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CUBICA: An Example of Mixed Reality

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Abstract: Nowadays, one of the hot issues in the agenda is, undoubtedly, the concept of Sustainable Computing. There are several technologies in the intersection of Sustainable Computing and Ambient Intelligence. Among them we may mention “Human-Centric Interfaces for Ambient Intelligence” and “Collaborative Smart Objects” technologies. In this paper we present our efforts in developing these technologies for “Mixed Reality”, a paradigm where Virtual Reality and Ambient Intelligence meet. Cubica is a mixed reality educational application that integrates virtual worlds with tangible interfaces. The application is focused on teaching computer science, in particular “sorting algorithms”. The tangible interface is used to simplify the abstract concept of array, while the virtual world is used for delivering explanations. This educational application has been tested with students at different educational levels in secondary education, having obtained promising results in terms of increased motivation for learning and better understanding of abstract concepts.

Keywords: Human-centric interfaces for AmI environments, ubiquitous and ambient displays environments, collaborative smart objects
Categories: H.1.2, H.5.2, K.3.1, L.3.1, L.7.0

1 Introduction

Nowadays one of the hot issues in the agenda is, undoubtedly, the concept of Sustainable Computing. Ambient Intelligence technologies may contribute to sustainability in many ways, as the core of Ambient Intelligence is related with understanding the environment and being able to actuate on it in an intelligent way. Several technologies are in the intersection of Sustainable Computing and Ambient Intelligence. Among them we may mention “Human-Centric Interfaces for Ambient Intelligence” and “Collaborative Smart Objects”, which will play an important role in applications such as smart cities, environmental monitoring, and smart control for eco-friendly buildings (see section 6). In this paper we present our efforts in developing these technologies for “Mixed Reality”, a paradigm where Virtual Reality and Ambient Intelligence meet.

Mixed Reality is based on the idea of making Virtual Reality and the real environments to be the same thing. In the view of this paradigm, the environment of a person is both real and cybernetic, and none of them prevails over the other. We propose the use of Tangible Interfaces (a technology related with “Smart Objects” and with “Human-Centric Interfaces”) to integrate the virtual world in the smart environment. In this way, events that take place in the smart environment have an effect in the virtual world, and events that take place in the virtual world have an effect in the smart environment, that is, in the real world. In this way, the user "lives" both worlds in an integrated way.

This paper presents a prototype that implements these ideas, as well as an experiment of using it in a specific application area. The technologies that have been developed are general and can be used in many other application areas, as they are related with achieving the integration of smart environments with virtual worlds by means of tangible interfaces. The application area that has been chosen for testing these technologies is education.

The constant evolution of technology is a key factor in the development and adaptation of educational models based on Information and Communication Technologies (ICT). 3D virtual environments such as World of Warcraft, The Sims, and Club Penguin have achieved significant popularity and acceptance among teenagers; thus there is a good prospect of incorporating virtual worlds as a learning tool.

A virtual world can be defined as "a persistent and synchronous network of people, represented by avatars, in a network of computers" [Bell 2008]. Virtual worlds may provide a wide variety of educational experiences using different tools, including interactive text and voice chat. These experiences allow developing different skills, e.g. more advanced communication skills may be developed through interaction with other avatars in real time.

Virtual worlds may provide significant improvements in students' motivation and interest, encouraging their active participation in learning experiences. 3D virtual worlds offer an environment for creating spaces where teachers and learners, although being geographically separated, nevertheless can engage in social learning activities, offering the participants a sense of presence and immediacy that is unavailable within other traditional Internet-based learning environments [Bronack, 06].

The use of virtual worlds allows students to explore and to experience new sensations in a constructivist approach [Vygotsky, 78] in which students build their own learning through interaction with the environment and with other students. Virtual worlds allow the development of activities in which students can improve their social skills through activities. They also allow creating scenarios in which the student is assigned a certain role (role playing) and she must learn to make decisions and to deal with the consequences. The integration of these capabilities with the "real world" enhances significantly its possibilities. Following this idea, this paper describes a system that aims to achieve these pedagogical objectives using virtual worlds blended with tangible interfaces in what has been called "mixed reality".

The rest of the paper is structured as follows. Chapter 2 presents a brief overview of existing work on Virtual Worlds and Tangible Interfaces in education. Chapter 3 presents the "Cubica" system, our proposal for "mixed reality" technologies. Chapter 4 describes the experiment that has been made to test the real impact of these technologies. Chapter 5 analyzes the results obtained. The rest of the paper presents the conclusions, future work and references.

2 Virtual Worlds, Tangible Interfaces and Education

Virtual worlds can be used in several ways with the goal of improving student skills in different areas, providing innovative educational opportunities. In this section some educational projects that deal with different aspects of learning will be reviewed, focusing on situated learning (within specific contexts), and on social, language and collaboration skills.

The River City Project [Ketelhut, 07] is a project for secondary education in which students travel back in time to the 19th century. River City is a virtual city in which citizens are supposed to be sick. The students have to investigate and to explore the city in search for evidence and clues for the reason of the plague. They may speak with residents of the city, take samples of water or insects, visit the hospital, etc. This project represents a kind of situated learning where students must solve the problems through exploration and interaction in virtual worlds. Working in a virtual world encourages the students to develop critical thinking through activities that allow them to interpret, analyze, discover, evaluate, and act in a realistic problem.

The Vertex Project [Bailey, 02] took place in primary school education in the UK with children in the range of 9-11 years old. Students worked in groups, combining traditional activities –such as creating a collage or writing a story- with the creation of their own virtual worlds. These activities allowed them to develop their imagination and to work different areas of the curriculum (literature, art, ICT…) Students improved their communication skills, learned to cooperate, and increased their self-esteem and confidence. The Vertex project is based on the constructivist approach, acknowledging the importance of learning by making, and focusing on using the imagination and gaming as two important factors in learning.

The NIFLAR Project [Jauregi, 10] is a European project completed in 2011 that was aimed to improve foreign languages teaching by using virtual worlds and communication through videoconferencing. They conducted sessions in which secondary school students in Spain and the Netherlands interacted with each other with the aim of improving social and intercultural learning. Other examples of projects related to language learning are the AVATAR project [Feliz , 09] and the AVALON project [Deutschmann, 10].

The ABV4Kids&Teens Project involves a cooperative team of experts and schools from Germany, the United Kingdom, Norway, Poland and Israel, being funded by the Comenius Program of the European Commission. The main goal is to help students and teachers to better understand the different European cultures, languages and values. They have created a virtual town called Anti-Bullying-Village [ABV, 12] in which events are held on racism, xenophobia, violence, and school bullying. This project allows the cooperation among young people in Europe in order to develop language skills and also to learn about various social and cultural aspects.

Virtual worlds may help to deal with inclusive education. For example, Brigadoon is a virtual island in Second Life that is used to help people with autism and Asperger syndrome. Other example in this line is using virtual worlds to facilitate the initial adaptation of immigrant students, as in the Espurna Project [Espurna, 13], where language and cultural aspects undermine the educational possibilities of low-income immigrant students.

Virtual worlds may also be used for teaching computer science. For example, the V-LeaF Project [Rico, 09] taught computer programming in an innovative and attractive way. Virtual worlds such as OpenSim or Second Life allow creating 3D objects and then providing behaviour to these objects by means of a programming language called LSL. This project was carried out in secondary schools in Spain.

Virtual worlds may be criticized for making the student "loosing contact" with reality. Just the opposite approach would be to locate some computation in the real world, thus enriching normal objects with computational functionalities. This is what has been called the "tangible interfaces" approach.

[Ishii, 97] proposed the term "tangible user interface" (TUI) as an extension of the conceptual framework "graspable user interface" proposed by [Fitzmaurice, 95] in order to link the physical and digital worlds. Tangible interfaces are useful in the educational domain because they allow hands-on activities and manipulation of physical artefacts. According to [Marshall, 07] some possible learning benefits of these activities are:

- Development of motor skills through physical activity.
- Development of collaborative skills.
- Younger children learn intuitively through a "hands-on" approach.
- The novelty of the experience improves motivation.
- Learning by playing is very effective.

From their early infancy children use all their senses to explore the world around them. Direct contact and interaction with the physical world are vital for the development of cognitive and motor skills. The use of tangible interfaces as an educational tool can help the assimilation of abstract concepts using analogies with tangible elements. It also can be used for empowering collaborative work, which would allow for a more active participation in class and the improvement of social skills. A brief review on the use of tangible interfaces in education is presented below.

According to [Zuckerman, 05] tangible interfaces in education can be classified in two types: "Froebel-inspired Manipulatives (FiMs)" and "Montessori-inspired Manipulatives (MiMs)".

The FiMs use modelled structures in order to represent the real world, for example a LEGO bricks construction that is used to represent a real-world object. Some projects that use this approach are ActiveCube [Kitamura, 01] , Block Jam [Newton-Dunn H., 2003], and Topobo [Raffle,04].

Topobo is a 3D system with kinetic memory that provides the ability to record and playback physical motion. By combining tangible components, students can quickly create biomorphic forms -such as animals, skeletons or robots- and then animate them by recording and reproducing movements. For example, you can build a tangible dog, which then can be taught to walk or to sit.

On the other hand, the MiMs approach is based on creating tangible abstract structures in order to help learning abstract concepts in domains such as mathematics, computer science or probability theory. The MiMs approach also uses building blocks in order to encourage children to make analogies among the abstract concepts and the real life. The prototype proposed in this paper (the Cubica system) uses the MiMs approach to explain the abstract concept of algorithm: students can interact and explore with a tangible interface that represents the abstract concept of “array“.

Examples of projects that use the MiM approach are FlowBlocks [Zuckerman, 05] and SystemBlocks [Zuckerman, 05]. FlowBlocks uses tangible artefacts to implement mathematical concepts such as “probability“ or computer science concepts such as “looping“, “branching“ and “variable“. SystemBlocks can simulate system dynamics, such as water flowing through a bathtub or food-chain models, by using tangible structures that represent stocks and flows.

One area that is specially suited for using tangibles interfaces is kindergarten and primary education. Collaborative activities -such as storytelling- develop young children’s imagination and foster creativity.

[Africano, 04] proposes the use of interactive games to promote collaborative learning. The system is provided with a set of tangible interfaces that are used by students to explore geography and foreign cultures. Elements such as postcards, a multitouch table, a camera, several knobs, etc. allow interacting with “Ely the explorer”, the computer character on the screen that serves as a link between the digital content and the tangible world.

[Stanton, 01] describes the process of creating tangible interfaces for a collaborative drawing tool called KidPad. KidPad is used to create narrative stories by means of collaborative activities in small groups. The tangible interface is a “magic carpet”: a pressure-aware tangible interface that is combined with video monitoring in order to allow kindergarten students creating stories.

[String, 04] proposes Webkit, a system for working the persuasive skills of the students, providing support for the different phases of the rhetorical process. A Webkit application is composed of a set of statement cards, each of them containing a RFID tag (radio-frequency identification tag) and an output light. The application has five argument squares that contain RFID-reading radio antennas, a “magnifying glass” square which also contains a RFID-reading antenna, and a projection screen on which the graphical user interface is projected. The teacher proposes a specific topic and the student must arrange the statement cards on the argument squares in order to create an argument.

Tangible interfaces help to learn abstract concepts in areas such as computer science. There are several educational projects where tangible interfaces are used for “tangible programming“: the students use a physical language that allows them to learn or to improve their programming skills. The majority of these projects use as tangible interfaces bricks (e.g. pieces of LOGO) and programming consists in putting together bricks to obtain a specific sequence.

[Horn, 07] proposes a system for teaching programming using a physical interface that facilitates the use of a complex programming syntax, and that is shown to improve the programming style and to create a positive climate in classroom. They have created two tangible programming languages to be used in the final year of primary school and in middle school. The first tangible language is Quetzal, which is used to control LEGO MINDSTORMS robots. The second tangible language is Tern, which is used to control virtual robots in a computer screen. The elements used by the language Tern are similar to pieces of a jigsaw puzzle, thus providing a physical constraint when constructing programming statements.

Tangicons [Scharf, 08] is similar to the previous project, but it is aimed to kindergarten children who are learning the basic concepts of programming by interacting with tangible programming bricks.

TurTan [Gallardo, 08] is a tangible programming language for creative exploration, which uses a tabletop interface with tangible objects in order to learn and explore the basic programming concepts in a playful, enjoyable and creative way. It is addressed to children and non-programmers and was inspired by turtle geometry.

[Timothy, 2004] proposal is designed for learning geometric concepts in physical space. It uses the Logo language with the goal of teaching programming concepts.

AlgoBlock [Suzuki, 93] is a tangible videogame where the student drives a submarine through an underwater maze, using a programming language similar to Logo. Suzuki and Kato, the developers of Algoblock, proposed the term of “tangible programming” for this kind of activity.

Garden Alive [Ha, 06] is a garden where you can interact with tangible interfaces. This system has cameras that detect hand gestures and sensors that detect light and water. Plants grow virtually according to sensor measurements and exhibit emotional states as a reaction to user interactions.

Some conclusions may be learned from these projects. In first place, both using virtual worlds and using tangible interfaces seem to be effective approaches for developing creative and collaborative skills, as it is illustrated for example by The Vertex Project [Bailey, 02], “Ely the Explorer” [Africano, 04] or the “magic carpet” [Stanton, 01]. The same pedagogical objective can be achieved using any of these two different approaches, thus there is a good prospect that combining both (virtual worlds and tangible interfaces) would increase this desirable characteristic.

It can also be noted that tangible interfaces projects, being the output of graphical nature, used computer screens for output in first place, then used digital projectors and finally used tabletop surfaces. Using a virtual world for output seems to be the logical next step in this direction.

Most of the reviewed projects on tangible interfaces are specifically aimed at children. The use of tangible interfaces seems to be more effective in early ages because children need direct interaction with physical artefacts in order to develop cognitive and motor skills. However, there is a good prospect of obtaining good results also in secondary education: more effort in this educational level is needed.

We can classify the reviewed projects according to their directionality: virtual to physical and physical to virtual. In virtual to physical projects the work is done in the computer, and then the results are reflected in the real world via a tangible interface (e.g. a program is written in the computer and the results are reflected in the real world through an animated toy or robot). In physical to virtual projects the interaction starts in the real world, using tangible interfaces, and the results are reflected in a computer screen in a graphical way (see for example, AlgoBlock [Suzuki, 93] or Garden Alive [Ha, 06]). It seems a reasonable next step to blend both directions (virtual to physical and physical to virtual simultaneously) in a “mixed reality” system.

Reviewed projects use a wide variety of technologies and software. A lack of homogeneity and interoperability may disturb the spreading and sharing of such educational solutions. It is very important to make an effort in order to integrate these technologies, taking into account the opinion of the educational community about the suitable technologies or platforms to apply at school.

Finally, many projects are only carried out as prototypes at laboratories; it is important to deploy the technology at a real classes and analyze the results of these experiences.

As a conclusion, the integration of virtual worlds and tangible interfaces seems to offer good opportunities to improve computer-based educational systems. This integration may exploit powerful synergies between the virtual and the “real” world, allowing a more vivid educational experience. Thus, this paper proposes a system that uses virtual worlds and tangible interfaces in order to explore such a “mixed reality” concept.

3 The Cubica System

The Cubica system uses tangible interfaces to combine the real world with a virtual world, thus providing a “mixed reality” experience. In order to test these technologies, an educational application was developed.

The pedagogical objectives of the application were: to improve students’ motivation and interest; to encourage their active participation in learning experiences; to explore a constructivist approach in which students build their own learning through interaction with the environment and with other students; to foster more advanced communication skills; to motivate engagement in social learning activities; to empower collaborative work teaching how to cooperate; to help the assimilation of abstract concepts using analogies with tangible elements; and to develop creative skills.

The choice of the virtual world platform is a key issue for several reasons. On one hand, the virtual world must be suitable for secondary education: it has to be a closed and controlled environment. For example, Second Life is a well known virtual world, but access is not allowed for users under 18 years old, and therefore it cannot be used at secondary schools. On the other hand, a virtual world with open communication protocols is to be preferred, as it has to be connected and synchronized with the real world.

Considering these two requirements OpenSimulator [OpenSimulator, 13] was chosen as the development platform. It allows the implementation of a controlled environment suitable for high school students, and it uses the same communication protocols as Second Life, but being distributed as open source software under a BSD license.

The limitations that are found in public schools at Spain imposed some requirements in the design of the system. In general, public schools at Spain have computers with limited capacity, low bandwidth internet access, and some firewall restrictions. Considering these limitations, an OpenSimulator (OpenSim) server was installed within the high school local area network (LAN) to overcome bandwidth and firewall restrictions.

The classroom where this experiment was conducted had 20 computers that used the LliureX operating system (a Linux distribution that is specific for educational institutions in Valencia), but due to limitations in the network and in the server only

10 computers were connected simultaneously to the virtual world. In each computer a 3D OpenSim viewer was installed.

A virtual world was implemented, called Algoritmia Island, in which students could visit different thematic houses where they were taught about sorting algorithms. In the thematic houses students found different animations, notice boards, exercises, links to web pages, QR codes, videos of animations on sorting algorithms, and other educational materials.

Figure 1: The Algoritmia Island

The thematic houses were virtual houses where the students could learn about sorting algorithms by interacting with different materials and by performing various activities. The thematic houses could be seen as virtual interactive museums on sorting algorithms.

There were four thematic houses: the first one was used to introduce the basic concepts about the topic. (e.g. “What is an algorithm?” or “What is an iteration?”). In order to learn and understand these concepts the students examined different examples of daily activities (e.g. the process of changing a light bulb).

The three remaining houses represented the three sorting algorithms that had to be studied: bubble sort, selection sort and insertion sort (see Figure 1). In each thematic house, students could watch a simulation of the corresponding sorting algorithm, and explore various educational materials on the topic.

Additionally, in “Algoritmia Island” there were places to learn other skills, like how to move an object in a 3D space, or how to program a simple script using a specific programming language for this virtual world called LSL (Linden Scripting Language).

Figure 2: the Bubble Sort Thematic House

Figure 3: Example of explanatory panel in a thematic house

Each thematic house offered various resources for learning sorting algorithms (see Figure 2 and 3): a running simulation of the algorithm, a panel with the pseudo code of the algorithm, links to web pages with additional material, etc.

In order to implement “mixed reality”, middleware software was created for linking the virtual world with the tangible interfaces in the real world. This middleware used the LibOpenMetaverse library [LibOpenMetaverse, 13]. LibOpenMetaverse is a .NET based client/server library used for creating and interacting with 3D virtual worlds such as OpenSimulator or SecondLife.

The core of the middleware software implemented the protocol, networking and client functionality. A Non Player Character (an avatar controlled by a program) was created inside the virtual world to be in charge of sending and receiving messages between the virtual world and the tangible interface. This communication was implemented as a middleware that acts as a mediator among the physical devices and the virtual world: when somebody modifies the state of the tangible interface, the change is propagated to the virtual world and vice versa.

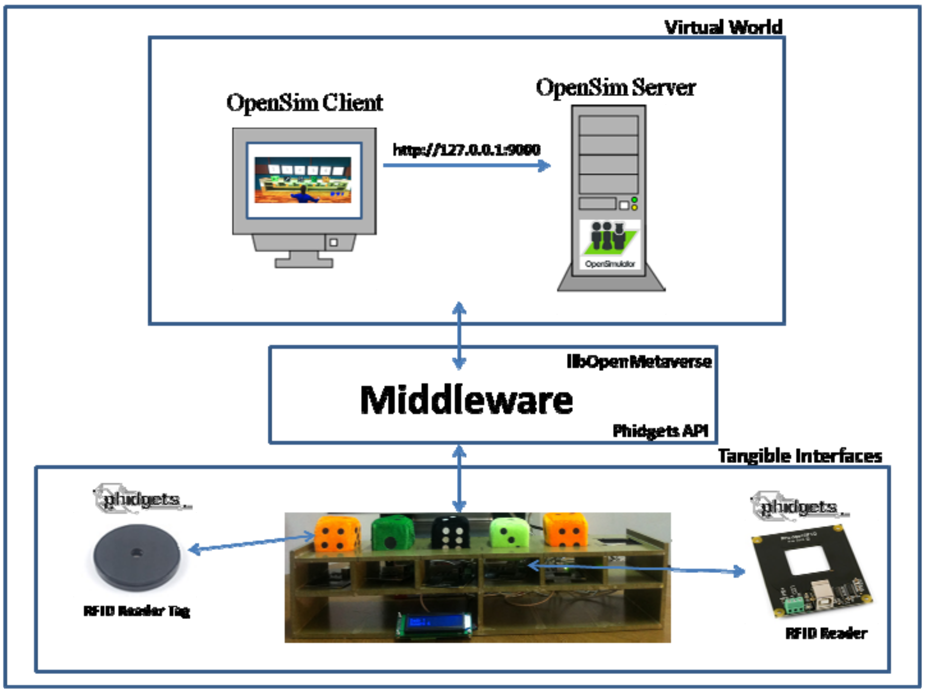

Figure 4: The Cubica System Architecture

Although this middleware may be used to interact with any tangible interface, a particular one was developed as a proof of concept. For this, Phidgets technology was used. Phidgets are low cost electronic components -sensors and actuators- that are controlled by a computer via USB. Although other alternative technologies could be used (e.g. Arduino), Phidgets were chosen because they are very simple to use and they are reasonably priced. The middleware was implemented using C# language and it contained the libraries to connect with the tangible interfaces (Phidgets) and the library to connect with the virtual world.

One of the problems while teaching computer science at secondary schools is the high degree of abstraction that is involved in the subject. The assimilation of abstract concepts may be facilitated by using “tangible” elements that are analogies or metaphors of these abstract concepts. In this line, the Cubica system implemented a tangible interface that represented the concept of array.

Figure 5: Mixed reality: the "array" tangible interface

The tangible interface had five holes representing the five vector elements. Cubes (dices) were used to represent the values of the elements of the array (see Figure 5). RFID readers were used to read each element of the array: RFID tags were inserted inside the cubes. The values of the different positions of the array were sent to a simulation of the array that was represented inside the virtual world, and which was synchronously updated using this information. The tangible interface also featured an LCD display that showed auxiliary messages, such as the number of iteration during a sorting process.

The objects In Algoritmia Island are programmed using the LSL programming language. This language allows modifying the state of an object according to the state of the tangibles artefacts. For example, when a specific die is put in a hole in the wooden model, the middleware receives a signal reporting this event and sends the adequate message to the virtual world in order to change the state of the corresponding object.

4 An Experiment Using Mixed Reality

The Cubica system was tested in a series of experiments carried out in a school of secondary education in Valencia, Spain. Each experiment was organized in 3 one-hour sessions, involving students at various academic levels: the fourth year of secondary education (ESO), two different groups of middle-level professional courses

(FP) and a small group of 2nd-Bachillerato students (last year before university). It has to be noted that the subject is a mandatory course for FP students, and optional for the rest. The same experimental design was used for all of them.

Each group had an average of 15 students that worked in pairs, due to constraints in the number of computers and bandwidth available, as well as to encourage peer tutoring. At the beginning of each experiment the teacher explained the basic aspects of using virtual worlds, such as the need of a 3D viewer to connect to the virtual world and the need of an avatar (a representation of each student in the virtual world) to access the "Algoritmia Island". After this explanation, the teacher provided the credentials of their avatars and they entered the virtual world.

The first session was an introduction to the use of virtual worlds. The first task was to change the appearance of their avatars and then to explore the virtual island learning the basic use of the interface (walking, communicating with other avatars, reaching the different places in the island, etc.) After this initial step, the students practiced how to create objects, how to change their textures and colours, how to move them, how to use the coordinate axes in 3D space, and -very briefly- how to program the behaviour of objects by creating scripts.

In the second session the teacher explained the concepts of algorithm, loop, array and iteration, which were needed to follow the sessions. The teacher explained these concepts in reference to the system, for example making clear the concept of "array" using the tangible interface. Once the main concepts were discussed, students began to explore the four "thematic houses" in the virtual island. One of them offered an introduction to the concepts of algorithm, iteration, array, and other basic notions. The other three houses were devoted to three specific sorting algorithms. In each house there were a number of teaching resources such as panels, QR codes that link to You-tube videos (for example, Bubble Sort explained with Hungarian folk dance), animations of sorting algorithms, exercises, etc.

In each "thematic house" the student interacted with a virtual model of the tangible interface, which showed an animation of the sorting algorithm. The student then used the tangible interface to check whether she had properly understood the algorithm. At every moment the system kept the consistency between the virtual world and the tangible interface, thus offering an experience of "mixed reality" (see Figure 6). At the end of the activity the system, through an LCD screen, indicated whether what has been done by the student matched any of the algorithms studied and whether it was advisable to re-visit again any "thematic house". Students could also review the topics using Sloodle (an open source e-learning platform that integrates Moodle with OpenSim) accessing glossaries and auxiliary materials.

Figure 6: A student using the tangible interface

In order to promote collaborative work, the teacher finally proposed an activity in which two teams competed to sort as quickly as possible a given array. In the virtual island there were two boards on the ground, one for each team, and a giant dice. One of the members of the team was in charge of moving the cubes in the virtual world for each iteration of the algorithm. So they used chatting to coordinate the work and to achieve the correct ordering. This activity allowed students to work the skills acquired in the virtual world and to organize themselves for collaborative work.

In the third session, students continued performing exercises and practicing with the training panels available in the Algoritmia Island.

Each student then performed two tests using the tangible interface. In each test the teacher proposed an array and the sorting algorithm to be used; the student had to carry out the corresponding iterations until the array was sorted. After each test was done, the system showed in the LCD screen whether it had been passed, and the result was also published in the Twitter account of the teacher.

Finally they filled a survey to assess whether the use of virtual worlds and tangible interfaces had motivated them and helped them to better understand sorting algorithms and some of them performed a written test with a series of exercises to confirm that they had understood the sorting algorithms.

5 Analysis of the results

As explained above, the experiment was carried out with several groups of students, at various educational levels. After each experiment, the students were administered a paper test and/or a survey, to check the usefulness of the system (both perceived and objective). In total, 42 students participated in the sessions. The results are summarized in the following tables:

Questions	**Yes**	**No**
Have you ever played with 3D virtual world games (World of Warcraft, Sims…)?	36(86%)	6(14%)
Did you find the system easy to use?	42(100%)	0(0%)
Do you think that the system has been helpful to understand the concept of array?	40(95%)	2(5%)
Did you understand better the sorting algorithms using virtual worlds with respect to the explanation on the blackboard?	35(83%)	7(17%)
Has the use of the system helped you to answer the exercises?	33(79%)	9(21%)
Has the use of the system helped you to distinguish among different sorting algorithms?	37(88%)	5(12%)
Has the tangible interface been helpful to understand how sorting algorithms work?	41(97.6%)	1(2.4%)
Do you think the use of virtual worlds has motivated you to work harder in class?	38(90.5%)	4(9.5%)
Have you found interesting the sessions in which you interacted with virtual worlds?	42(100%)	0(0%)
Would you spend more time studying at home if you could use virtual worlds there?	35(83%)	7(17%)
Would you like to participate in further sessions?	42(100%)	0(0%)

Table 1: Results of the survey of 42 students

Analyzing the survey (see Table 1), the first thing that can be noticed is that many students had previous experiences with 3D virtual environments such as World of Warcraft, Sims o Club Penguin: 86% of students who participated in the sessions had interacted before with such 3D virtual environments, mainly for gaming. This willingness in using 3D virtual worlds made the students showing more interest and being more receptive during the sessions, as they were using what they perceived as a funny environment. Thus the objectives of achieving “learning by playing” and “learning by doing” were met: the students were protagonists of their own learning. Furthermore, the data from the survey shows that 65% of the students thought that the use of virtual worlds had motivated them to work harder than they would have done in traditional classes and 83% of students said they would devote more time to study at home if they could use virtual worlds there.

The above data is related with the learning curve in using virtual worlds: the fact of having interacted previously with 3D games allowed them to quickly adapt to the environment, so that 100% of students found the interaction with virtual worlds easy or very easy: it seems that this learning curve was not very steep. Even students in the first year of ESO had their avatars customized in minutes, being able very quickly to move around the virtual island and even to create or modify objects.

83% of students believed they had achieved a better understanding of sorting algorithms by using virtual worlds and the tangible interface, compared with traditional methodologies (blackboard, paper…) The use of virtual worlds also allowed the students to involve in collaborative activities in a more orderly fashion, using text chatting and having frequent interactions among them inside the virtual environment. Students were allowed to assume different roles (role playing) and collaborative activities conducted inside the virtual world created a pleasant climate of healthy competition among students. The sessions were about learning sorting algorithms, but indirectly many other skills were worked, such as, for example, digital competence or understanding 3D coordinate axes.

The analogy provided by the system through the tangible interface was very useful to understand the concept of sorting: 95% of students believed that it helped. The tangible interface along with the use of the dice let them following in a clearer way each particular algorithm. Also 88% of students thought the system helped them to better distinguish the differences among sorting algorithms.

The sessions were very positive and 100% of students said they would like to participate again in similar sessions. Even students from other schools expressed interest in participating in the sessions as they had heard from friends or relatives.

Also noteworthy is the motivation in the teacher side. From informal talks with the teachers who participated, we found that they have loved the sessions and would like to work with such tools in the future. However they have a lack of knowledge on the use of the virtual worlds that may jeopardize these desires.

Let us analyze now the results of the written test that some of the students did after using the mixed world system for learning sorting algorithms (see Table 2). Judging both the results and the attitude of the students, the groups in which the experience was most helpful were the second year of Bachelor and the fourth year of ESO. This experiment suggests that the right time to begin with higher-level abstract concepts related with algorithmics and programming is the fourth year of ESO.

Despite having been a very successful experience, some problems were detected that have to be addressed in future sessions. Firstly, although 69% of students have found that the time devoted to the sessions has been adequate, teachers have found it to be insufficient: many activities were developed in a fairly short space of time. Therefore it would be desirable to include one or two more additional sessions to accomplish everything more calmly and to properly consolidate all the concepts.

Another aspect to consider is the distraction that the interaction with virtual worlds may cause. 20% of students spent 30 or more minutes to set up their avatars and 52% of students visited other parts of the island not directly related with the topics to study. The nature of the environment may cause some students to waste time in non relevant activities. Table 3 summarizes the main pros and cons observed during these sessions.

Course	Perfect Test	Test with a single minor fault	Test with more than one fault
Professional courses (FP, 16 years old) (morning group)	6(54.5%)	3(27.3%)	2(18.2%)
Professional courses (FP, 16 years old) (evening group)	2(20%)	0(0%)	8(80%)
2nd course of bachelor (opcional course, 17 years old)	1(25%)	3(75%)	0(0%)
Fourth year of ESO (optional course, 15 years old)	7(53.8%)	3(23.1%)	3(23.1%)

Table 2: Test results by courses

6 Discussion, Conclusions and Future Work

This paper describes a mixed reality system that has been implemented using human-centric interfaces and collaborative smart objects technologies. The system has been tested in an educational environment, but the underlying technologies allow its deployment in other application areas.

Mixed reality is a paradigm that promotes the idea of blending the virtual world with the real world. Nowadays many people lives in two intermixed worlds: the “real solid world” that also our grandfathers experienced, and a new “cybernetic world” where we find information, we communicate with others, we create social networks, we expose our self-image and our creative works, etc. This cybernetic world is evolving into a “virtual world” that may be as vivid, complex, demanding and enticing as the “real world”. The challenge is to develop systems that offer a unified experience of both real and virtual worlds, in a way that the user “lives” in both as a single and unified experience.

The work presented in this paper takes some steps in this direction. The hardware, middleware and applications that connect the virtual and real worlds have been developed, allowing the users to experience both as a single experience. The technologies have been implemented as an educational application that has been tested with students at different educational levels in secondary education, having obtained promising results in terms of increased motivation for learning and better understanding of abstract concepts.

Pros	Cons
• Improves student motivation. • Lower learning curve. • More active and dynamic learning (meaningful learning) • Improves understanding of abstract concepts • The tangible interface is an excellent analogy of the concept of array • The interaction with the dice helps not to get lost in following the algorithm. • Improves other skills (digital literacy, communication, group work, leader-ship …) • The system helps to better distinguish the sorting algorithms. • The dice helps to settle doubts about performance of sorting algorithms. • The system can improve attention and concentration of students. • Feedback is obtained from both the system (through the LCD) and the virtual world. • It is perceived as apleasant working environment • Excellent acceptance by the educational community	• May cause distraction. • Lack of teacher training in 3D virtual environments • Need to improve infrastructure (network, computers…) • Inability to connect many students at the same time. • High effort to prepare activities in virtual world. • The inability to use the system or virtual worlds from home in our current setting (the Virtual world server is running only during the experiments)

Table 3: Pros and cons in the sessions

The next steps may involve finding other application areas to test the generality of our approach. Examples of such application areas may be:

- Smart cities: we are currently developing guiding systems -based on smart phones- for the cognitively impaired, so they can travel alone over the city. Mixed reality may improve these systems making a smooth transition between the “training” and the real travelling. Training will be done by virtual displacements over a virtual copy of the city. Then, when the cognitively impaired is really travelling the city, the mixed reality system will offer help in a way that is exact to the training mode.
- Environmental monitoring: Mixed reality systems may offer the perfect user interface for environmental monitoring. A virtual representation of the environment, with the values of all relevant sensors and an interpretation of them, may be projected into the real world by tangible interfaces and augmented reality.

- Smart control for eco-friendly buildings: The control of a smart home, or even a whole building, may be improved by using a virtual copy of the building in a mixed reality application. The smart home thus may be controlled indifferently from the virtual world and from the real world. The user may experience both realities as a single thing.

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