourage active learning within a highly immersive and interactive environment. Since it is often difficult to organize a field trip to visit a Mediterranean Sea ecosystem due to high costs, safety, and organizational logistics, the objective of E-Junior was to easily transport children from a traditional room setting in the museum to an underwater environment without even getting their toes wet.

In E-Junior, children interact with the system collectively; four students participate together in all parts of the game. Each student is assigned a fish avatar that represents a different species of fish: Sea Bream, Mediterranean Rainbow Wrasse, Ornate Wrasse and Painted Comber. With these avatars, each student can explore, experience, and interact with the Virtual aquatic world (see Figure 5). To successfully complete each interactive-gaming part, the students must find and collect some elements in the aquatic Virtual World according to the rules previously established by the Virtual tutor, which is a fish that represents Brown Grouper specie. The Brown Grouper guides the students through the different stages of the game.

Figure 5: A fish avatar participating in the dynamics of the Posidonia oceanica ecosystem.

2.1.5 Virtual Globes and education

A specific type of Virtual Worlds are Virtual Globes, which can be considered as the digital version of traditional desk Globes adopted for learning Geography. They are a 3D model of the Earth or of another world showing spatial data at multiple scales and in different ways [79].

Virtual Globes enable the user to select what to display, spin the Globe around and zoom in and out between a full overview of the Globe down to detailed views of the user home. It is also possible to add a 3D rendering of a specific environment. Tilting the image allows the user to see the terrain in three dimensions. The coupling of three-dimensional models with the three-dimensional representation of the terrain enables the user to "fly" over the terrain with the perspective of the pilot, as it happens in flight simulator.

In addition, Virtual Globes are Web 2.0 applications. Indeed, they permit to share geolocalized information generated by the user.

Concerning the adoption of Virtual Globes to support learning activities in the classroom, in [79] Rakshit and Ogneva-Himmelberger detailed the differences among the most popular Virtual Globes, taking into account educational aspects. They considered them as a tool fun for learning Geography, but they do not performed any evaluation.

In [80] Virtual Field Trips to sites around the world were proposed to the students, adopting Maps, images and video clips in a variety of formats. The contents were accessed through a web site, map resources were developed using Adobe Flash. Preliminary results were encouraging in terms of students' engagement and learning outcomes.

2.2 Learning exploiting Gestural Interfaces

This section gives an overview on gestural human-computer interfaces, its high expandability with several accessories and the possibility of offering to users experiential games improved with active gestures and really playing metaphors and learning.

In the last years, the game console market has been a really competitive sector that was exploiting and often driving the development of state of the art processing and graphical technologies to compete on a really exigent customer population. Recently, the market trend has changed and has been mainly focused on realistic gestural human-computer interfaces than on computing performance or on graphical capabilities of the proposed products [72]. With Wii^{TM} console, Nintendo (2006) has proposed a game platform not particularly exciting in terms of performance but very sale [73]. Reasons for this success are the revolutionary characteristics of Wii control system, the Wiimote [71], its high expandability with several accessories and the possibility of offering to users experiential games improved with active gestures. The success of Nintendo Wii clearly states the influence of the associated novel gestural interfaces on user satisfaction. Following Nintendo, Sony and Microsoft, the other two competitors in the game console sector, were proposing their motion sensing game controllers for answering to the user need of playing in a natural manner. Their answers to the market demand have been the PlayStation Move^{TM} (2008) and, only in November 2010, the Kinect^{TM} controller. While Wiimote and PS Move offer two similar controlling experience to the users, limited by the need of holding the controllers with hands, Kinect represents the first consumer full body motion capture device simply based on an Infra Red emitter and two video cameras. However, thanks to motion detection, all these controllers let the gaming experience to be realistically based on gestures analogous to the mimicked ones.

Among the vast research work on multimodal interfaces, gesture-based interfaces are of particular interest [22][23]. Although the word "gesture" may have different interpretations in different scenarios, here we adopt a broad definition of the term, referring to any intended human movements that convey meaningful information for interaction. Freehand gestures, or bare-hand

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gestures, are probably the most straightforward interpretations when people think about gestures. Typically the freehand gestures are captured using computer vision techniques, i.e. cameras watching the user's movements [21][27][28]. However, the interpretation of the gestures is not related to the particular implements, but depends only on the movements of hands. Usually freehand gesture interaction systems make use of intuitive gestures and hand movements that are familiar in people's everyday life, especially those used to communicate between people.

Therefore the gesture interfaces are easy to learn and understand. There has been a lot of work on freehand gesture interaction that covers various applications. Freeman et al. [20] describe a system for controlling a television using freehand gestures tracked by a camera. To simplify the scenario and recognition algorithm, the user uses only one gesture which is an open hand facing the camera. A hand icon is displayed to follow the user's hand, and the user moves his/her hand to operate various graphical widgets with the hand icon. The interface is simple to use and easy to understand, but it does not breakthrough from the mouse/pointer metaphor, and does not make use of the rich information conveyed by human hands. Segen and Kumar [27][28] describe GestureVR, a VR system that uses vision tracking of a small set of hand gestures for spatial interaction. The user's index finger and thumb are tracked in 3D by a pair of cameras, and three simple gestures are defined to control spatial applications: a 3D graphical editor, a Virtual fly-through, a video game, and an articulated hand model. The system provides an intuitive interface for simple 3D applications, and the 3D information of human hands is fully exploited. But due to the difficulty of vision-tracking of human hands, the background and illumination are strictly specified, and the hand movements are restricted in the elevation angle of $\pm 40°$. Some other similar work has been done to exploit freehand gestures to interact with desktop displays or VR systems. And the robust tracking of full 3D information of hands remains a hard problem.

Freehand gestures are also used in desk/tabletop interaction systems. Sato et al. [24][25][26] introduce a set of applications, which use bare hand gestures to interact with an augmented desk system called EnhancedDesk. Infrared cameras are used to track the human hands in 2D, and visible-light cameras are used to capture the physical objects on the desk. Baudel and Braffort [19] describe an interaction model that allows the user to give a lecture by navigating through a set of slides with gestural commands. When interacting with intelligent appliances, gesture interaction makes more sense since standard computer input devices are usually unavailable. Starner et al. [29] describe a wearable device for control of home automation systems via hand gestures. The system is aimed to serve people with loss of vision, motor skills and mobility. It also analyzes the user's movements for pathological tremors. While interacting with computers through freehand gestures is appealing in many scenarios, another set of gesture interfaces uses physical implements to facilitate the interaction between the user and computing devices.

Before designing GeoFly, we experimented the gesture recognition features of Kinect as detailed in Cuccurullo *et al.* [81], where we presented an approach exploiting the availability of the Microsoft Kinect[TM] [88] advanced game controller to support a lecture in the control of a presentation software through a gesture-based interface. The approach adopts motion capture to recognize body gestures representing interaction metaphors. In particular, in this research we performed a preliminary evaluation aiming at assessing the degree of support provided by the proposed interaction approach to the speaker activities. The assessment was based on the combined usage of two techniques: a questionnaire-based survey and an empirical analysis. The context of this study was constituted of Bachelor and PhD students in Computer Science at the University of Salerno, and teachers and employees from the same university. The results were

adequate both in terms of satisfaction and performances, also when compared with a wireless mouse-based interaction approach.

The approach, named Kinect Presenter (KiP), consists in a PowerPoint controller exploiting Microsoft Kinect^{TM} as the only input device for the lecturer which interacts through hand and arm gestures. The system provides gesture commands to control the presentation, go to the next slide and go backwards during the talk.

The system tracks the body skeleton generated by Kinect and Maps it into the configured set of gestures representing the various commands that can act on the presentation. When a user position is similar to a predefined one, the corresponding command is enacted.

The interaction metaphors adopted to control the slide presenter has to be intuitive, but at the same time they have to prevent conflicts with the user movements. In addition, the gestures should be meaningful when managing a presentation. To this aim we consider the interaction modality offered by PowerPoint to manage a presentation and try to translate these commands in simple gestures. The command gestures proposed in this approach are depicted on Figure 6.

Figure 6: KiP command gestures.

To start a PowerPoint presentation in traditional modality the user clicks on the presentation button in the lower right part of the application screen. As shown in Figure 6(a), to start the presentation in KiP modality the speaker raises both the hands, forming a right angle with each arm. To go to the next slide, the PowerPoint user presses the right arrow. KiP does the same action when the user raises the right hand, forming a right angle also in this case, as shown in Figure 6(b). Similarly, to go to the previous slide the PowerPoint user presses the left arrow and the KiP user raises the left hand (Figure 6 (c)). Let us note that a natural speaking movement like the one shown in Figure 6 (d) is not recognized by the system as a command.

Yang *et al.* proposed the *PILE system* designed for supporting English learning by physically interacting with the environment [82]. The system integrates video-capture VR technology into a classroom environment. The PILE system (Figure 7) requires a minimal amount of equipments which includes a personal computer, a webcam, and a projector. The learning activities comprise six stages, holding specific tasks and learning objectives. Each stage is designed with a distinct device. These devices, including a conical cap, a pistol, a searchlight, a magnet, and a spray paint can, are designed to improve the accuracy of detection as well as to increase student enjoyment during the learning process. As an example, gestures are adopted to drag a picture towards its corresponding word, or for shooting a picture that represents the phrase proposed during a listening comprehension activity. Results of the evaluation showed that this approach effectively assists English learning in a classroom environment.

Figure 7: The experimental group using the PILE

Learning Math Using Gesture [83] (Figure 8) is an approach to interface 3D animation software and gesture recognition hardware to create an interactive learning environment. Math learning is supported by exploring a gesture controlled mathematical maze. The system models

and animates the environment by using Blender (an Open Source 3D animation tool), while Microsoft Kinect is adopted for capturing real time gestures of users.

Figure 8: Learning Math Using Gesture

The *SAMAL Model* (Smart Ambience for Affective Learning Model) [84] (Figure 9) adopted the Wiimote and the Nunchuk extension (an additional controller) for controlling the flight of a bird in a Hummingbird Flying Scenario of the Natural Science teaching. The model is based upon experiential theories and the use of the body moving within the Virtual reality space. SAMAL project investigates the application of immersive interactive media and Virtual reality as a tool in education to enhance learners' motivation to learn, and makes a bridge between affect, cognition and learning. The focus of project is the learning of the concepts of animal survival. Students may cognitively understand survival needs through traditional learning modes such as teacher prepared written material or watching a wildlife survival documentary. The SAMAL approach enables the student "to be" the considered animal, e.g. a bird, in the VR learning scenario, as he/she perceives oneself as that animal (full immersion).

Figure 9: SAMAL model

In [85] two systems, *King* (in Figure 10) and Wing, were proposed and compared on the idea of using gestural interfaces for simulating fly. In particular, the comparison proposed evaluates the adoption of a Wiimote controller versus a Kinect one when simulating a flight on Bing Maps. The evaluation sample was composed of undergraduate students and employees, assessing a user preference for Kinect.

Figure 10: The Kinect device controls Bing

Ling *et al.* in [86] proposed the idea of adopting wearable body sensors for improving Geography teaching combining them with Google Earth. Their work was mainly focused on the gesture recognition features. No evaluation has been performed, neither suggestions on the relationship of this approach with the Geography curriculum. They did not specify which are the target users neither provided suggestions on how integrating learning material with the Virtual Globe.

Boulos *et al.* based on Kinect their application, *Kinoogle* [74], where a gestural interface is adopted for controlling Google Earth navigation. The proposed gestures are mainly based on hand tracking and resemble the classic multi-touch interaction style. Differently from them, we propose a navigation control that is inspired to natural flight gestures and the user actions reflect on the map navigation according to the bird metaphor. In addition, we explore and evaluate the use of Geofly for supporting Geography learning.

2.2.1 Geography games for supporting learning

The integration of learning materials into games does not only require good script, production techniques, character design, environment modeling, but also knowledge management ability. Currently, there are many researches that try to integrate digital games in teaching of various subjects, such as math, biology, computer science and geography, and find that games can have better learning effects than traditional teaching, especially for subjects that are complicated.

Cheryl Arnett, teacher at Elementary School in Craig, Colorado, in *Disneyland Adventures*[4] introduced Kinect into her classroom (Figura 11).

Figura 11: Kinect in the Classroom

She observed that the use of Kinect has led improvements in comprehension and retention of what the students learn. At the end of the project, each group of first graders will have to agree together on how to spend their time in the Virtual Magic Kingdom. The adopted learning approach is collaborative.

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[4] http://www.microsoft.com/en-us/news/features/2012/mar12/03-06kinecteducation.aspx

Ola AHLQVIST in *Virtual Globe Games for Geographic Learning* [75] presented an experimental platform that integrates an existing Virtual Globe interface with added functionality to develop engaging learning activities around geographically situated scenarios in Figure 12. It does not exploit a gesture-based interface for interacting with the system.
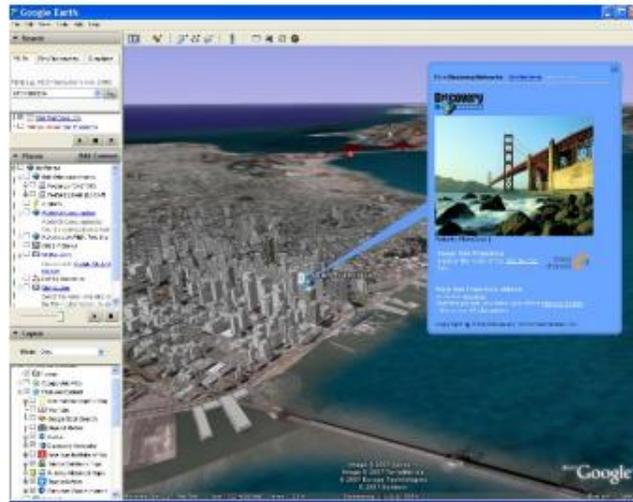
Figure 12: Google Earth applications

Chapter 3: a Virtual World for supporting environmental learning

The main research question to address in this thesis is RQ: *Do Virtual Worlds satisfactorily and effectively support learning activities?*

In this section we address RQ by investigating the specific aspects related to city-game based learning approaches by proposing the following sub-question:

RQ$_1$: Do city-building games based on Virtual Worlds effectively supports learning?

To this aim we propose and evaluate a learning approach based on a city building-game to promote environmental learning. The game is a 3D Virtual World serious game, named Pappi World, designed according to pedagogical theories and to the Italian Environmental Ministry guidelines. Pappi World aims at helping children to learn how to dispose waste and to understand that waste can become a relevant resource when correctly managed. The game proposes individual and collaborative activities and exploits the city evolution mechanism proper of city-building games to involve the students. Pappi World is also evaluated 1) considering the learning efficacy and the student perceptions and 2) collecting the teachers opinions related to the game usability, fun, engagement, mechanism and metaphor adequateness as well as expected learning outcomes.

3.1 Inducting an Environmental Responsible Behavior

Hines, Hungerford & Tomera (1987) define an Environmentally Responsible Behavior as the action and intention of a person to live in an ecologically sustainable manner. The main problem is to induct such a behavior in all the people. The Tbilisi Intergovernmental Conference on

Environmental Education[5] asserted that main objectives of such an education program should build awareness of ecological issues, increase the sensitivity to these matters, and developing values and attitudes which motivate action and change.

3.1.1 Behavior Change

Often government organizations deducted that low recycling rates were due to a lack of knowledge [50]. From this basic assumption, they distributed educational materials on recycling to increase recycling rates.

Generally, they focused on the transmission of *Procedural Knowledge*, i.e. knowledge about where, when, and how recycling. For example, a person knows that paper is collected on Friday and knows where the paper bin is, where he/she has to put his/her paper waste.

Another type of knowledge is the *Impact Knowledge*, which refers to individual beliefs about the advantages of recycling in terms of reduction of pollution and energy saving. A third type of knowledge is the *Normative Knowledge*, i.e. the knowledge about the behaviors of others. As in case of the evaluation, knowledge is often assessed by asking to identify the recyclable materials and evaluating the percentage of waste correctly classified. As discussed in [50], normative beliefs and recycling behavior are strictly related. Indeed, social pressure has a strong impact to recycle, i.e. the belief of a person that friends, family, or neighbors think he or she should recycle, and the perception that other people recycle.

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[5] http://www.cnr.uidaho.edu/css487/The Tbilisi Declaration.pdf

According to [50], a change in normative beliefs can cause a change in behavior. The problem is how to change normative beliefs. In this thesis follow the suggestions proposed in [50] by adopting the following strategies:

- *promoting block leader*, i.e a person particularly motivated, belonging to a small community, that recycles diligently and encourages his/her neighbors to recycle;

- *disseminating data on community recycling rates*, such as the percentage of people that recycle regularly for each community.

To get the best results it is important that an individual can directly compare his or her behavior with the provided information [50]. It is also worth making comparisons considering groups near to that person, such as the neighbors or the classmates, instead of the country or the city.

3.1.2 The Italian Environmental Education Guidelines

In Italy the environmental priority requires structural interventions that will be effective in the long period only if they are accompanied by modification of behaviors, orientations and beliefs, specially investing in the new generations. As suggested by the the Italian Environment Ministry[6], this objective can be pursued by deepening the understanding of environmental issues. To this aim cognitive activities providing the knowledge related to the environmental problems and of the factors that generate them should be complemented by activities that develop operational and relational skills. The latter activities lets the children become builders of their knowledge and aware of their behavior. Thus, besides the typical instruments of the formal education proposed to the students there is the need of giving a strong impetus to the informal

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[6]http://www.minambiente.it/export/sites/default/archivio/notizie/Linee_ guida_ ScuolaxAmbiente_ e_ Legalitx_ aggiornato.pdf

education to promote a constructive relationship with the physical environment and environmental awareness.

The didactic activities should be scheduled considering the context, i.e. the territory and the age of children. On this basis, each individual can develop an organic transition process from knowledge to environmental consciousness. The concept of sustainable development is therefore reflected in the fundamental concept of *sustainable city*. The city is the place where the largest amount of emissions waste and polluting materials is produced, and where, at the same time, the highest quantity of energy is consumed. The youngest have to learn how to ensure the sustainability within the city itself, without sacrificing the quality of life. A topic of critical urgency in our country is the reduction of waste. It is possible an intervention aimed at enhancing the sustainability only if each citizen activates appropriate modes of behavior, such as differentiation and recovery of materials.

The competencies specified by the Italian Environmental Education and Instruction Ministries include: understanding the concept of waste as a resource and the value of the differentiated collection, according to the practice of the three R's (Reuse, Recovery and Recycling). The educative process should include laboratory activities conducted considering real tasks, group work and cooperative work, also in a edutainment modality. The laboratory, through experimentation, play and research activities provides new knowledge, creating the basis for reflection and interiorization.

3.2 The TIE Project

The TIE project funded by Campania Region (Italy) aims at creating on-line learning activities related to environmental education for primary school children. It is designed to assist

school teachers in the education on sustainable waste management principles. In this way, the children can contribute to influence their families and the broader community in disposing waste correctly. Moreover, behaviors and skills acquired may have a long-lasting impact in later life. Thus, early childhood education has a relevant impact on the efforts for sustainable development.

The TIE educational program is based on the following Waste[7]:

- *Avoidance*, including actions to reduce the amount of generated waste;
- *Resource Recovery*, including reuse, reprocessing, recycling and energy recovery;
- *Disposal*, managing all options in the most environmentally responsible manner.

    The TIE project consisted in the development of:

1. multimedia lectures on all the three topics and the related self-assessment tests;
2. an on-line Virtual Reality serious game, named Pappi World, enforcing the acquisition of these concepts by involving the students in learning-by-doing activities.

In this work described the second activity, while the first was in the charge of the partner 3Dart, a communication and 3D consulting organization. In addition to the development staff, the team members also included a primary school teacher and an ecologist.

3.3 The Pappi World

In this section we describe the objectives of the Pappi World game.

The approaches for reducing the amount of solid waste generated by households can be classified as either Reduce, Reuse, or Recycle [50]. *Reduce* focuses primarily on purchasing, e.g. purchasing items with minimal packaging or items that can be composted. *Reuse* focuses on

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[7] HierarchyDirective 2008/98/EC on waste (Waste Framework Directive),
http://ec.europa.eu/environment/waste/framework/index.htm

repeated uses of purchased items, i.e. using canvas shopping bags. *Recycle* that is the focus of this game, refers to the collection of waste items that can be exploited for manufacturing new items.

Pappi World is a 3D Virtual World city game addressed to 8-10 years primary school kids to promote the practice of waste collection and garbage recycle. The activities are proposed to spread the didactic message and to reward participants who more closely adhere to the principles taught by the play actions and the simulations. It has been designed as a game to be conducted in a class laboratory, even if the students can independently access on-line to it.

Pappi World consists in the simulation of an imaginary Virtual planet, where each school is represented by an archipelago, composed of islands associated to each class. Each student controls a city in his island (class). The game aims at stimulating the students to advance their city, their island and their archipelago by contributing to the improvement of the planet quality of life. Participant involvement is stimulated by adopting rankings mechanisms, game level progression, collaboration and competition. The behavior of the students, according to the principles taught, determines the success in the game.

The educational objectives of the game are:

- to provide the main knowledge related to the waste problem (General Knowledge)
- to enable the students to recognize and catalog the various materials (Procedural Knowledge)
- to present waste as a resource that is useful to make the students' cities grow and have success in the game (Impact Knowledge), inducting correct behaviors and attitudes.
- to induct the belief that the other participants follow the waste recycle practices and that they think it should be done (Normative and Social Beliefs). The student's reputation

increases when he/she demonstrates to recycle diligently and to encourage his/her classmates in it.

3.3.1 The game structure

All the students involved in the game contribute to the sustainable development of the Pappi World. Pappi is an alien that lives in an ideal sustainable world, structured in five perspective views:

- View 0: the Pappi World,
- View 1: the Archipelago (the school),
- View 2: the Island (the Class),
- View 3: the City (the student's land),
- View 4: the Mini Games.

Pappi World (View 0) does not have a graphical representation. When a student enters the game, he/she accesses his/her school by default, but if he desires he can visit the archipelago of another school.

As shown in Figure 13(a), each school is represented by an archipelago, where the island of the class of the student is highlighted by two arrows. Also in this case, the student can access the other islands.

Figure 13: The school archipelago and a class island.

In Figure 13(b) an island representing a class is shown. Let us note that the different buildings represent the different levels reached by each student. Clicking on a building, the student can access the selected city, shown in Figure 14.

Figure 14: A student's city.

Each learner can act on Levels 3 and 4. When he registers, he has at his disposal a city that has a minimum set of street furniture, some houses and a playground, with the same appearance of the ones represented in the 3Dart video lessons.

By collecting and recycling the garbage the user will get some credits and special rewards that he can use for growing the city, by modernizing it and building new houses, community buildings like post offices and schools, add plants and decorations.

A player can visit neighbors' cities and collect their garbage, obtaining precious resources for growing his city.

3.3.2 The proposed technological solution

The educational content cannot be simply "superimposed" on a game structure, since the game would risk to be boring. Thus, the proposed approach avoids adding game features (e.g., score competition or graphic effects) to educational exercises but inserts largely adopted learning-oriented mechanisms into the game technology [33].

In this section we describe the requirements that the Virtual World representing the student's city had to satisfy. These requirements deeply influenced the selection of the technology and of the open-source software. In particular, the Virtual World has to satisfy the following requirements [41][51]:

- *Synthetic*. It should refer to environmental sensory data such as visual
- image, gravity force, etc., which can be regarded as those of the real world.
- *Tri-dimensional*. A 3D representation should be adopted to enforce the perception of realism, immersion and presence. The user should move in the environment, perceiving its depth.
- *Multi-sensory*. Moving in the environment should solicit several user senses, such as vision, sound, space sense, depth.

- *Interactive*. The user inputs have to be detected in real-time and the Virtual World should react accordingly.

- *Realistic*. The items of the world (trees, buildings, roads, etc.) should have a precision (number of triangles) that enables an efficient rendering and real time interaction for a user with a high band connection.

- *With presence*. This means the user's sensation of being part of the Virtual environment, feeling of ''being there'' [52]. This expression denotes the perception of being in the place specified by the Virtual environment, rather than just watching images depicting that place. The more this sensation is strong, the more the experience is meaningful. Thus, presence and learning are strongly related: increasing presence also increases learning and performance.

- *Multi-users*. A student owning a city can meet the other students and visit their cities.

Pappi World has been developed adopting open-source software. The open-source server game that better seemed to satisfy the previous requirements is RedDwarf[8].

We integrated the following components:

- *The RedDwarf server*, a multi-threaded Server Game. It is an event-driven transactional system that provides automatic data persistence. It is largely adopted for online games, Virtual Worlds, and social networking applications because it provides true transparent, horizontal scalability to support large Virtual Worlds, thousands of simultaneous connections, and intelligent load balancing. RedDwarf provides persistence concerning the

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[8] http://www.reddwarfserver.org/?q=content/open-source-online-gaming-universe

state of the game (i.e object positions, user avatars present in the game and their appearance and positions on the map).

- *The Persistence server*, which wraps MySQL DBMS and complements the limited information stored by RedDwarf with information concerning the user level, the user permissions, his city, the building to show, etc.
- *The Database Server*, a MySQL DBMS adopted to store and retrieve the game data;
- *the Web Portal*, adopted as front-end for the administration and for deploying the application via Java Web Start Technology.
- *the Pappi World Client*, the 3D user front-end.
- *the Web Browser*, to access the game web site and the game administration features.

During the development, the map of the Pappi World has been composed and assembled using the World Editor proposed in the Snowman project of Darkstar[9].

3.4 The Learning approach

Pappi World follows a Game-Based-Learning approach based on learning-by-doing and learning-through-playing [53]. According to accredited pedagogical theories [54][55], children develop their cognitive structure through actions and spontaneous activities. In addition, playing enables the children to merge imagination and intellect while discovering knowledge in the way most appropriate for them [54].

In the world of the alien Pappi the undifferentiated waste is seen as a danger, while the differentiation process enables the students to collect resources useful to make their own city progress. The children learn how to differentiate waste thanks to the feedbacks provided by the

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[9] http://sourceforge.net/projects/rd\-snowman/

system, which signals them when a differentiation error occurs and rewards them in the opposite case increasing the scores. Indeed, in a learning-by-doing approach feedbacks and scores are a mechanism for informing learners about the characteristics of appropriate behavior [56]. By observing which actions are correct and which are not, children construct conceptions of new behavior patterns and their appropriateness.

The main idea is to provide the concept that garbage is a resource and this goal is pursued adopting: (i) a collaborative approach, when the resources are exchanged with the other users, (ii) a competitive approach, when a user can collect the garbage of the others, visiting their city, (iii) individual learning-by-doing, stimulated by the individual games, where users learn how to properly separate the garbage and put it in the appropriate bin. The correct disposal of garbage enables the city to grow and increases the progress speed.

In particular, the learning mechanisms adopted by Pappi World are the following:

Scores. Scores are videogame mechanisms to provides feedbacks to the players: they support participation and inform players of the level they have reached [57]. Pappi World provides constant feedbacks throughout the game, aiming at strengthen the participants partial achievements [58].

An appropriate design of a learning game is achieved when the game provides timely and constant information concerning the performances of the participants, their success and failure [59]. Together with feedbacks targeted to each individual player the game provides also collective feedbacks to promote Normative Knowledge. Collective feedbacks are targeted to all the players, such as the school students, or a subgroup of players, such as the classmates. To this aim the student has to collect the following scores at individual level:

- *Waste scores*. Students collect these scores by recycling waste and by playing the games in the game room (see 3.4.1.3 The game room). They are expressed in recycled resource units.

- *Level scores*. The scores that a student collects by making new buildings and by making his city cleaner. When 100% of a level is reached, the city level is incremented and the level score is reset.

The game tries to address to the suggestions reported in section 3.1.1 Behavior Changefor Making Recycling Normative. To this aim, the *Class and School Leaders* are individuated. They are students that recycle diligently and are encouraged by the teacher and by rewarding mechanisms, such as to appear on the game website at the top of the best recycle behavior list of the class/school, where students appear in decreasing score orders. This mechanism is extended to the class, signaling the most virtuous classes of a school and also to the schools, highlighting which school performs better. This approach is related to *disseminating data on community recycling rates*, such as percentage of students that recycle regularly for each class/school (Normative Knowledge).

The teacher's role Salmon underlined that moderators or mentors are important for learning communities mainly when they guide the students in meaningful learning activities, rather than when they provide knowledge [60]. The Pappi World game provides the teacher instruments to control the class progress and the actions of a single student. He/she can control the flow of the game and communicate with the students, supporting them when there is the need, and also providing public rewarding on the game site to reinforce the Class Leader role.

The game rules. The game rules are presented both at the beginning of the game and throughout the game. The rules are related to the learning objective and describe how to

differentiate waste, to exchange materials, to improve the city, etc. These explicit rules help to reinforce both the goals in the game and the learning objectives [59].

In the following subsections we detail the various learning activities offered by the Pappi World game.

3.4.1 The Individual activities

Individual activities aim at increasing the student reputation. Indeed, by correctly differentiating the garbage the student city evolves and this evolution is visible to the others. During these activities the player can discuss with a Virtual Assistant, the *PappiBot*, an AIML character with the appearance of an alien that is automatically activated when the player stays in one place for a long time or needs some help. It is also useful to avoid the loneliness sensation that a student can perceive in case he/she is the only user of the island.

3.4.1.1 Garbage collection and recycle

The student city has been designed considering the most common actions that a citizen can perform to contribute to a correct waste disposal. The garbage is randomly disposed in the city and the waste typology (i.e., paper, plastic, iron, aluminum, glass) is also randomly assigned to each garbage unit. Each Virtual bin requires a specific type of garbage to be introduced in it. If the type of the garbage collected by the student is the same of the bin, the score related to material accumulated of that kind is increased and the waste disappears from the map, otherwise, a warning message is provided. At regular intervals the garbage is regenerated.

This approach graphically enforces the message that recycling waste supports the growing of the city and has a positive effect.

3.4.1.2 The student city evolution

Each city should be completed in 9 levels. Also the objects and the buildings are organized in 9 macro-categories and can evolve as well. A player should have reached a specific waste score in order to be able to let the city grow. When this score is reached, the system asks the student if he/she wants to add new buildings by accessing the objects that are available for the considered game level. This mechanism enables the city evolution and reflects the recycle ability of the owner of the city. The city evolution is visible on the class island map (class), as shown in Figure 13(b). Figure 15 depicts three building icons representing three increasing macro-levels, from left to right.

Figure 15: The evolution of a city.

The city evolution is a well known motivating mechanism adopted in several games (i.e., SimCity, The Sims, Caesar, Faraon, Travian). In the case of Pappi World this feature supports Normative Knowledge since it graphically highlights the recycle behavior of others and induces an active participation. Indeed, the players are generally proud of their city progress.

3.4.1.3 The game room

To evolve his/her city the student has to collect waste scores. In addition to collecting garbage in the roads of his/her city, he/she can speed up the collection by playing an individual game

available in a game room. The game room enables the student to collect extra waste scores. The game room offers two games which have been adapted to the spirit of Pappi World. They have been chosen since they are appropriate to the user target and are not too complex. In particular, the room game offers the following games:

- *Pac-Waste*. It is an adaptation of the famous Pac-Man game, where the player is represented by a waste truck that has to collect all the garbage of a specific type which is displayed in the game square, without being eaten by the undifferentiated bin.

- *Recycle Bubble*. It is an adaptation of the famous game Bubble Bubble, where the player has to help the alien Pappi in putting the waste in order. Each time three waste objects of the same type are put together they explode and disappear from the game square. The Recycle Bubble objective is to make all the waste disappear. If the waste fills all the game squares and touches Pappi, one life is lost.

At the end of each game the system appropriately increments the waste score.

3.4.2 The collaborative activities

To create a new building or to upgrade an existing one, the player has to accumulate material of several types (e.g. ten sacs of plastic, three of organic and four of paper are needed to create a building of two floors). If he does not have the required material, but he has, for example, ten more sacs of plastic, he can:

- try to exchange the material with his neighbors. In this way, the user learns that recycled garbage can be a source of income.

- visit the city of the other players and collect their garbage. This provides competition and stimulates the users to clean their city to avoid losing valuable material.

3.5 Evaluation

In this section we describe the evaluation conducted to answer two main research questions:

RQ1: did the participants improve their knowledge and behavior in recycling waste after playing Pappi World?

RQ2: if they did improve their knowledge and beliefs in recycling waste, which are the factors influencing such improvement?

We tried to answer RQ1 and RQ2 performing an evaluation aiming at assessing (i) the learning efficacy of the proposed game, the participant satisfaction and their motivation, and (ii) the opinion of 24 teachers belonging to primary and secondary schools on the utility and the efficacy of the game.

3.5.1 Student Evaluation

3.5.1.1 Methodology

In case of an educational game based on Virtual reality it is important to evaluate the environment usability. Indeed, since this kind of environment is typically complex, we have to verify that we are not making learning too difficult. Moreover, it is very important to evaluate if the students effectively like the game. The general experimental designs of studies evaluating games-based learning are often based on pre-test/post-test approaches [61][62]. In the specific case of this study, we evaluate the cognitive outcomes adopting a pre-test / Pappi Game intervention / post-test approach and by making a quantitative analysis of the scores reported before and after playing with the game. Connolly *et al*. proposed an approach for the evaluation of learning games which, in addition to the learner performance, includes motivational variables such as interest and effort, preferences, perceptions and attitudes to games [63]. We evaluated

areas such as student motivation, engagement and attitudes by collecting the student perceptions after playing the Pappi World game during a school laboratory sessions lasting an hour.

3.5.1.2 Context and data set

The participants in this study were 24 children between 9 to 10 years randomly selected from the primary school of the Town of Baronissi (Italy). They all attended the 5th grade and had the same learning objectives related to natural science and ecology.

Each student answered a pre-test questionnaire which was designed to collect demographic and learner type data, details on level of experience with Internet and video/online games, their involvement attitude and motivation for playing during the proposed evaluation session. A 7-point Likert scale [64] anchored at 1 by Strongly Agree and at 7 by Strongly Disagree has been adopted.

The BoxPlot in Figure 16 summarizes the participant background concerning their skills in PC Usage (PCU), level of experience with Internet (IU), Video Game use (VG), On-Line Game (OLG), level of enjoyment when playing with Video Games (ENJ), level of experience in using Virtual Worlds (VWK), level of involvement while playing (INVG), tendency to be distracted when playing (DIS), general involvement aptitude (INV), the level of curiosity towards the games that will be presented (CUR), and motivation level in trying the proposed games (MOT).

As shown in Figure 16, the sample had a good technological knowledge on average and was accustomed to playing with video games and to visiting Virtual Worlds. 100% of the participants was strongly curious of playing with the new games and most were motivated ($\breve{x}(MOT) = 2$).
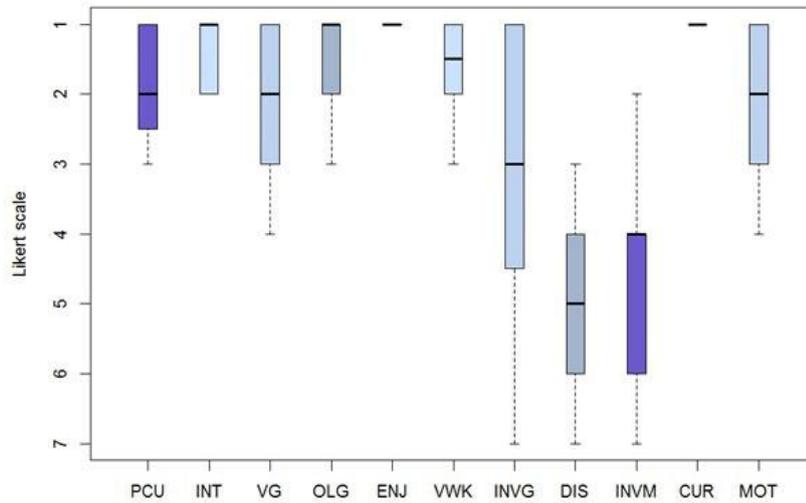
Figure 16: Participant background.

3.5.1.3 Procedure and material

Each student answered the pre-test questionnaire, discussed in the previous section. Successively, they answered the Waste Disposal Test, aiming at evaluating their knowledge concerning the waste disposal before playing with Pappi World. A score from 1 (low) to 5 (high) has been attributed.

The study has been divided in two steps and performed in one laboratory session (i.e., three supervisors for all the 24 subjects). In the first step, a presentation of 10 minutes introduced to all the subjects the main features of Pappi World. The students played Pappi World for an hour. After playing, they answered again the Waste Disposal Test. Finally, the subjective evaluation has been collected. Table 1 reports the Student Post-Game Perception Questionnaire. A 7-points Likert scale anchored at 1 by Strongly Agree and at 7 by Strongly Disagree has been adopted.

ID	Question	% Positive answers	$\tilde{x}$
Q1	The game environment was stimulating. (Environment)	100	1
Q2	When I made a mistake while playing, I was able to solve the problem easy and quickly. (Behavioral Control)	75	2
Q3	I quickly learnt to play the game (Learnability)	100	1
Q4	I'm satisfied with this game. (Satisfaction)	100	1
Q5	I will recommend the game to a friend.	100	1
Q6	I enjoyed the game. (Enjoyment)	100	1
Q7	I would like to use the game in the future. (Intention to use)	88	2
Q8	I was able to control the avatar and the events. (Control)	67	3
Q9	The avatar control distracted me from what I had to do. (Distraction)	0	6.5
Q10	It was easy to collect garbage. (Easy to use)	100	1
Q11	I played without effort. (Mental effort)	100	1
Q12	I think I have learnt to make the waste separation better. (Learning result)	100	1
Q13	Material exchange was stimulating. (Collaboration, only for Pappi World)	100	1
Q14	It was stimulating to collect the garbage in the city of the others. (Competition, only for Pappi World)	100	1
Q15	It is important for me to appear in the list of the most virtuous students that are an example of correct behavior. (Class/School leader Reputation)	93	2

Table 1: The Student Post-Game Perception Questionnaire.

The students involved were accustomed to answer questionnaires. Considering their young age open questions were avoided and the questionnaires have been designed to keep focused and straight forward, trying to avoid any confusion. In particular, question Q1 is related to the game environment and aims at evaluating if the student perceives it as stimulating. When the student easily interacts with the environment and is able to manage problems without the need of an external help his avatar behaves as expected and moves in the Virtual World according to his commands (Q2). Learnability is an important quality of a game since low learnability gets the student to abandon the game (Q3). Question Q4 measures the overall satisfaction, while question

Q5 considers if the user is satisfied with the game so as to recommend it to friends. Enjoyment is the most relevant perception related to a game (Q6). A user can find a game satisfactory, enjoyable, easy to learn and to control, but, at the end, he/she decides not to play it. Thus, also Intention to use is a relevant aspect (Q7). A high control on the environment and on the interaction contributes to get a high experience of presence (Q8). Another factor that contributes to increase immersion and participation is a reduced Distraction (Q9). If the user does not control his avatar in a natural way the presence perception is reduced. Question Q10 is specific to assess the ease of the garbage collection feature of the game. It could happen that the game is easy to use in general, but the user could have some problems with its most relevant feature. Question Q11 collects the perception related to the mental effort of the user while playing. An excessive effort could discourage the use of the game. The perception of the learning outcomes is collected by Q12. Question Q13 is related to the satisfaction concerning the material exchange feature, while Question Q14 collects the perception related to the possibility of growing his own city by collecting the garbage of the other participants. Finally, question Q15 collects the perception of the user of being appreciated by the community for his success.

3.5.1.4 Hypothesis formulation

The number of correct answers provided before (PRE) and after (POST) playing Pappi World was adopted as a performance metric of the objective assessment for empirically evaluating the following null hypothesis, answering to the research question RQ1:

- H_n Playing Pappi World does not affect the student knowledge related to waste disposal.
  The corresponding alternative hypothesis is:
- H_a Playing Pappi World improves the student knowledge related to waste disposal.

In addition, we verified that the median answer of the user perception questionnaire is at least Agree (i.e., $\tilde{Q}_i(PW)\leq3$, i=13…15).

3.5.1.5 Results

The effect of the game on learning and the survey questionnaire results are analyzed in this section.

Effect of the Game. The quantitative evaluation consists in the measurement of the knowledge of the children before and after playing. Figure 17 depicts the boxplots of the scores gained by the participants before (PRE) and after (POST) playing the game PW; as shown in Figure 17 and in Table 2 the students'knowledge improves.
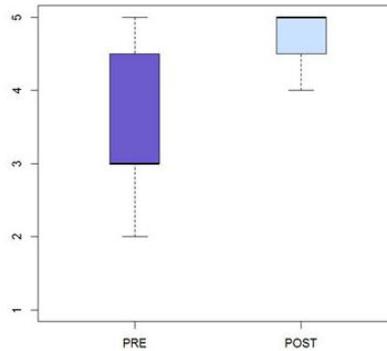


Figure 17: Game Efficacy

Dependent variable	μ	σ	$\tilde{x}$
PRE	3.58	1.06	3.5
POST	4.75	0.44	5

Table 2: Descriptive statistics for learning outcomes.

By applying Shapiro normality test to the PRE scores we obtain p-value = 0.004854.

Since p-value < 0.05, the sample is not normally distributed and we need to adopt a nonparametric test. Applying the Wilcoxon test we determine p-value = 3.682e-05. Since p-value < 0.05 it is possible to reject the null hypothesis and state that there is a significant statistical difference between the student knowledge before and after playing.

To measure this improvement we calculate the *Cohen d* effect size, which indicates the magnitude of performance differences achieved with two different user groups on the dependent variables (the effect size is considered negligible for $d < 0.2$, small for $0.2 \leq d < 0.5$, medium for $0.5 \leq d < 0.8$, and large for $d \geq 0.8$). In our case (paired analyses [65]), it is defined as the difference between the means μ_{POST} and μ_{PRE} (reported in Table 2) divided by the standard deviation of the (paired) differences between samples σ_D.

$$d = \frac{\mu_{POST} - \mu_{PRE}}{\sigma_D}$$

- Since $\sigma_D = 0.92$, the effect size is $d = 1.27$. Thus we can reject H_n, with a positive and large effect size.

Survey Questionnaire Analysis. The student feedbacks were collected through the survey questionnaire in Table 1, as discussed in Section 3.5.1.3 Procedure and material. The subjective results related to perception of playing Pappi World are reported in Figure 18.
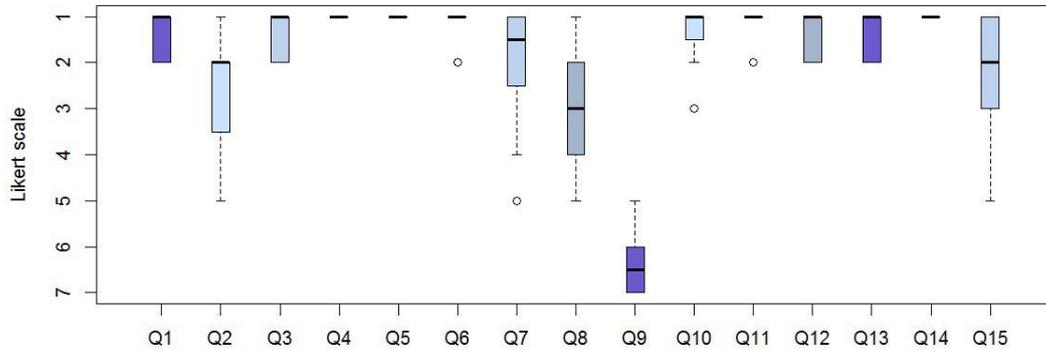
Figure 18: Participant perceptions.

The participant perception results are detailed in Table 1. All the users considered the game strongly stimulating (Q1). The proposed game is perceived enough easy to be controlled (Q2) and the positive scores are more than 70%. PW game was also perceived to be easy to learn (Q3), with 100% of positive answers. Almost all participants were very satisfied with it (Q4), with 100% of positive answers. 100% of them would recommend the game to a friend (Q5). Pappi World is considered very enjoyable (Q6) and 88% of participants would like to use it in the future (Q7). The avatar control was not considered a distracting factor (Q9) and the garbage collection was easy to perform (Q10). In addition, no particular mental effort was required to the users (Q11) and the game was perceived with a good level of instructiveness (Q12).

Also respect to collaborative/competitive activities, the student perceptions were very positive.

Collaborative approach analysis. After one hour of game, we collected the data reported in

Table **3** concerning the city level reached by the students.

μ	σ	$\widetilde{x}$	min	max
2,37	0,76	2	1	4

Table 3: City evolution during the game.

This data confirm that the game is appropriate for three laboratory sessions of one hour. Indeed, after one hour, half of the students reached the second level of the game. Only one remained at level 1, while two of them reached level 4. Thus, one hour session is enough for exploiting the reputation approach, being the differences among the students visible. We also evaluate if the students really collected the garbage of the others. Indeed, they subjectively appreciate this aspect, but only if this had de facto happened during the game, it can be considered as an important mechanism. Table 4 reports the results concerning the competitive approach (take waste from the others) and the collaborative one (exchange of material). A greater number of visits has been performed w.r.t. exchanges. Thus, the first approach seems to be preferred.

Collaborative approach	μ	σ	$\widetilde{x}$	min	max
Neighbor visit	6	1,83	6	3	8
Waste exchange	3,70	1,4	4	2	6

Table 4: The collaborative approach data.

3.5.2 Teacher Evaluation

In the evaluation in the classroom laboratory a group of teachers has been actively involved. They were required to answer the questionnaire in Table 5. In particular, 15 primary school and 9 middle school educators voluntarily took part in the evaluation.

ID	Question
Q1	I think it is easy to play the game Pappi World.
Q2	I think the mechanism to progress in the game motivates students to correctly perform differentiated garbage collection.
Q3	In my opinion, more fun and engaging characteristics of the game are ...
Q4	The game implements an appropriate challenging and a motivating dynamic for my students.
Q5	I would adopt the game as supplemental classroom didactic material or as homework.
Q6	The game performs as I expect it should do.
Q7	I think the Pappi World to be effective for learning.
Q8	I think the Pappi World may be distractive.

Table 5: The Teacher Questionnaire.

The questionnaire is composed of 8 questions aiming at evaluating usability, fun, engagement, game mechanism and metaphor adequateness as well as expected learning outcomes. Each question of the questionnaire has been evaluated on the Likert scale anchored with the range 1 for Strongly Agree to 7 for Strongly Disagree. The last two questions have been formulated for the evaluation of the game in terms of learning benefits and induced distraction.

In addition to question Q3, that requires an open answer, the questionnaire proposes a free form for collecting open suggestions.

Figure 19 reports the results for a sample size of 24 individuals aggregating the two classes of teachers (15 primary and 9 middle school teachers). All questions scored high values and results revealed that the teachers were really interested in the proposed serious game and appreciate the didactic support it provides. In particular, with respect to question Q1, more than the half of the sample "strongly agreed" on the ease of Pappi World gaming and the remaining were almost all "agreeing". The same positive result has been obtained by question Q2 aiming at evaluating if the teacher approves the game dynamic specifically adopted to motivate students in playing PW. Almost all teachers agreed that the game dynamic can enforce the sensitivity for differentiated garbage collection. The open question Q3 collected positive appreciations of the scoring and progress mechanisms that enforce motivation by example and/or competition among the students. In particular, they wrote:

- "The class island is an immediate way to highlight the progress of the students. I noticed that they were very interested in observing the levels reached by the others."
- "I think that the possibility of collecting the garbage of the others is very motivating, as we saw while they were playing, and can have a deep impact on the student attitude towards the recycle practice."
- "I didn't know that social features were so motivating. This is the first time that I see students play videogames all together in a lab and I'm very impressed by their engagement."

This is also confirmed by question Q4 results that scored "strongly agree" or "agree" for 19 teachers. Question Q5 scores confirm the interest of the teachers with respect to this kind of

didactic instrument and the intention of adopting the game. Question Q6 is focused on the user expectations related to the game (i.e. behavior, graphical details, sounds). The teachers considered PW effective for learning (as shown by question Q7 results of the teacher questionnaire). Also in a free space for comments, we collected some suggestions to improve the graphical aspects of the 3D scene. Even Q6 scores are all above the "neutral" value except for 3 participants. In addition, it is possible to notice that only one teacher is enthusiastic while the great part of participants was scoring "agree". It is important to point out that most teachers do not agree with the possibility that students may be distracted by the game mechanics and environment characteristics.

While for the other questions it is not possible to observe effects of the student age, the teacher opinions about the distraction due to the nature of the proposed experience (question Q8) reveal some differences due to the classes of teachers, as shown in Figure 20. In particular, even if the system cannot be considered distractive (median 7 for middle school teachers and 6 for primary school ones) it seems that the higher the school is (between primary and middle) the less distractive the game is perceived. The observation has been statistically evaluated and confirmed by a Moods median and a Mann Whitney tests, both chosen because the dimensions and the distribution of the samples (15 primary school and 9 middle school teachers) do not accomplish the normality requirements of parametric tests. Both Moods test (p-value=0.006 at a significance level α=0.05) and Mann Whitney (p-value= 0.0171 at a significance level α=0.05) confirm the perceived differences between the classes of teachers. In our opinion, and according to some suggestions provided by teachers, the 3D environment adopted for PW may result complicated to some of the younger students not skilled in similar videogames and this teacher perception is

reflected in the scores shown in Figure 19. In addition, the free forms adopted for collecting open suggestions from the participants provided interesting suggestions and cues.

In particular, some conclusive comments are:

- "The game is very useful. Only the avatar graphics should be improved."
- "This game can be useful for teaching to special needs children. It should be interesting to perform experimentation in that direction." and "Is it possible to simplify the interaction for special needs children?"
- "Very useful: I think that after playing with this game the recycle practice should become more familiar."
- "Perhaps the game room may generate distraction. The student can forget the main aim of the game".
- "I find it useful that the teacher can interact with the students while they are playing."
- "Why do not introduce features related to zero kilometer environmental sustainability?"
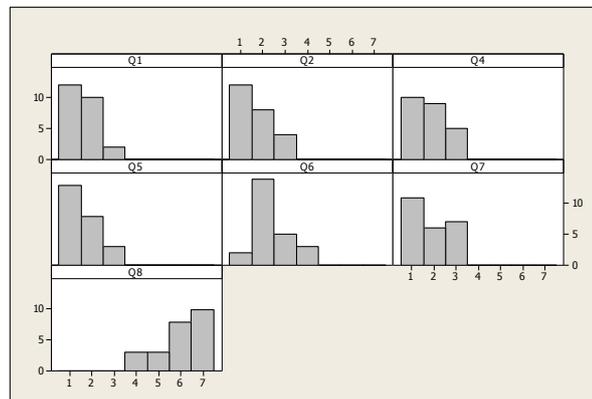
Figure 19: Teacher questionnaire results.
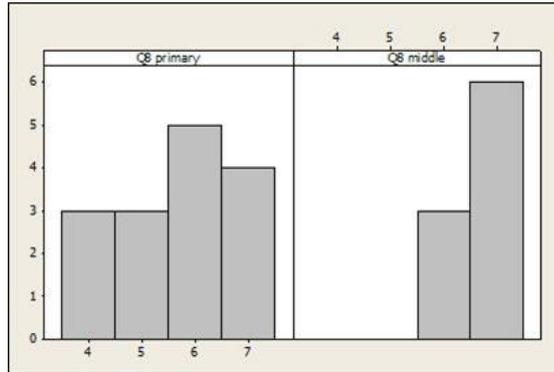
Figure 20: Game distraction perception for primary and middle teachers.

3.6 Discussion

In this section we interpret and explain the results related to the evaluation described in the previous section.

The evaluation shows a statistical significant difference in the Pre-Game and Post-Game performances with large effect size. The student perception related to the question Q12 confirmed this result. Also the teachers considered PW effective for learning (question Q7 teacher questionnaire). Thus, it is possible deduct that **the use of Pappi World improves the knowledge on waste recycling** (RQ1 is true). Concerning the *behavior change* in everyday life, the evaluation does not provide quantitative results to verify it. The game follows the directions exposed in Section 3.1.1 Behavior Change related to the promotion of block leaders and disseminating data on community recycling rates, but it is not possible to verify the effectiveness

on the behavior change. In addition, the study involved short-term usage of the game. We consider that a long-term evaluation would provide more effective results on behavior change, even if it is difficult to make a quantitative assessment.

To answer the research question RQ2 we do not compared the use of Pappi World with a traditional class. The main reason is that, as some authors suggest [66], a traditional class can be used as the control group in order to compare it with the new technology (i.e., a game-based learning activity), when the new technology is destined to replace traditional instruction. Pappi World is related to a class laboratory activity destined to complement the transmission of procedural knowledge through traditional lessons. Question Q5 of the teacher questionnaire revealed that all the teacher sample was intentioned to adopt the game as a complementary learning activity.

The pre-experiment questionnaire analysis indicates that 100% of participants were curious about the games, this is a very relevant intrinsic motivational factor. Observing the results of the Post-Game Perception questionnaire, the children seemed to be more satisfied and engaged when playing with PW. These results were confirmed by the informal observations made by the researchers during the experiment. This means that the additional features offered by PW (i.e. collaboration and competition in collecting garbage, class/school leader awarding) improve their involvement and participation. All the teachers considered the city progress mechanism to be effective.

We also evaluated the Pearson's correlation coefficient $\rho_{q15,kimp} = -0.844$, between the scores of question Q15 and the *knowledge improvement* (kimp) computed as the difference between the scores reported after and before playing PW. It is possible to be 95 percent confident that the true correlation is between -0.93 and -0.67. This means that the more a student considered important

to appear in the list of the most virtuous players (with lower scores) the higher the improvement was. Thus, **the class/school leader individuation positively influences the improvement (RQ2).** This aspect could also influence the behavior, as stated by [50]. Also for RQ2, we do not have quantitative data to assess the behavior change, but the observation revealed that the students opened the window related to the class statistics in a corner of the screen and were continuously monitoring their advances and those of their classmates.

Primary school teachers identified **Distraction as a factor that negatively affects improvements**. As reported in the previous section, one of them specified the game room as a possible distraction cause.

Chapter 4: Going beyond: Gestural Interfaces

In this section we complete the discussion on the main RQ "*Do Virtual Worlds satisfactorily and effectively support learning activities?"* by investigating the aspects related to new forms of interaction associated to gestural interfaces. In particular, we aim at answering at the following research question:

RQ$_2$: Are gestural interfaces an effective interaction modality to support to Learning activities in Virtual Worlds?

To this aim we investigated the adoption of gestural interfaces. In particular, in [81] we designed and evaluated a gesture-based interface aiming at controlling a presentation software. The gesture detection technology was based on Microsoft Kinect. The proposed interaction modality has been evaluated by computing subjective and objective measures to compare with that obtained by a traditional presenter based on a classic remote control. Successively, we experienced whether gestural interfaces offer new interaction modalities for supporting learning, since they are well known by primary school children. Gesture-based interactions represent, together with geotechnologies, new opportunities for learning Geography.

In this chapter we present and evaluate GeoFly, a system for supporting the Geography learning based on a Virtual Globe and on the interaction modalities offered by Microsoft Kinect.

4.1 The GeoFly system

The aim of this research is to support primary school children in Geography learning exploiting technologies that are appealing for them. This work is the result of a deep consultation with primary school Geography teachers aiming at select the interest area related to the curriculum. In particular, the teachers suggested to follow the learning activity proposed at the

end of each chapter of their textbook: a path the students have to follow on a map, where pictures and additional information are provided. We proposed a solution, the GeoFly system, that makes use of Virtual Globe and adopts the learner's body motion to give a concrete physical dimension to the Virtual dimension of a Virtual Globe. According to the teachers' directions, the proposed learning activities follow the Virtual trip metaphor. In this way, the didactic approach proposed by a GeoFly activity is *Learning-by-Exploring*,i.e., the learning that results from explorations (structured or otherwise) of installations, communities, and landscapes within a Virtual world [87], also strengthened by a physical activity (*kinesthetic learning*). Gesture interfaces overcome the limit of the desktop metaphors that restrict the user interaction on a 2D plane (e.g., mouse, point, click and drag) and naturally support the 3D navigation allowed by Virtual Globes: the gestures and their relationships with the movement on the Globe help understanding of the spatial relationships and the distances among the places on real Earth real or concepts related to them [84].

Concerning the selection of the interaction technology we based on the results reported in [85], where we performed a controlled experiment aiming at comparing two different kinds of gestural interfaces for interacting with a Virtual Globe: Wii Motion Controller and Microsoft Kinect. The results were positive for both the interaction modalities with a preference for Kinect, since the Wii controller requires the user to hold in his hand the physical device.

GeoFly can be adopted in a classroom laboratory or at home. It provides the teacher the means to organize a Geography laboratory activity respecting the curricular requirements. To this aim, GeoFly provides the features to associate learning content to specific Earth coordinates. Thus, in addition to the spatial content, which are characteristics of the Virtual Globes, the

learning experience can be improved by adding pictures, or any other kind of multimedia materials.

4.1.1 The GeoFly Architecture

The architecture of the system is shown in the deployment diagram of Figure 21. It is composed of the following two subsystems:

- *the Teacher subsystem*, on the right side of Figure 21, composed of the following modules:

- *Path Management*, which supports the teacher in the association of information content, such as video, audio, text and images, to specific Earth coordinates;

- *Teacher Viewer*, which enables the teacher to access the path management features and shows the results on the Bing map Virtual Globe, adopting a point and click interface for controlling the Virtual Globe.

- *the Student subsystem*, on the left side of Figure 21, composed of:

- *Microsoft Kinect Controller*, which captures video data in 3D. It is equipped with a normal camera and a depth sensor consisting of an infrared laser projector combined with a monochrome CMOS sensor;

- *Microsoft Kinect Natural User Interface Library*, which tracks the student movements in the video acquired by the Microsoft Kinect Controller by using skeletal tracking;

- *Motion Capture* component, which matches the user skeleton description provided by the Microsoft Kinect Natural User Interface Library with a set of predefined user positions representing commands;

- *Student Viewer*, which shows to the students the Virtual Globe and the multimedia contents;

- *Bing map Virtual Globe*, the external 3D Virtual Globe of Microsoft which communicates with the Globe Controller and the Student Viewer through a set of API;
- *Globe Controller*, which receives the user command corresponding to the movement recognised by the Motion Capture Component and transforms it in commands to be sent to Bing map Virtual Globe.

Both the subsystems access to the *Persistent Data*, storing the data related to the learning path.

The application has been developed in C#. A prototype of the system is running on a Windows 7 laptop, and uses Kinect SDK version 1.5.
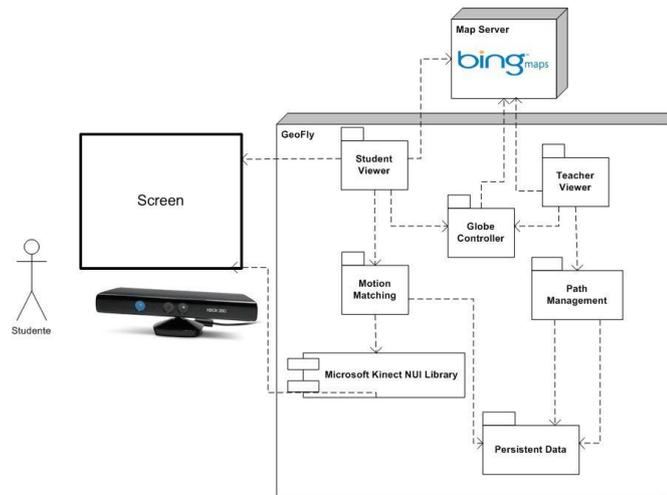

Figure 21: The GeoFly architecture.

4.1.2 The GeoFly gesture-based interface

The teacher tool exploits the traditional point and click interface, while the student follows the path exploiting a bird metaphor offered by the gesture-based interface. The GeoFly motion capture feature is based on Microsoft Kinect, which does not require the wearing of heavy, expensive sensors. This interaction modality enables the children to control the Virtual Globe in a game-like way.

As shown in Figure 22, a child interacts with the system using only her body movements. The Student Viewer shows the Bing Maps client and additional contents related to the position of the user, as shown in the right-hand part of Figure 22.

Figure 22: The GeoFly interaction.

The system recognizes a set of gestures to control the Virtual Globe navigation. Figure 23 shows the user skeleton positions associated to the control gestures. In particular, the *stop command* is depicted in Figure 23(a): when the user stands with open and aligned arms, the

navigation halts. The *go forward command* is detected when the user moves both hands ahead of the elbows. These movements are depicted in Figure 23(b) (arms bent), but this command is also detected when the user extends forward both his arms, as Figure 22. GeoFly does not support backward movement, since birds and planes do not perform any movements in that direction. To go back it is necessary to perform a rotation of 180°. Figure 23(c) and (d) depict the turn left and right gestures, respectively. The height of navigation is controlled by the gestures in Figure 23(e) and Figure 23(f), *fly-up* and *fly-down*, respectively.
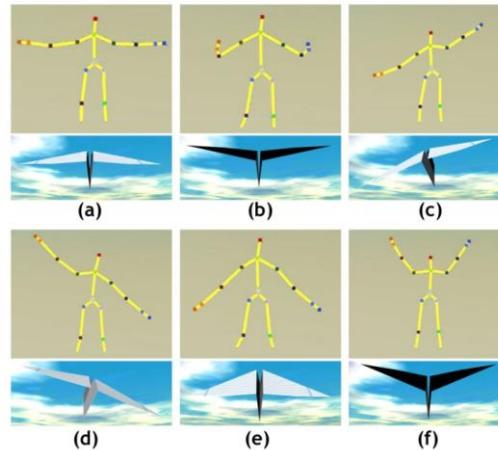
Figure 23: The control gestures.

Microsoft Kinect detects the user body and provides the coordinates of each joint of the user's skeleton. In particular, the sensor considers a set of points for each player as shown in Figure 23 by the joint points, that are overlayed, in official Microsoft documentation, on Leonardo's Vitruvian man. Leonardo Da Vinci drew the Vitruvian man approximately in 1490, inspired by

the previous work of the Roman architect Vitruvius (*De Architectura*). This drawing depicts the correlations of ideal human proportions with geometry and highlights the relationship among the body dimensions. Inspired by the SDK documentation, and in particular by this drawing, the GeoFly interface exploits these correlations for customizing the interaction on user body dimensions. Indeed, GeoFly detects the user stature aiming at obtaining the independence from body measures, avoiding the adoption of fixed thresholds for building controls. In particular, the proposed system detects *dist*, the semidistance between the user elbow and his wrist and triggers the opportune control events, considering the relationship among the body dimensions. When the distance of some joints, i.e. right hand and elbow, exceeds *dist*, the controller starts the commands depicted in Figure 23, according to Figure 24.

This pseudocode depicts the behaviour of GeoFly and the exact commands triggered by the event *nui_SkeletonFrameReady*. This event happens around 30 times for second and launches the pseudocode which performs all the checks on the joint positions and combines the opportune control actions. As an example, if the user stands with is arms bent and directed upwards the command is twofold: GeoFly performs a *forward* navigation movement combined with the *fly-down* command and decreases the navigation height when moving ahead.

```
// (a) is the default, i.e. stay
//go ahead
if ((Joints.HandLeft.Position.Z − Joints.ElbowLeft.
    Position.Z) > dist) AND ((Joints.HandRight.Position.
    Z − Joints.ElbowRight.Position.Z) > dist) execute(b)
//turn left [resp. right]
if ((Joints.HandLeft.Position.Y − Joints.HandRight.
    Position.Y) < − dist [resp. > dist ]) execute(c) [
    resp. execute(d)]
//go up [resp. down]
if ((Joints.HandLeft.Position.Y − Joints.ShoulderCenter.
    Position.Y > dist [resp. <−dist] ) AND ((Joints.
    HandRight.Position.Y − Joints.ShoulderCenter.
    Position.Y )> dist [resp. < −dist])
  execute(f) [resp. execute(e)]
```

Figure 24: The pseudocode for detecting the gesture commands of Figure 23

4.2 Definition and planning of the empirical evaluation

This section provides the design and planning of the experiment, structured according to the guidelines of Wohlin *et al.* [65]. The *goal* of the experiment is to examine the effects of the use of the GeoFly system from the following perspectives:

- *Learning Outcome*: Do the students get improved in their Geography knowledge?

- *Arousing Interest*: Does the system motivate the students less interested in Geography?

- *Comparison with the Traditional Learning Method*: Does our proposed system outperform a traditional Geography lesson?

4.2.1 Experiment Context

The experiment was carried out with 59 children attending the last year of a primary school of Salerno (Italy) with a comparable background, but different abilities and attitudes related to their

interest towards Geography, their abilities of use of kinect and map software, as depicted in Figure 25. The participants were asked to provide also demographic information, including their gender.
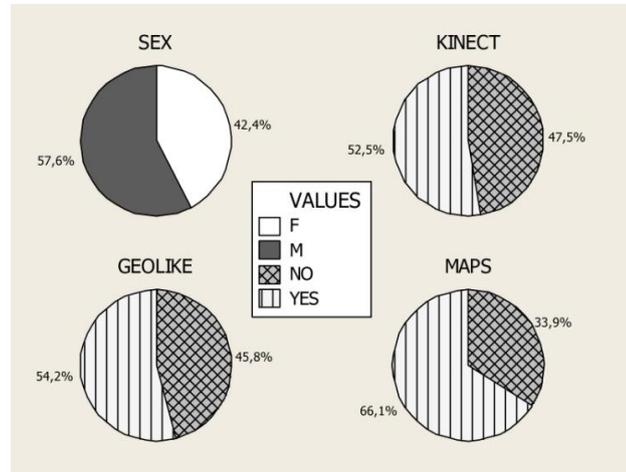
Figure 25: Experiment participants abilities and attitudes.

4.2.2 Hypothesis Formulation and Variable Selection

The null hypothesis the controlled experiment aimed at testing is:

H_n: The use of GeoFly does not significantly improve the Geography participants' knowledge (measured with the scores of Post-Task Questionnaire) w.r.t. a traditional lesson.

The corresponding alternative hypothesis is:

H_a: he use of GeoFly significantly improves the Geography participants' knowledge w.r.t. a traditional lesson.

In order to properly design the experiment and analyse the results, we considered the following independent variable:

Method: this variable indicates the factor the study is focused on. As we wanted to investigate the effectiveness of GeoFly on the Geography Learning, the experiments foresaw two possible methods:

1. *No GeoFly (NOGF)*: participants answered the Post-Task Assessment Questionnaire after a traditional lesson in classroom.

2. *With GeoFly (GF)*: participants answered the Post-Task Assessment Questionnaire after performing the task using GeoFly.

To verify the null hypothesis related to the learning effectiveness of GeoFly, we considered as dependent variable the Individual Performance (*IP(Method)*) defined as follows:

$$IP(Method) = \sum_{i=1}^{5}(s_i)$$

where Method $\in$ {NOGF,GF}; $s_i \in$ {0,1} for ($i = 1\ldots5$) are the scores reported by a participant in the Post-Task Assessment Questionnaire composed of 5 questions concerning the Geography content explored during the task..

4.2.3 Experiment Design

The study has been divided into three steps. In the first step, a lesson of 10 minutes introduced the gestures to control the Virtual Globe and the main features of GeoFly to all the participants. The training session of the evaluation was concluded presenting detailed instructions on how to

perform the tasks. Each student performed two different tasks, as shown in Table 6. The students were randomly distributed among four groups. The experiment design ensures that group of participants worked on two different tasks in the two labs, receiving a different treatment (GF and NOGF) each time. The use of two different tasks in the two lab sessions should limit the learning effect (i.e., the knowledge acquired during the first lab session may help in the second task). More than allowing us to consider different combinations of task and treatment, in different order across labs, the adopted design also allowed the use of statistical tests for studying the effect of multiple factors on performances. The proposed tasks followed the Geography trip approach, which is consistent with the curriculum of the students. In particular, GF tasks were performed in one-to-one sessions (i.e., a supervisor for each participant) while NOGF tasks consisted in a lesson to the entire group conducted in the classroom by the teacher. In this case we were carefully controlling that provided content were the same for GF and NOGF treatments. The tasks had similar complexity and concerned with the learning of the information related to a Geography path in central Italy, taken from the students' textbook. In particular, when a task was performed with method GF, each user had to follow a path consisting of 5 points of interest. When a point of interest was reached, GeoFly provided multimedia content related to that place, including a speech indication on how to reach the successive point of interest. In the case of method NOGF, the participants followed a lesson given by the teacher with support of a slide presentation showing the path and the same content exposed by the GeoFly task.

	Group 1	Group 2	Group 3	Group 4
Lab 1	T1-GF	T1-NOGF	T2-GF	T2-NOGF
Lab 2	T2-NOGF	T2-GF	T1-NOGF	T1-GF

Table 6: Experimental Design.

After each task, the objective evaluation has been collected by filling the *Post-Task Assessment Questionnaire*, shown in Table 7. It consists of 5 questions on the Geography topic concerning the proposed task. After the two tasks, each participant also filled the *User Perception Questionnaire* shown in Table 8. The questionnaire statements were adapted from previous studies dealing with an extension of the Technology Acceptance Model (TAM) [67], defined to evaluate the attitude of learners toward learning in an augmented reality environment with changes in expressions in order to adjust them to the context of the technologies adopted by GeoFly. The model suggests that when users are presented with a new technology, a number of factors (or categories) influences their decision about how and when they will use it, such as: Interface Style (IS), Perceived Usefulness (PU), Perceived Ease of Use (PEU), Perceived Enjoyment (PE), Attitude Toward Using (ATU) and Intention To Use (ITU). As shown in Table 8, the questionnaire is composed of 18 questions, grouped into six groups representing the constructs of the questionnaire model [67]. An additional question (P19) was proposed to verify the perception of the Physical Effort (PHY E) required to perform the task since, if the gestures are tiring, the student can abandon the system. All the questions are scored using the following Likert scale [68] anchored from 1 (Strongly disagree) to 7 (Strongly agree).

ID	Question
Q1	What is the name of the Eternal City?
Q2	What is the drained lake in Abruzzo?
Q3	What direction should be followed to go from Rome to the drained lake (North, East, South or West)?
Q4	What is the most important foreland in middle Adriatic Sea?
Q5	Write the name of an island of Toscana?

Table 7: The Post-Task Assessment Questionnaire for task T1.

ID	Question
	Interface style (IS)
P1	Moving on the map using GeoFly is easy.
P2	Moving around the Globe using Kinect is a good idea.
P3	I can easily follow the path using GeoFly.
	Perceived usefulness (PU)
P4	The use of such a system improves learning in the classroom.
P5	Using the system during lessons would facilitate understanding of certain concepts.
P6	I believe that the system is helpful when learning.
	Perceived ease of use (PEU)
P7	I think GeoFly is easy to use.
P8	Learning to use the system is not a problem.
P9	Operation with the system is clear and understandable.
	Perceived enjoyment (PE)
P10	I think the system allows learning by playing.
P11	I enjoyed using the system.
P12	Learning with such a system is entertainment.
	Attitude toward using (ATU)
P13	The use of such a system makes learning more interesting.
P14	Learning through the system was boring (reversed item).
P15	I believe that using such a system in the classroom is a good idea.
	Intention to use (ITU)
P16	I would like to use the system in the future if I had the opportunity.
P17	Using such a system would allow me to follow Geography paths on my own.
P18	I would like to use the system to learn Geography and other subjects.

	Physical Effort (PHYE)
P19	I think that GeoFly is tiring.

Table 8: The User Perception Questionnaire.

4.2.4 Bias factors

To assess whether other factors could either directly influence the dependent variables or interact with the main factor, we considered the following bias factors:

- *Participants' Geography attitude*. Participant sample is characterized by a varying attitude towards Geography that can produce different results and benefits from the usage of GeoFly.

- *Lab*. As we explained in Section 4.2.3 Experiment Design, the experiment was organized in two laboratory sessions. Although we designed the experiment to limit the learning effect, it is still important to investigate whether participants perform differently across subsequent labs.

- *Attitude with Maps*. Participant have a different experience with digital Maps and Virtual Globes. These differences may influence experiment results and the detected benefits may be due to confidence with Maps.

- *Attitude with Gestural Interfaces*. The adoption of a novel interface (i.e., a gesture based one) may alter the evaluation results respect to confidence participant have with these forms of interaction.

4.2.5 Analysis Procedure

In all of our statistical tests, we rejected the null hypotheses for p-values <0.05, i.e., we accept a 5 percent chance of rejecting a null hypothesis when it is true [69].

Before choosing the appropriate tests suitable to perform the core of the data analysis, we checked the normality of performance results obtained. The discrete nature of scores requires the adoption of a chi-square goodness-of-fit test [89] for evaluating the null hypothesis that the observed data are a random sample from a normal distribution, against the alternative one that the data are not normally distributed. In particular, with the chi-square goodness-of-fit test, the normality of scores has been rejected and, as a consequence, we adopt the nonparametric Wilcoxon Signed Rank [90], Mann-Whitney [91] and Kruskal-Wallis [92] tests, as well as a Bootstrap hypothesis testing [93], which that relax the requirement of normality in evaluating the experiment results.

The Wilcoxon Signed Rank (also known as one-sample Wilcoxon) is a nonparametric test that makes inference about the median of a population and provides a confidence interval for the statistic. It is based on evaluating two opposing hypotheses: H_0 (null hypothesis) the population median is equal to the tested value against H_1 (the alternative one) the population median differs from the reference value. The test requires that the observed distribution is symmetric. In our evaluation, this test has been adopted on questionnaire subjective impressions for assessing their average values (see Table 11).

The Mann-Whitney test (also known as two-sample Wilcoxon rank sum) is used to make inferences on two samples and, in particular, about the difference between their medians. Like the one-sample Wilcoxon, this nonparametric test also provides a Confidence Interval (CI) as an estimation of the difference between the unknown population medians. Concerning the samples,

the Mann-Whitney test requires the data to be independent. This requirement is accomplished by the design of our experiment so that the results obtained on each task can be considered independent, since:

- the tasks on which the comparison is based are suggested as a depth study by the class book and, as a consequence, performances are not influenced by students' previous experiences;
- the topics are different, and scores are in that way unrelated.

The Kruskal Wallis is a non-parametric alternative to one way analysis of variance (ANOVA [94], that requires the observed data to be normally distributed) that adopts the null hypothesis that no difference exists in the populations medians, against the alternate one that states some differences. This test requires the distribution functions to have the same shape and their variances to be equal. In addition, samples must be random and independent and each sample should consist of, at least, five measurements.

The Bootstrap is a montecarlo technique that performs a resampling with repetition on a set of data [93]. This statistical technique enables inferences on resampled data that, "under mild regularity conditions", are an approximation that is at least as accurate as first-order asymptotic theory approximations. In our analysis, we exploit the technique, as asymptotic refinement, for obtaining a statistic that is a consistent estimator of the asymptotic distribution of performance results. In particular, we exploited Bootstrap hypothesis testing for performing the evaluation of H_0 according to the test proposed by Efron and Tibshirani for comparing the means of two distributions [93]. Given two samples (let them be A and B), the test formulates the null hypothesis that there is no difference between the two probability structures that generated A and

B. In particular, Efron and Tibshirani proposed the technique of "mimicking" the null hypothesis with Bootstrap data. Indeed, by resampling the pooled combination of A and B, because of repetitions, the Bootstrap transforms the data "according to H_0". The starting samples' mean difference is then adopted as a reference value for a comparison between the original data and the Bootstrap sample, that enables to evaluate the likelihood of formulated hypotheses.

In addition to the tests for the hypotheses formulated in Section 4.2.2 Hypothesis Formulation and Variable Selection, we also evaluated the magnitude of performance difference achieved with the same user group with different methods. To this aim, we adopted the *Cohen d* effect size which indicates the magnitude of the effect of the main treatment on the dependent variables (whereas p-values reveal whether a finding is statistically significant, effect size indicates practical significance [70]. For paired samples, it is defined as the difference between the means (μ_1 and μ_2), divided by the standard deviation of the (paired) differences between samples (σ_D):

$$d = \frac{\mu_1 - \mu_2}{\sigma_D}$$

The effect size is considered negligible for $d < 0.2$, small for $0.2 \leq d < 0.5$, medium for $0.5 \leq d < 0.8$, and large for $d \geq 0.8$.

To evaluate any effect of other factors and their interaction with the performance results, we used Kruskal-Wallis tests [92].

To analyze the answer provided for each category of each category of the Perception Questionnaire (*μC is the average of the category C*, $\forall C \in \{IS; PU; PEU; PE; ATU; ITU; PHY E\}$) we performed Wilcoxon Signed Rank tests starting the comparison with the null hypothesis

µC < 4, where 4 corresponds to *Undecided* and going up, in the adopted Likert scale, to *Somewhat agree* (i.e., 5) and *Agree* (i.e., 6).

4.3 Results of the empirical evaluation

In this section we report the results of the controlled experiment. The experiment, detailed in Section 4.2.3 Experiment Design, provided us four groups of results (all the 59 participants completed the experiment successfully) that were adopted for evaluating the research question and the associated statistical hypotheses:

- Pre Experiment Questionnaire results concerning subjects' gender, skills in Geography, map navigation and gestural interfaces;
- GF performance scores obtained after navigating with the GeoFly tool, measured with the Post-Task Assessment Questionnaire, on a scale ranging from 0 to 5;
- NOGF performance scores after assisting to a classroom standard lecture, collected with Post-Task Assessment Questionnaire and arranged on a scale ranging from 0 to 5;
- Subjective impressions about GeoFly collected via a User Perception Questionnaire concerning Interface Style, Perceived Usefulness, Perceived Ease of Use, Perceived Enjoyment, Attitude Toward Using and Intention To Use.

GF and NOGF difference is a further result set adopted as a performance metric.

4.3.1 Effect of Method

Descriptive statistics of the obtained performances, grouped by treatment (GF and NOGF), are reported in Table 9. The results achieved are also summarized as boxplots in Figure 26. A

first observation on treatments revealed that GF performed better that NOGF, with medians respectively 3 against 1.

The chi-square goodness-of-fit test performed on performance results confuted the normality of GF scores, rejected with a p-value= 3.7604e-009, and of the NOGF ones (p-value= 4.7947e-009). As a consequence of the nature of results, we adopted the nonparametric tests and the Bootstrap resampling.

Dependent variable	μ	σ	$\tilde{x}$
GF	2,525	1,394	3
NOGF	1,678	1,456	1

Table 9: Descriptive statistics for learning outcomes.
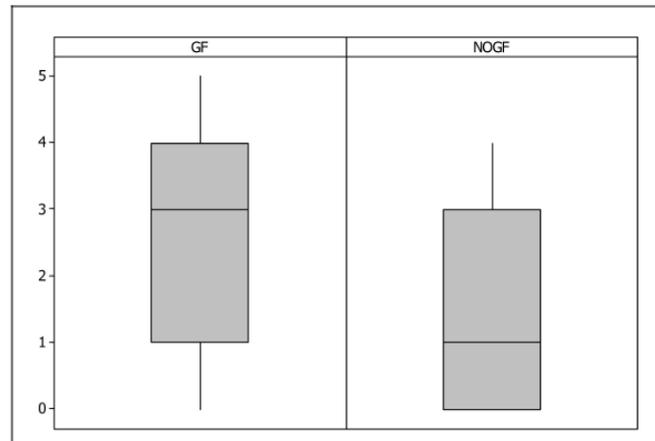
Figure 26: Boxplots of performances for different treatments.

In particular, to test the null hypothesis H_0, the effects of Method on the dependent variable IP have been analyzed both with Mann-Whitney as well as, with Bootstrap hypothesis testing. Applying the Mann-Whitney nonparametric test to the GF and NOGF samples, we statistically observed (at 95% confidence level) that GF performed better than NOGF (p-value = 0.0010 and a CI for medians in [-0.0001, 0.9997]). It was possible to reject the null hypothesis and state that there is a significant statistical difference between the student knowledge after playing with GeoFly w.r.t. the traditional lesson.

To stabilize our analysis respect to the not normal distribution of performance data, we also performed Bootstrap-based hypothesis testing [95]. In our case, the reference value for the comparison was the difference between the averages of GF and NOGF (t*=0.8475) and we pooled in the same vector GF and NOGF results before performing a 100000 Bootstrap resampling. Only in 84 samples out of 100000, the Bootstrap statistic adopted was larger than t* giving enough statistical evidence for rejecting H_0, with a p-value=0.00084. Obviously, the Bootstrap operation is not deterministic, but we noticed, in repeated tests, that our result were stabilizing around the fourth decimal digit.

The second Bootstrap was resampling both the GF and the NOGF results before computing the difference between the two resultsets. Figure 27 depicts the averages of differences between 100000 resampled GF and 100000 resampled NOGF, computed after bootstrapping the two resultsets. As graphically shown, the expected value is between 0.7 and 1 for more than half of the Bootstrap samples and signals an improvement of the performances obtained after studying with GeoFly (GF) respect to the traditional teaching paradigm (NOGF). Indeed, a set of paired Mann-Whitney tests, performed on bootstrapped GF against the bootstrapped NOGF, was rejecting the null hypotheses of no differences between means in 88747 cases out of 100000.
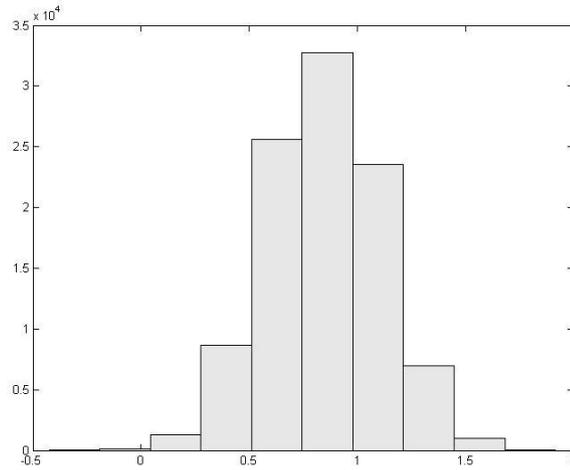
Figure 27: The distribution of difference averages after a Bootstrap on GF and NOGF performances scores.

With the Mann-Whitney and the Bootstrap analysis, we collected enough statistical evidence to assess a difference in performance due to the adoption of GeoFly. To measure this improvement we calculated the *Cohen d* effect size, which indicates the magnitude of performance differences achieved with the same user groups on the dependent variables. In our case, it is defined as the difference between the means μ_{GF} and μ_{NOGF} (reported in Table 9) divided by the standard deviation of the (paired) differences between samples σ_D.

$$d = \frac{\mu_{GF} - \mu_{NOGF}}{\sigma_D}$$

Since σ_D = 1.04, the effect size is d = 0.81. Concluding, we can reject H_0, with a positive and large effect size.

4.3.2 Analysis of Bias factors

The evaluation of the learning performances has considered also any possible interaction between the Method treatments and the bias factors described in Section 4.2.4 Bias factors. At this aim, we analyze these effects (if any) by means of Kruskal-Wallis Test and Table 10 shows the influence of these different factors on Method treatments. In particular, the Table reports the p-values of the tests between parentheses. As shown, no direct and significant interaction effect can be observed between the method and the other considered factors. In the following, we discuss in detail the influence of the factors on performance scores.

Effect of bias factors			
Geography attitude	Lab	Maps	Gestural Interf.
N(0.670)	N(0.736)	N(0.590)	N(0.582)

Table 10: Analysis of the Influence of bias factors on performances by Kruskal-Wallis (p-Values between parentheses).

4.3.2.1 Effect of Participants Geography attitude

The Kruskal-Wallis analysis of variance has been performed to asses any significant interaction between results and participants' attitude towards Geography. Our sample is characterized by 32 students that like Geography against 27 ones that do not. The application of a Kruskal-Wallis test to user performances (computed as GF-NOGF score) versus Geography, refuted this interaction with p-value=0.670. This excludes (in terms of statistical evidence) that

the results of the experiment are biased by user passion or antipathy for Geography. The effect of Participants' Geography attitude can be better analyzed by looking at the interaction plots of the population means in Figure 28. As can be noted, the GF treatment helped all (participants that like (Y) and dislike (N) Geography) in improving their performances, although participants with a positive Geography attitude performed better. It is important to point out that the GF treatment reduced the gap between participants with positive and negative Geography Attitude.
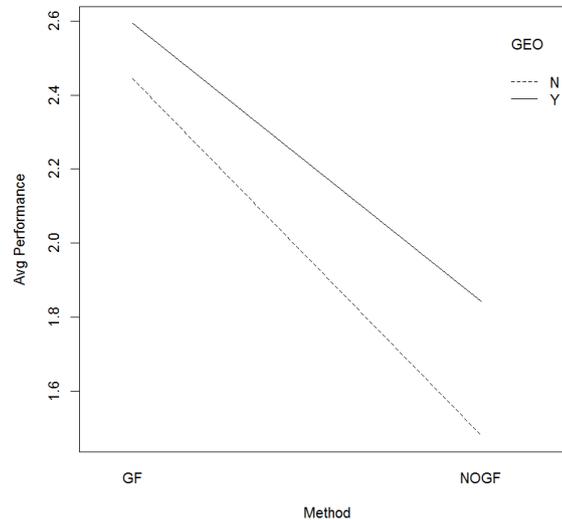

Figure 28: Interaction plot of performances and Geography attitudes.

4.3.2.2 Effect of the Lab

The design of the experiment has to be checked respect to factors that can alter the obtained results. One of the possible sources of wrong conclusions is related to the difficulties of the two

tasks that are at the basis of the organized comparison. Even if the experiment has been designed adopting a fully balanced schema (half of the students solves task 1 using GeoFly, and the remaining subjects experiment the Kinect driven navigation on task 2), a difference in terms of difficulty can still undermine the value of the proposed comparison. At this aim, the Kruskal-Wallis Test performed on all user performances (task 1 and 2) versus Lab, with a p-value= 0.736, did not give us enough statistical evidence for hypothesizing, as a consequence of differences in task difficulty, an influence on performances. This results provides also evidence about the absence of a significant learning effect between the two tasks proposed to students.

4.3.2.3 Effect of attitude with Maps

GeoFly adopts Virtual Globes for organizing its geographical content. As a consequence, a bias source for conclusions may be related to user confidence with the adopted Map instrument (in the sense of practice with Virtual Globes). According to the pre experiment questionnaire, the results can be organized in two groups: 39 students are confident with Maps while 20 are not. To confute the relationship between GeoFly performances and confidence with Maps, a nonparametric Kruskal-Wallis test has been performed. In this case, the p-value=0.590 did not support any difference in performances that can be detected among different levels of user practice with Virtual Globes.

4.3.2.4 Effect of attitude with Gestural Interfaces

The novelty introduced by gestural interfaces may bias the results of the experiment. At the aim of evaluating if any interaction may be deducted in the case of users confident with gestural

interfaces, we performed a Kruskal-Wallis Test aiming at evaluating the effect of previous user experiences with gestural interfaces (i.e., system based on Nintendo Wii Motion Controller, Sony PlayStation Eye/Move or Microsoft Kinect) and their impact on GeoFly performances. Our subject sample is composed of 31 students confident with gestural interfaces and 28 without experience with gestures. The result of this test (p-value=0.582) did not give us enough statistical evidence for hypothesizing any differences between GeoFly performance scores in the case of different levels of user practice with gestural interfaces.

4.3.3 Survey Questionnaire Analysis

In addition to the objective analysis presented in the previous sections, we carried out a subjective analysis by exploiting the feedbacks provided by each participant filling in the User Perception Questionnaire. This investigation was carried out to check whether GeoFly is able to motivate the students in the learning process. Figure 29 shows that the proposed system has been appreciated by all the students. It is considered interesting and able to motivate subjects to learn. The rightmost boxplot in this figure concerns the opinions related to the perception of the physical effort needed to control the Virtual Globe and should be reversely interpreted. Most of the children were not tired after the experience.

To verify that the average answer provided for each category of the questionnaire is at least Somewhat agree (i.e., 5), we performed a Wilcoxon Signed Rank test for the null hypothesis $\mu C < 4$, where 4 corresponds to *Undecided* and μC is the average of the C category, $\forall C \in \{IS, PU,$

PEU, PE, ATU, ITU, PHY_E}. The same test was also performed against the greater scores (somewhat agree (5) and agree (6) of the Likert scale) and Table 11 reports the results. Specifically, we can observe that the median is under 6 only for two categories, since the p-value is over 0.05 (significance level adopted) for PEU and PHY_E and the null hypothesis of median equality cannot be rejected. However, also for these two categories, the expected median is greater than 5, on average.
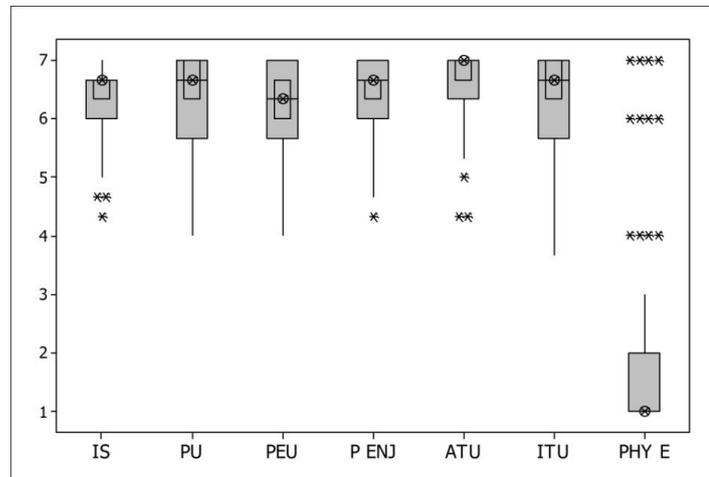

Figure 29: Perception results.

Hypothesis	IS	PU	PEU	P_ENJ	ATU	ITU	PHY_E (reversed)
H_0: $(\mu C < 4)$	Y(0.000)	Y(0.000)	Y(0.000)	Y(0.000)	Y(0.000)	Y(0.000)	Y(0.000)
H_0: $(\mu C < 5)$	Y(0.000)	Y(0.000)	Y(0.000)	Y(0.000)	Y(0.000)	Y(0.000)	Y(0.001)
H_0: $(\mu C < 6)$	Y(0.001)	Y(0.001)	**N(0.062)**	Y(0.000)	Y(0.000)	**N(0.022)**	**Y(0.135)**

Table 11: Participant Agreement .

Figure 30 shows the acceptance of the system w.r.t. the different Geography attitudes of the participants. It is possible to observe that all the two groups (Yes, No Geography Like) revealed a good acceptance of the proposed approach, since all the means of each category are greater than 5, for both the groups.
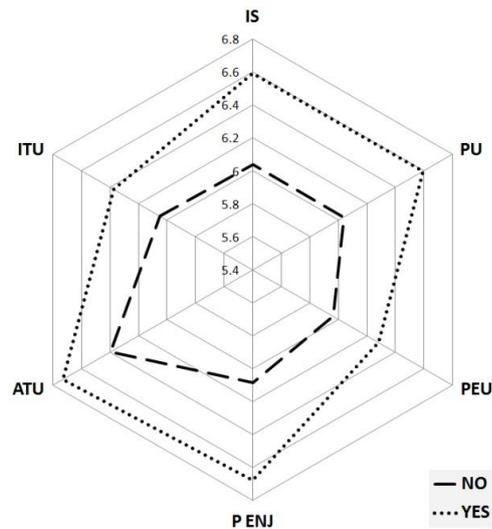
Figure 30: Perceptions classified w.r.t. Geography attitudes.

4.3.4 Threats to Validity

We discuss the threats to validity that could affect our results, focusing attention on construct, internal, conclusion, and external validity threats.

Construct validity threats concern the relationship between theory and observation. They can be mainly due to the measurements used to assess the performances. The adopted measures are

derived from the answers to a questionnaire proposed by the teachers during their assessment activities. Concerning the selection of participants, we observed that the selected students belonged all to classes of the same year of the same school. They have different attitude towards Geography learning. The survey questionnaire was proposed and evaluated in [67]. It adopts a Likert scale, to facilitate its evaluation and aggregates the single questions in 6 categories.

External validity concerns the possibility of generalizing our findings. The participants were all target users, primary school children, thus the results obtained are generalizable to this user category. Other external validity threats are represented by the tasks assigned to the subjects. The tasks we selected were taken from the students' textbook and proposed together with their teachers. Thus, they are representative of the typical Geography learning activities conducted in a classroom.

Conclusion validity concerns the relationship between the treatment and the outcome. Regarding our experiment, proper tests were performed to statistically reject null hypotheses and we were carefully checking their requirements. Since the data were not normally distributed, we applied the nonparametric Wilcoxon Signed Rank, Mann-Whitney and Kruskal-Wallis tests to experiment results. In addition, we also performed Bootstrap analysis and hypothesis testing. Aiming at testing the presence of significant differences, we also evaluated the different magnitude using the *Cohen d* Effect Size. The application of Kruskal-Wallis test needs the distribution functions of data to have the same shapes. In this case, the assumption is not accomplished and this can introduce threats to the validity of the conclusions deduced from the test. As a partial solution to this issue and a further check on our analysis, we exploit the ANOVA robustness respect to deviation from normal distribution, even if it may not be the most powerful test available for nonnormal distributions ([96] and [97]).

The ANOVA analysis of variance confirmed that no significant interaction is present between Treatment and participants' attitude towards Geography (Method:GEOLike *p-value* = 0.688).

In addition, the results of the test did not indicate any significant effect of the Lab factor on the Treatment (*p-value* = 0.740). This result provides further evidence about the absence of a significant learning effect.

Conclusion

This research work has investigated and experimented the adoption of 3D Virtual Worlds combined with innovative interaction modalities, for student engagement and didactic success in the classroom.

The experimentation was conducted in two learning domains: Environmental Education and Geography learning.

In both cases we get a significant improvement of didactic experience in terms of student involvement and acquired skills. In particular, Pappi World received positive evaluations both from children and teachers. The log analysis revealed that the children largely adopted the social features of the game and were enthusiast of the competitive approach.

We also collected many useful tips from teachers for Pappi World, such as:

- to implement the concept of "Zero Km";
- to test the game in the long run to assess the impact on the behavior of young people;
- to develop a support tool for teaching the guys with special needs.

Respect to Geography learning, GeoLike collected a specific positive result: children not liking Geography also improved their performances and the gap respect to the other participants (the ones liking Geography) was reduced. Gestures and Virtual Globes give emphasis on the main principles of Geography learning for primary school children, such as acquiring a sense of place and space, familiarizing with maps and globes and getting geographical investigation skills.

In summary, these experiences revealed that positive results can be reached by adopting Virtual Worlds to support learning when their use is accompanied by specific pedagogical

approaches (such as social approaches) and/or by the adoption of interaction modalities that result appealing for the students.

At present, we are planning to adopt the proposed approach also for supporting the social learning related to the study of cities and their monuments.

Publications

- *Journals*

– S. Cuccurullo, R. Francese, I. Passero, G. Tortora (2013). Geography learning in Virtual Globes via Body Interaction. Submitted, 2014

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