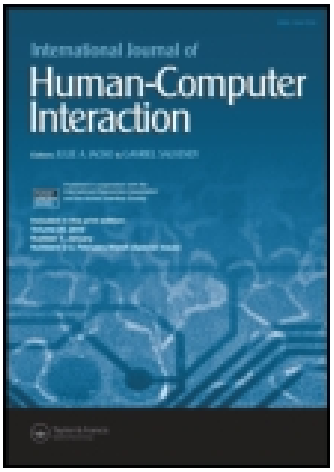

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VirtualTouch: A Tool for Developing Mixed Reality Educational Applications and an Example of Use for Inclusive Education

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This article describes VirtualTouch, a tool for developing mixed reality educational applications. VirtualTouch proposes the use of virtual worlds and tangible user interfaces to offer a "mixed reality" experience. Using VirtualTouch a teacher may easily design learning modules, which are immediately implemented and used in the classroom. A first experience of such use, focused in the area of inclusive education, is also presented. The results of this experience are encouraging, showing that mixed reality applications have a high potential for use in this area.

1. INTRODUCTION

This article describes VirtualTouch, a tool for developing educational applications based on the "mixed reality" paradigm. A virtual world is used as the means for simulation and interaction in three dimensions. The virtual world is augmented with tangible and gestural interfaces for shape and gesture recognition.

Using mixed reality we can take advantage of the contribution of virtual worlds to the field of education: simulation of real contexts, implementation of role-playing activities, and acquisition of problem-solving abilities. This is complemented with the contribution of tangible interfaces, which allow to experiment with physical materials, to implement a "hands-on" learning approach and to develop collaborative activities.

The first prototype version of VirtualTouch has been tested in the development of educational activities designed for foreign high school students just arrived to the school. They lack the necessary knowledge about the language and the culture of the country they have just arrived at and need to adapt to their new situation.

In this article, we propose the use of the Kinect device as a means of interacting with virtual worlds. Two modalities of interaction have been developed: Natural User Interfaces (NUI), which are based on gestural interaction, and Tangible User Interfaces (TUI), which are based on interaction with physical objects.

The rest of the article is structured as follows. Sections 2 and 3 analyze the state of the art in the use of virtual worlds and tangible interfaces for educational applications. Section 4 describes the VirtualTouch tool suite, in particular the middleware that allows the interaction between the virtual world and the "real world," thus implementing the "mixed reality" paradigm. Section 5 describes a case study of mixed reality applications focused on inclusive education. Finally, section 6 presents some conclusions and future work.

2. VIRTUAL WORLDS IN EDUCATION

A three-dimensional (3D) virtual world is a networked virtual reality application in which users move and interact in simulated 3D spaces (Dickey, 2005). Virtual worlds allow to carry out new educational methodologies in the learning–teaching process based on the constructivist paradigms as proposed by Vygotsky (1978) and Piaget (1951), where learning is focused on students as active learners.

Vygotsky (1978) considered learning as a social activity where students learn most effectively when working cooperatively with other students. On the other hand, Piaget (1951) conceived of learning as an individualized process where the student interacts with the surrounding environment through discovery and exploration. Virtual worlds allow developing both individual and collaborative learning activities under the constructivist approach where the teacher is seen as a learning facilitator for the student.

A virtual world, following the constructivist paradigm, can be used in different ways for problem-based learning, cooperative learning, situated learning, and role-play/game-based learning. In all these cases, virtual worlds are used to simulate real situations that are difficult to represent in the traditional classroom (e.g., the control of a chemical plant, a surgical intervention, etc.), allowing students to improve their skills through deep and meaningful learning.

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Virtual world platforms such as Second Life or OpenSim allow the construction of 3D objects and the definition of their behavior using scripting languages. Students can create their own constructions: a house, a museum, and so on. Virtual worlds allow developing collaborative activities in which avatars (self-representations of people in the virtual world) can perform specific roles to solve a problem and can interact and cooperate with the rest of avatars.

Table 1 summarizes and compares some interesting examples of virtual worlds used in education.

The rest of this section comments on some aspects of these projects. First, it is interesting to note that the European Union has shown considerable interest in promoting and funding this research area. For example, AVATAR, CAMELOT, and TILA are three projects in the Lifelong Learning Programme, with participation of several European institutions. These three projects are aimed to second-language learning. This is a common trend in the area: A good part of the projects are related with foreign languages learning.

A further example in this direction is Euroland, which is a project funded by the European Union involving seven primary and secondary schools in Italy and the Netherlands. In this project, cultural aspects are shared using virtual worlds, working on communication and social skills by means of collaborative activities.

Other educational area that is well represented in the projects analyzed, apart from second language learning, is situated learning. For example, River City and EcoMUVE are projects that allow students to investigate and explore, with the purpose of drawing conclusions based on the collection and analysis of data within a virtual world.

With respect to the development platform, it is clear that the first choice is Second Life (or its open software version, Open Sim). Active Worlds is used in some cases, and more recently some tools for video games development are also being used (i.e., Unity 3D).

Finally, a trend may be noted in the direction of integrating the virtual world activities with the rest of the learning and evaluation activities. Many of the projects are linked with the Moodle platform (which is a standard tool for managing e-learning) in order to create complete e-learning courses where the virtual world is used in part of the process.

2.1. Virtual Worlds in Inclusive Education

Virtual worlds provide the opportunity to try out alternative social interactions, encouraging the reflection upon feelings and thoughts (Sheehy & Ferguson, 2008). Babu, Suma, Barnes, and Hodges (2007) conducted a study on the effectiveness of immersive virtual humans (avatars) as a way of teaching social and nonverbal protocols, versus traditional approaches such as a study guide with images. This work confirmed a significant improvement in learning due to a more practical interaction and also to the immediate feedback thus obtained.

This suggests that virtual worlds may have a high potential for being useful in inclusive education. Virtual worlds for inclusive education can provide a safe environment for practicing skills avoiding the risks that can be found in the real world (Stendal, Baladin, & Molka-Danielsen, 2011). Furthermore, the anonymity provided by virtual worlds can be positive for individuals who have trouble at socializing in the real world.

Virtual worlds can break down stereotypes and prejudices that occur in real life, allowing anyone to change the appearance of the avatar at their convenience. For example, an obese person may appear in the virtual world as a thin avatar. However, some users prefer to appear with the same aspect they have in the real life, as in the case of Simon Stevens, who is the creator of Wheelies Club (Wheelies, 2014): He refuses to appear in this 3D virtual environment without his wheelchair. Wheelies is the world's first disability-themed virtual nightclub, based in Second Life. It tries to guard against social isolation through a learning and interaction tool.

Table 2 summarizes and compares some interesting examples of virtual worlds used in inclusive education.

From these projects we can see that virtual worlds are a useful tool for people with several types of disabilities. They can interact with other users without any physical barrier and with different means of communication (text chat, voice chat, and gestures). Exclusion risks are greatly reduced, and the stress of face-to-face interaction is diminished.

It can be noted that most of these projects are not deployed in educational centers but are "public" islands available to people with disabilities. There is a lack of such implication of educational centers (i.e., high schools, special education centers) in these technologies. The project presented in this article tries to advance in that direction.

3. TANGIBLE INTERFACES IN EDUCATION

Fitzmaurice et al. (1995) defined the term "Graspable User Interface" as a virtual object that can be manipulated and controlled through physical artifacts. Ishii and Ullmer (1997) presented a new paradigm in human–computer interaction under the name of "Tangible User Interfaces" where ordinary physical objects are used as the means of interaction with digital contents.

According to Marshall (2007), tangible interfaces can deliver many benefits to the learning process, such as the following:

- Benefits in cognitive and motor skills: Tangible interfaces facilitate activities that exercise cognitive and motor skills using multiple senses (vision, hearing, and touch).
- Collaborative learning: Students learn to share the space, to work together, to organize, and to plan how to solve a problem, promoting situated learning. Tangible interfaces enhance the visibility of actions and allow students to learn by imitating the actions of their peers,

TABLE 1
Virtual Worlds in Education

Author/ Main reference	Project Name	Project Description	Virtual World Platform	Main Goals	Ages or Level
Avatar (http://www.avatarproject.eu/)	AVATAR Project	The AVATAR project provides teaching tools and methodologies for secondary school teachers.	Second Life	Teach to use virtual worlds in education	Secondary school teachers
Bailey and Moar (2002)	The Vertex Project	Students design an imaginary virtual world using 3D modeling tools.	Active Worlds	Collaborative learning, language and communication skills, imaginative abilities	K-12 (9-11)
Bers (2001)	The ClubZora Project	Zora is a multiuser virtual environment that provides a safe space were children can build 3D objects, their own virtual places, etc.	Active Worlds	Computer programming skills, communication skills	11-14
Callaghan, McCusker, Losada, Harkin, and Wilson (2013)	The Circuit Warz Project	The Circuit Warz project is used to teach electronical engineering using a game based approach in a competitive format.	OpenSim	Teaching electronic and electrical engineering	University
Camelot Project (http://camelotproject.eu/)	CAMELOT project	CAMELOT is a 2-year EU funded project for teaching how to create videos (machinima) using virtual worlds	Second Life	Provide a set of language teaching resources	Language educators
Jauregi, Melchor-Couto, and Vilar Beltrán (2013)	TILA Project	Tele-collaboration activities among students from different countries. Improvement in language teaching and social and intercultural skills in a blended learning approach.	OpenSim	Language skills, literacy skills, social and intercultural competence	Secondary school
Ketelhut (2007)	The River City Project	The inhabitants of a virtual village are sick. The students are grouped in teams to investigate why, taking samples, interacting with villagers and generally exploring the virtual environment.	Active Worlds	Situated learning, problem-based learning, nonlinear approach to learning.	6-9
Ligorio and Van Veen (2006)	Euroland	A collaborative project between Italian and Dutch classrooms where a 3D virtual world contains “cultural houses“, for example the Dutch House of Art and House of Food.	Active Worlds	Cognitive, social and language skills, collaborative learning	Primary/Secondary schools (9-15)
Lorenzo, Lezcano, and Sánchez-Alonso (2013)	SLRoute	Creation of a specific platform for teaching Spanish language.	MMOL platform (over OpenSim)	Learning foreign language	University (20-37)
Metcalf, Tutwiler, Kamarainen, Grotzer, and Dede (2011)	EcoMUVE	EcoMUVE is used to help students to understand ecosystems and causal patterns. Students can explore the environment and collect and analyze a variety of data.	Unity 3D	Inquiry-based learning, learn causal relationships in ecosystems	Middle school
Rico, Martínez-Muñoz, and Alamán (2011)	V-LeaF	V-Leaf is a platform used in several high schools in order to learn programming concepts.	OpenSim	Programming skills	Secondary school
Sosnoski and Carter (2001)	The Virtual HARLEM Project	A virtual representation of Harlem, NY during the 1920 Jazz Age.	Second Life (initially), OpenSim (currently)	Collaborative learning, role playing	University

Note. MMOL = Massively Multiuser Online Learning.

TABLE 2
Virtual Worlds in Inclusive Education

Author/ Main Reference	Project Name	Project Description	Virtual World Platform	Main Goals	Type of Inclusion
Balandin and Molka-Danielsen (2010)	Virtual spaces for building friendships and learning about a lifelong disability	A virtual world aimed at people with lifelong disability, encouraging them to engage in collaborative activitivies and social settings.	Second Life	Social and collaborative skills	Autism, intellectual disability, cerebral palsy
Espurna (http://www.espurna.cat)	Espurnik Project	Foreign students interact in the virtual world to learn the language and culture of the country where they have recently arrived.	OpenSimulator	Social and language skills, avoid the risk of isolation	Immigrant students
Sheehy (2010)	Accessibilty in Virtual Worlds	Blind students can navigate and interact in a virtual world using sounds.	Active worlds	Improve accessibilty to curricular contents	Blind people
Sheehy (2010)	Brigadoon	People with autism can perform various virtual activities such as sailing boats, sitting and chatting with each other, etc. Activities that might be considered as impracticable in the physical world are less stressful, and thus feasible, in virtual worlds.	Second Life	Social skills	Austim or Asperger's Syndrome
Virtual Ability Inc. (2012)	Virtual Ability Island	Virtual Ability Island provides a 3D environment for the support and training of disabled people where they can meet people, establish friendships and explore different places.	Second Life	Social skills	Disabled people
Wheelies (http://simonstevens.com)	Wheelies Club	Wheelies is the world's first disability-themed virtual nightclub.	Second Life	Avoid the risk of isolation	Disabled people

providing a multitouch interface and promoting group discussion.

- Accessibility: Tangible interfaces are more intuitive and easy to use by children or people with learning disabilities.
- Novelty: Physical manipulation with tangible objects may increase reflection in children.
- Playful learning: Children learn in a more relaxed, fun and playful atmosphere.

Tangible interfaces can be used to carry out serious games with educational goals. Educational games are more effective when they are tailored to the abilities of the players: a mismatch in the difficulty level may cause the user to get bored (if excessively easy) or frustrated (if excessively difficult).

Verhaegh, Fontijn, and Jacobs (2008) showed an experiment on comparing the use of tangible interfaces with the use of virtual games for educational purposes. The game was developed for students 5 to 7 years old, and the objective was to match a block with a given card. The results showed that the tangible version of this game was more accessible: Students who used the game with tangible interfaces took less time to complete the puzzle. Tangible interfaces allowed the activity to be carried out more easily and intuitively. Also, students using the tangible version had less hesitation in deciding where to place the pieces in the puzzle.

A similar study is described in Xie, Antle, and Motamedi (2008), where children ages 7 to 9 solved a jigsaw puzzle using three different interfaces: physical (traditional), graphic, and tangible. This study concluded that the use of tangible interfaces was the best option for this type of activities in terms of accuracy. Children using the tangible interface solved the problem quicker and better. This study used a tabletop prototype, some fiducial markers, and a camera to monitor user events.

Table 3 compares various educational projects that use tangible interfaces. As can be seen in the table, most of the projects make use of tangible interfaces for teaching abstract concepts such as programming or mathematics. In fact, tangible interfaces facilitate the understanding of abstract concepts by performing activities, which provide immediate feedback, allowing for trial-and-error learning. Many of these projects are targeted to primary education because at this age children are developing psychomotor skills.

In this table we can see that the vast majority of projects that use tangible elements are targeted to younger students (5–13 years old). Possibly younger students obtain larger benefits from the "hands-on" approach that tangible interfaces offer.

There are two kinds of projects in this table. Some of them make use of interactive tables (tabletop, multitouch surfaces). Multiple users can simultaneously interact with tangible interfaces, facilitating the integration (or socialization) among peers through collaborative activities in a shared space.

The other type of project is based on using building blocks for learning abstract concepts. In fact, 40% of the analyzed projects are centered on learning programming, geometry, probabilities, and other abstract topics. Making abstract concepts "touchable" seems to be a good strategy for their better understanding. On the other side, 33% of the analyzed projects are aimed to improve communication and language skills through activities such as storytelling.

It is interesting to note that all the analyzed projects use a large number of heterogeneous devices (tabletop, webcam, projectors, RFID, microcontrollers, etc.). It may be too complex to deploy such a system in a real educational environment (i.e., a high school). In this article we propose to reduce the number of components and the complexity of assembly by using a Kinect device and a few blocks or wooden models.

3.1. Tangible Interfaces in Inclusive Education

International initiatives such as UNESCO and UNICEF among others have reached a consensus about inclusive education: All children have the right to be educated together, regardless of their physical, intellectual, emotional, social, linguistic, or other conditions (UNESCO, 1999, page 9).

According to UNESCO (2005, page 12), inclusion in education is a "dynamic approach of responding positively to diversity and of seeing individual differences not as problems, but as opportunities for enriching learning."

Tangible interfaces allow developing collaborative activities where interaction and cooperation of students is encouraged. Tangible interfaces can improve the social skills of students with special educational needs.

Muro et al. (2012) showed an example of using tangible interfaces for teaching children with the Down syndrome, promoting collaborative learning in a friendly environment. For this project an interactive tabletop and a series of augmented digital tools along with the necessary teaching materials were used. The activities allowed the student to learn how to associate a word with its corresponding image. The student had to choose among different tangible objects, getting feedback from the system depending on whether the choice was correct. The results were positive: The students found the interaction with the system interesting and exciting. It was observed that the children paid constant attention and gave signs of excitement and interest in such activities.

Tangible interfaces are an excellent way to interact with physical objects and therefore can be useful in rehabilitation therapies. Li, Fontijn, and Markopoulos (2008) proposed that a tangible tabletop game can be used as therapeutic support for children with cerebral palsy. To do this, children performed certain movements repetitively as specified by therapists. These movements were part of a game that encouraged children in a fun and motivating way.

Alja'am et al. (2011) proposed a project aimed at children with moderate intellectual and learning disabilities in order to

TABLE 3
Tangible Interfaces in Education

Author	Project Description	Types of Tangible	Main Goals	Ages or Level
Africano et al. (2004)	Explore different cultures through the adventures of a fictional character	Postcards, multitouch table, camera.	Promote collaborative learning, teaching geography and foreign cultures	6-12
Agarwal, Luthra, Jain, Thariyan, and Sorathia (2013)	ChemicAble is an interactive tabletop interface to teach ionic bonding (chemistry) to Indian students.	Tabletop, projector, webcam, table with acrylic glass sheet	Learn the concepts of ionic bonding and atoms, collaborative learning	8-10
Gallardo, Julià, and Jordà (2008)	Turtan is a tangible programming language that allows learning programming skills.	Tabletop interface**, Turtan** (based on Logo)	Teaching programming for nonprogrammers	Children
Horn and Jacob (2007)	Learn computer programming with tangible programming languages	**Quetzal** (language for controlling LEGO Mindstorm robots), **Tern** (language for controlling virtual robots on a computer screen)	Teaching computer programming using a physical interface	K-12
Johnson & Thomas (2010)	Children can create squishy circuit sculptures to learn the basis of electronics.	**Squishy Circuits,** LEDS, batteries, insulating molding compound, dough compounds	Teaching electronics through the use of squishy circuits	Children
Raffle et al. (2004)	Children can create different constructions and can program the movements of this constructions	**Topobo** (Reconfigurable robotic set of tools with kinetic memory)	Develop sensory capabilities, control their own learning process, learn through personal exploration, enhance creativity	5-13
Roberto, Freitas, Simoes, and Teichrieb (2013)	ARBlock is a dynamic platform for educational activities using projective augmented reality and tangible user interfaces.	Dynamic blocks, projector, webcam	Develop literacy skills	4-8
Scharf, Winkler, and Herczeg (2008)	Tangicons is used by students in order to learn programming through a physical game	**Tangicons** (nonelectronic physical programming cubs), digital camera, LEGO RCX	Learn first steps of programming	7
Stanton et al. (2001)	The magic carpet allows children to work collaboratively to tell stories to an audience.	**Magic carpet** (use sensor pads), computer, video-tracking, physical barcodes, back-projector	Collaborative learning	5-7
Stringer, Toye, Rode, and Blackwell (2004)	A TUI-supported rethorical application.	**WebKit,** RFID-reading antenna, projection screen, cards with RFID	Teaching rethorical skills	Children
Suzukia and Kato (1993)	Tangible videogame (guiding a submarine on the computer screen)	**AlgoBlock** (minicube system, using electronic building blocks), tabletop	Teaching programming skills, collaborative learning	Children
Zuckerman, Arida, and Mitchel (2005)	SystemBlocks: simulations, dynamic models. FlowBlock: mathematical concepts (counting, probability . . .)	**Flow Blocks** (battery magnetic connectors . . .) **System Blocks (**components: accumulators, LED, stock, flow valves)	Teaching abstract concepts	4-11

improve their communication, collaboration, data exploration, and creativity through tutorials. This system is composed of set of tangible interfaces such as “Magic Stick,” “Foot Learn-Pad,” and “Lenovo IdeaPad.” Students can perform activities through puzzles and edutainment games. Their parents are involved in the learning process by adding or customizing contents.

Starcic, Cotic, and Zajc (2013) carried out a study where tangible interfaces were used for teaching geometry in inclusive education. Tangible interfaces allow the creation of geometry activities for people with reduced motor skills that are not able of using the compass, rules, triangles, or even the computer mouse. TUI also improved mathematical intelligence and space orientation for students with learning difficulties.

As a precursor to the use of tangible computer interfaces LeGoff (2004) conducted group sessions aimed at children with autism to improve social skills and social interactions using LEGO. The LEGO blocks manipulation allowed incorporating social skills strategies such as turn-taking, eye contact, following social rules, and talking with peers. The LEGO intervention promoted self-initiated social interaction, increased the duration of interaction, and reduced autistic behavior in children with autistic spectrum disorder in a pleasant environment with positive emotional responses.

In this direction, tangible interfaces can encourage the development of emotional relationships. Topobo (Raffle, Parkes, & Ishii, 2004) is a modeling system (similar to LEGO) with kinetic memory, which allows building toys and programming their movements. For example, it allows creating a horse and programming how it walks. Topobo was presented to children with autism (Farr, Yuill, & Raffle, 2009) to observe whether this tangible interface provided benefits compared to the use of passive building blocks, such as LEGO. Topobo allowed for tangible programming, encouraging collaboration among peers and reducing solitary behavior.

Table 4 summarizes and compares these applications of tangible interfaces in the area of inclusive education. From this table we can see that most projects using tangible interfaces for inclusive education make use of interactive tables. In fact, interactive tables are an excellent tool to conduct collaborative activities and to provide appropriate visual and sound feedback for students with special educational needs. It is interesting to note that many of the projects analyzed relate to autism and other intellectual disabilities. It seems that this technology is well suited to these individuals’ needs.

However, there is a lack of projects deployed at educational centers; most of them are laboratory based. In this article we emphasize this aspect. There is a need to develop educational programs that will take advantage of these tools for integrating children with special needs.

4. DESCRIPTION AND IMPLEMENTATION OF THE SYSTEM

This article describes VirtualTouch, a tool that allows the development of mixed reality applications that use virtual worlds as a means to create educational activities. Mixed reality is achieved by blending virtual worlds with tangible and gestural interfaces, using the interaction possibilities provided by the Kinect device.

The first task was to choose the most adequate virtual world platform from the wide variety of existing ones, such as Second Life, Active Worlds, or Open Simulator. The best option was Open Simulator (http://www.opensimulator.org) for three reasons. First, OpenSim allows the creation of protected environments where the contents presented and who is allowed to enter the world are well-controlled aspects. This is much more difficult to ensure using other platforms such as Second Life, and it is an essential issue when dealing with schoolchildren. Second, OpenSim is an open-software platform that allows the creation of extensions or modifications. This is very convenient for the stated goal of including tangible interfaces as a means of interaction. Third, OpenSim is free, thus encouraging the spread of the system among public high schools in Spain, where budgetary restrictions have to be considered.

OpenSim enables the creation of a 3D simulated environment where you can embed different types of educational activities. Using these activities, students can interact with each other and with teachers in real time with the aim of improving weak skills.

Using the VirtualTouch tools, various educational spaces were defined within a virtual world, where students performed different activities allowing them to practice language skills (see Figure 1). Students were able to interact with other students and teachers in real time through their avatars (their representations in the virtual world), making extensive use of language in a specific context (situated learning). For example, the students could practice speaking while pretending being at a store, a bank, and so on. Cultural activities were easy to develop, such as the celebration day of Sant Jordi in Catalonia, which possibly was unknown to recently arrived immigrant students and helped them to better integrate in their new country of residence. Finally, collaborative activities using virtual worlds and tangible interfaces helped improving social relationships with peers in a friendly atmosphere of work.

Once the virtual world platform was selected, the next goal was to develop a tool that would allow the creation of mixed reality applications linking the virtual world with the real world. Two kinds of interactions were needed for these educational spaces: gestures and tangible artifacts. To enable these modalities of interaction, a middleware was developed for the communication between a Kinect device and OpenSim.

To develop the middleware, Microsoft Visual Studio 2012 was used as the programming environment, using the C# programming language and several third-party libraries: Kinect Library SDK 1.7 (Microsoft, 2014), LibOpenMetaverse, and Open Source Computer Vision (OpenCV) libraries (http://www.opencv.org).

Kinect provides a good support for skeleton tracking and gesture recognition, but it is not so good for object detection or recognition. A complementary library for blob recognition

TABLE 4
Tangible Interfaces in Inclusive Education

Author/Main Reference	Project or Study Description	Type of Tangible	Main Goals	Type of Inclusion
Alja'am et al. (2011)	The system use some edutainment games and puzzles based on TUIs to improve the learning process.	Magic Stick (simple electronic device Bluetooh based) Learn-Pads (food pads interface), Lenovo IdeaPAD (IdeaPad device)	Communicative,collaborative, creative and memorization skills	Moderate intellectual disability, moderate learning disability
Muro et al. (2012)	This project presents a tangible augmented reality system to support teaching with Down Syndrome.	Interactive tabletop and augmented digital tools	Improving the reading process	Down Syndrome
LeGoff (2004)	Children wih autism built constructions using LEGO	LEGO blocks	Social and collaborative skills	Autistic spectrum disorder
Raffle et al. (2004)	Children can play with Topobo in a collaborative settings where students create creatures or objects and play with their constructions	Topobo: modeling system with kinetic memory	Collaborative skills	Autism
Starcic et al. (2013)	This study presents how to teach geometry concepts through physical and cognitive activity using TUI with geometry application.	Tabletop system, easy-to-grasp objects with a unique circular barcode, web-camera	Learn mathematics and geometric concepts, develop motor skills	Low fine motor skills and learning difficulties
Villafuerte, Markova, and Jordà (2012)	This study use a musical TUI called Reactable, applied with nine children with ASC to improve their social interaction.	Reactable (tabletop TUI), tangible blocks	Help in the acquisition of social interaction abilities	ASC
Li et al. (2008)	In this study, children interact with a tangible tabletop game where certain movements should be specified by therapists as part of the game.	Tangible tabletop, color hammer, wooden block	Assisting fine motor skills training	Cerebral palsy

Note. TUI = tangible user interface; ASC = autism spectrum condition.

FIG. 1. Language activities in the virtual world.

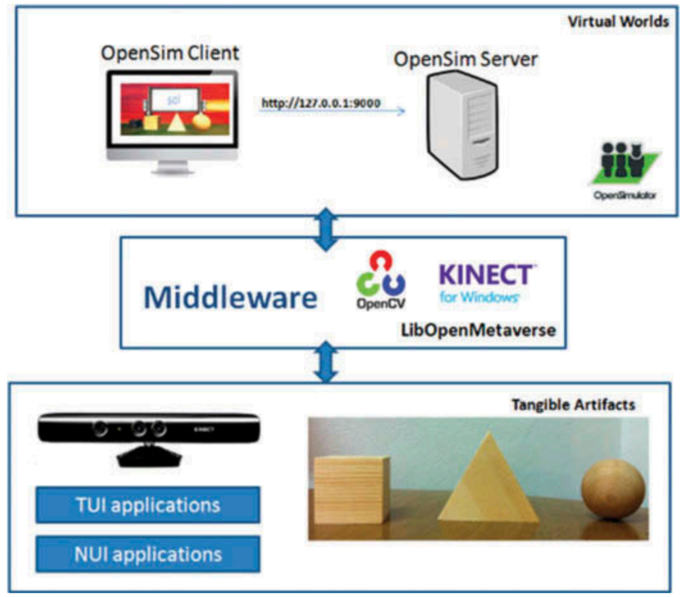

FIG. 2. Architecture of VirtualTouch.

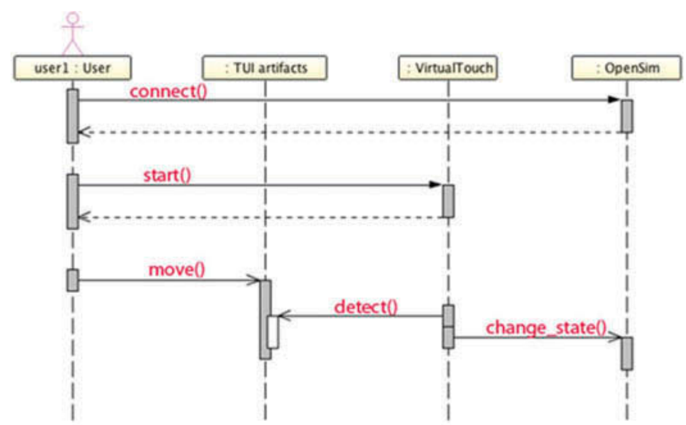

FIG. 3. Sequence diagram.

(OpenCV) was used to overcome this. OpenCV is a powerful library under a BSD license that is used to develop computer vision applications in areas such as augmented reality, robotics, surveillance, and object detection. In this work the OpenCV library was used for recognition of simple shapes such as squares, circles, triangles, or pentagons.

LibOpenMetaverse (http://www.openmetaverse.org) is the .NET based client/server library used for accessing and creating 3D virtual worlds. LibOpenMetaverse was used to link the virtual world (OpenSim) with the real world (Kinect device). When a real action or event occurs in the real world, it is incorporated to the virtual world using LibOpenMetaverse.

The middleware includes some bots populating the virtual world, which are part of the mechanism for communicating OpenSim with the Kinect. (Note that a bot is an avatar in the virtual world that is programmed to act o respond without the need of being driven by a person.)

As an example of how this middleware works, suppose that a pyramid (a wooden block with the shape of a pyramid) is shown. The middleware detects this shape using the Kinect device and the OpenCV library and sends a message to the virtual world (using LibOpenMetaverse). A bot receives this message and makes a pyramid shaped form appear in the virtual world. Gestures in the real world are also recognized and communicated to the virtual world using this mechanism (see Figure 2). This blending of a virtual world with tangible artifacts and gestures is what provides a "mixed reality" experience.

Figure 3 displays a sequence diagram showing the initial scenario in which the user connects to the virtual world and then starts the middleware that connects the virtual and the real world. It can be also observed how the middleware captures the position when the user moves an object, being communicated to the virtual world.

Figures 4 and 5 show how the communication is implemented using the HTTP protocol (LSL HTTP, 2014). When there is a change in the real world, the middleware sends a HTTP message communicating this event to a specific object in the virtual world. This object then reacts to the real-world change, performing the corresponding change in the virtual world. Figure 5 shows the complementary process: When something changes in an object in the virtual world, the middleware sends a HTTP message to the real world (to the tangible interface), that changes its state accordingly. Figure 6 shows an example of the code implementing such communication in a virtual object.

5. CASE STUDY: APPLYING THE SYSTEM FOR INCLUSIVE EDUCATION AT HIGH-SCHOOL

VirtualTouch has been tested at a public high school with a high ratio of immigrant children. The IES Ernest Lluch is

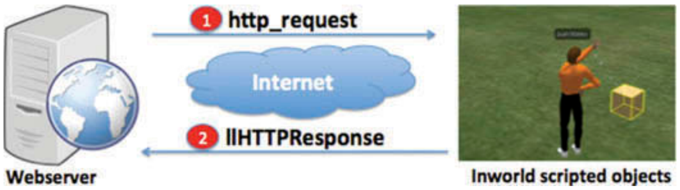

FIG. 4. Sending a message into OpenSim.

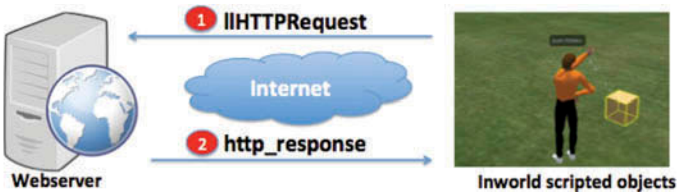

FIG. 5. Sending a message out of OpenSim.

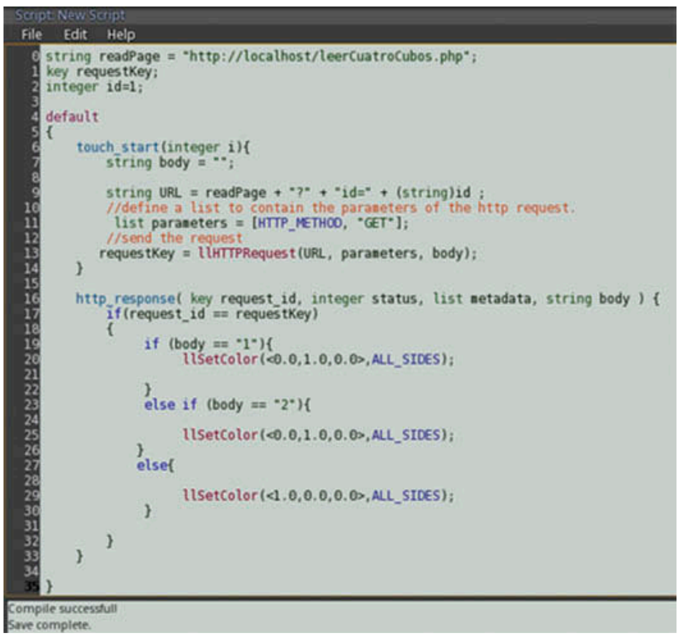

FIG. 6. LSL script using HTTP to communicate with the real world.

located at Cunit (northeast of Spain) where the working language is Catalan. New students from other countries (Ukraine, England, China, Morocco, etc.) and from other regions of Spain have to learn the Catalan language to properly follow the rest of the classes as well as to integrate adequately into the local society.

To integrate these children, the Catalonian Educational System has created the "Welcome Course," in which students receive special training several hours per day to learn the Catalan language, cultural aspects, and other basic skills. The welcome course normally covers ages 12 to 16, each student being assigned an Intensive Individualized Plan with the adequate curricular adaptations.

Some educational activities were prepared using VirtualTouch to see the degree of acceptance of the proposed technologies among immigrant students. The work was done in the context of a network called Xtec (http://www.xtec.cat), which has a section with activities and materials for students who participate in Welcome courses.

Within the developed virtual world, students were encouraged to explore a virtual island where there were various educational activities. These activities were related to learning new concepts about Catalan language and culture. Students also could practice speaking through the interaction with other students or teachers using the text chat and voice chat.

There were two types of activities: NUI activities and TUI activities. Both encouraged the active participation of students in the class, allowing working individually or in pairs under a friendly environment.

As an example of NUI interaction, students used gestures to solve different exercises such as to change the clock digits in the virtual world according to instructions given in Catalan language. When the student finished, he received feedback from the virtual world indicating whether the activity was correctly done. Using NUI interactions a student could also, for example, change the color of an object or could move objects from one place to another.

As an example of TUI interaction, tangible wooden blocks may represent grammatical concepts. For example, the cube represents a noun, the pyramid represents a verb, and the sphere represents an adjective (see Figures 7 and 8). The activity consisted of guessing the correct grammatical category of some Catalan words that were consecutively shown in the virtual world.

A similar activity used the concepts related with verb tense, for example, the cube represented the present tense, the pyramid represented the past tense, and the pentagon represented the future tense. A phrase was displayed in the virtual world,

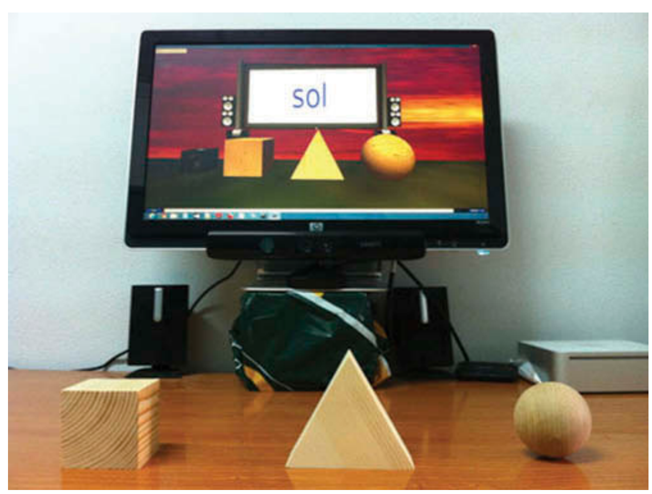

FIG. 7. The virtual world and some tangible interfaces.

FIG. 8. Sorting sentences.

FIG. 9. A student interacting with the tangible interface.

and the student had to choose the correct verb tense for that phrase.

Other TUI-based activities used the relative positions of wooden blocks to sort the different parts of the sentence: subject, predicate, and verb (see Figure 7). Students had to identify what words corresponded to the subject, verb, and predicate and sort them correctly.

Finally, other activities involved the association of words with shapes. Some words were presented in the virtual world, and the student had to choose the tangible that better conformed to the shape of the object named by the word. For example if the word "sun" appeared, the student had to choose the tangible sphere, and if the word "box" appeared, then the student had to choose the tangible cube (see Figure 9).

All the described activities were designed by the teacher of the Welcome course and then implemented "on the fly" by a programmer, using the tools provided by the VirtualTouch system. One of the goals of VirtualTouch (in the medium term) is to get the programmer out of this process, providing teachers with the necessary tools to develop by themselves mixed reality educational activities similar to the ones previously described here.

The system was used in four sessions in 2 days, involving students from other regions of Spain and from other countries: China, Ukraine, England, Colombia, Cuba, and Morocco. The students came from various courses and had various levels of background knowledge of Catalan language and culture:

- Students who had arrived to Catalonia very recently and whose native alphabet was not the Latin one.
- Students who had arrived recently from other parts of Spain. They did not speak Catalan, but they spoke Spanish (which is quite similar to Catalan).
- Immigrant students who had been living in Catalonia for some time and therefore could speak a little Catalan but not enough to attend the normal courses.

As previously described, the teacher designed the activities according to the pedagogical needs of each student. Then a programmer used the modules provided by VirtualTouch to develop the proposed activities on the fly. The activities were then performed by the student or students, and the teacher assessed the grade of success of the activity.

According to these assessments (obtained from semistructured interviews with the teacher after each experiment), the three types of students found the system easy to use for both activities based on gestures and on tangible artifacts.

Table 5 summarizes the information obtained from these interviews.

6. CONCLUSIONS AND FUTURE WORK

VirtualTouch is a new tool that combines virtual worlds and tangible interfaces using OpenSim and Kinect technologies, providing a "mixed reality" experience. The prototype has been tested by developing activities for inclusive education and then trying them in a high school. The case study presented in this article will be further worked into a full-fledged experiment, where we expect to be able to analyze in depth the efficiency and accuracy of the approach.

Our goal is to provide in the future more tangible elements to the system and to include more possible interactions. For example, composite shapes will be available by combining several basic shapes.

As stated earlier, one of the future goals of the system is to provide teachers with the necessary tools to develop by themselves mixed reality educational activities similar to the ones described in this article. In this moment the teacher can design a learning activity and a programmer, using the tools already developed, can implement it in minutes. In the future the teacher will implement the activity by herself or himself without the need of programming assistance, depending on that teacher's technology background.

TABLE 5
Evaluation of the Case Study

Evaluated Factor	Teacher Appreciation/Findings
Motivation	During the experience a significant increase in student interest in the activities was observed. Students were motivated for being able to control objects in the virtual world using tangibles and gestures.
Accessibility and usability	VirtualTouch was found easy to use. After some minutes students interacted seamlessly using both tangible interfaces and gestures.
Self-improvement	It was observed a desire to excel in the activities that made most of the students to engage in an active process of self-improvement.
Learning effectiveness	Effectiveness was assessed according to the level of each student and the type of activity conducted. It was found that the tangible elements helped the understanding of the different parts of speech, especially in cases of students whose language is quite different from Catalan. Proof of this is the case of a student that recently moved from Morocco to Catalonia and who barely understood even sentence structures. With the instructions of the teacher and the use of tangible elements she began to identify the parts of speech. The more activities she performed, the lesser doubts she had, reducing the error rate significantly. It was noted that tangible interfaces, together with the methodology of "trial and error," allowed learning in a more effective way.
Progression	Students engaged in activities with different levels of difficulty according to their previous knowledge of the language. The activities were classified into three levels (beginner, intermediate and advanced). The teacher always adjusted the activity level to the student, to avoid frustration in case of a too advanced activity, and boredom in case of a too easy one. For example, one student who had spent several years in Spain found that the activity of identifying the parts of speech was too easy and therefore the activity had to be adapted accordingly for her.
Methodology	The progression of the student's role from passive to active was observed, due to the fact that using a more innovative approach made them more attentive and eager to participate. It was found that students felt themselves as the protagonists of their learning, engaging in further exercises under their own initiative.
Evaluation	VirtualTouch allowed different types of assessment such as initial assessment, self-assessment, co-assessment, formative assessment, and final assessment, among others. The most used one was student self-assessment. VirtualTouch provided immediate feedback to students, so they knew whether the activity was well performed without the need of the teacher assessment. In any case, the teacher also observed in detail the activities in order to follow the progress of students. It was noted that the trial and error approach enabled by the tangible elements significantly reduced the error rate in the exercises.
Drawbacks/Difficulties	After the experiments we identified the need to develop more examples of each activity: some responses could be memorized, spoiling the effectiveness of the activity. It was also observed the distraction of some students when they were not interacting with the system. Finally, it was observed that the more introverted students were not comfortable performing activities based on gestures.

Three levels of technology expertise are being considered. Teachers with basic technology expertise (i.e., knowledgeable about web navigation, able to use office applications or create blogs, etc.) should be able to customize existing learning applications by changing some parameters, images, and texts. For example, a teacher with such expertise should be able to adapt the examples described in this article to a different language (e.g., English).

Teachers with intermediate technology expertise (i.e., able to create basic Microsoft Excel macros, able to install new programs in the computer, etc.) should be able to combine existing "learning modules" and existing tangible interfaces to create new "mixed reality" learning applications.

Finally, teachers with advanced technology expertise (i.e., able to do basic programming or scripting, able to build and program LEGO Mindstorm robots, etc.) should be able to create new “learning modules” and new “tangible interactions” using the tools provided by the system.

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