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Clara Bonillo Fernández

Toolkits for the Development of Hybrid Games: from Tangible Tabletops to Interactive Spaces

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DOCTORAL THESIS

Toolkits for the Development of Hybrid Games: from Tangible Tabletops to Interactive Spaces

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Cualquiera que haya tenido la experiencia de escribir una memoria, como esta que estáis a punto de leer, estará de acuerdo conmigo en que tener listas la introducción y las conclusiones cuesta casi tanto como escribir el propio trabajo en sí.

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RESULT: *The Magic Spell* hybrid game making use of a PICOO device.
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STAY: With the "NOVA LINCS" group of the Faculty of Sciences and Technology (FCT NOVA), under the supervision of Dr. Teresa Romão.
AIM: to make use of the JUGUEMOS toolkit to carry out the creation of a persuasive game.
RESULT: *The Hidden Treasure* hybrid game to foster good social behaviors in children.
YEAR: September - October 2018.

FINAL DEGREE PROJECTS SUPERVISION

AUTHOR: Paula Labarta Blanco.
SUPERVISORS: Clara Bonillo, Eva Cerezo.
UNIVERSITY DEGREE: Grado de Diseño Industrial y Desarrollo del Producto.
TITLE: Juegos educativos tangibles para niños con TDAH.
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AUTHOR: María Nebra Burillo.
SUPERVISORS: Eva Cerezo, Clara Bonillo.
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SUPERVISORS: Clara Bonillo, Eva Cerezo.
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CHAPTER 1:

INTRODUCTION AND OBJECTIVES

1.1 Motivation and Context

During the last few years, the development of ubiquitous technologies has offered new possibilities to digitally augment traditional games: firstly, this kind of technologies allows to identify and track physical playing pieces as they are manipulated by players; secondly, these new technologies allow the system itself to "intervene" in the play space. However, the use of ubiquitous technologies means an added complexity to the design and development process: they have begun to be used recently and, therefore, they still lack stability and homogeneity. This is why there is a necessity of tools that facilitate the development of games that make use of these technologies.

An emerging field in the Human-Computer Interaction field is the exploration of new interaction techniques that merge virtual and physical environments. In this context, Tangible User Interfaces (TUI) aim to give a physical form to the visual information, connecting the manipulations that users carry out in conventional objects to the digital information contained in computer systems [Ishii and Ullmer, 1997]. In the TUI field, **tabletop active surfaces** are becoming popular. A tabletop is a device with an aspect similar to a conventional table whose surface is digitally-augmented through image projection and sound. Generally the interaction is performed by fingers' movements on direct contact with the tabletop surface (tactile). However, some tabletop devices do not just detect fingers' movements, but they are also able to track and identify conventional objects manipulated on their surface (tangible).

The Affective Lab at the University of Zaragoza developed NIKVision [Marco et al., 2013a], a tangible tabletop device initially designed for very young children. A toolkit, ToyVision [Marco et al., 2013b], was also developed to help programmers to create tangible applications for NIKVision. From the experience of using NIKVision during years it was clear that it could have a great potential not only for small children but for children with special needs [Marco et al., 2010]. However, to use the tabletop in therapy sessions with those children it was necessary to constantly adapt or redesign the activities to every child's specific characteristics. In spite of the usefulness of ToyVision, this one was a toolkit developed with programmers in mind, not therapists nor educators, so they were unable to develop or adapt the activities to their clients, making it difficult to use the tabletop in their daily routines.

Nevertheless, and thanks to the ToyVision toolkit, several activities and games were developed [Cerezo et al., 2015]. In fact, it was observed that games were a perfect area of application for the tabletops, especially to foster social interaction between players, as board games do [Rogers and Rodden, 2003]. With the toolkit, board games could be easily translated to the tabletop device allowing to keep the game pieces in the physical space while digitally augmenting the game space. This way the emotional impact of the game in the player was enhanced [Iwata et al. 2010][Hinske and Langheinrich, 2009]. Compared to other videogames, the manipulation of conventional pieces allows a more comfortable and accessible interaction to certain user groups, such as small children or adults with cognitive problems [Li et al. 2008][Al Mahmud et al. 2008]. For this reason, tabletop devices have been generally adopted as an ideal environment for **hybrid games**: a field in the computer entertainment area that combines traditional games techniques with the new possibilities of augmenting the game space with digital images and audio.

However, hybrid games are not just restricted to tabletops. They also allow to widen the game environment even more, so that the interactions between the user and the environment are not limited to manipulate pieces on a tabletop surface, offering new ways of interaction. Other interaction paradigms may be involved in the game, such as multimodal interfaces, gestural interaction, mixed reality, and embodied interaction. In fact, all these paradigms are converging into **ubiquitous computing**, aiming to achieve an interaction embedded in the user's physical space. Particularly, the use of ubiquitous technologies in **Interactive Spaces** is gaining strength. Interactive spaces (IS) are Distributed User Interfaces supporting several ways of interactions in digitally augmented rooms [Jetter et al., 2014]. A panoply of related interaction paradigms such as physical computing, context-aware computing, mixed reality, wearable technology and tangible user interfaces can be combined and converge in an IS, allowing multiple users to interact with the different devices at the same time or in a distributed way.

In fact, during the last few years there has been an increasing number of projects and prototypes of hybrid games in IS [Khoo and Cheok, 2008][Morreale et al., 2014]. Existing systems have greatly contributed to the hybrid games research by emphasizing different natures of ubiquitous interaction. The key to bridge the gap between the design and development of hybrid games is to be able to quickly prototype and tweak game rules as well as the involved user interfaces and interaction devices [Ullmer and Ishii, 2000]. However, the prototyping of hybrid games arises important technical challenges for interaction and game designers. It is common to find that the design process usually starts with paper prototyping to test the game rules [Magielse and Markopoulos, 2009]. Paper prototypes enable designers of hybrid games to quickly manipulate the game rules, goals, and interactions, but it would be difficult to evaluate the player experience using only this kind of prototypes. The common design process relies on interactions with short cycles of implementation of a functional prototype, alternating game design and play-tests to quickly test the effects of game design decisions [Montola et al., 2009]. As the iterative design process advances, more advanced and high-fidelity prototypes are required. Without a functional prototype and a quick iterative design process, hybrid game experiences cannot be properly evaluated.

In this context, a multidisciplinary work-group emerges: engineers and hardware experts are required to deal with hardware, and software developers to code the application. Therefore, the prototyping process depends on the communication between designers and developers, but the gap between the design and implementation processes is especially critical in the context of hybrid games [Satyanarayanan, 2001]: as the prototype becomes technologically more complex, the times between iterations are longer, since changes in the design may have a critical impact on the hardware and the code, which lengthens the implementation process and hinders the iterations [Ullmer and Ishii, 2000]. In addition, the number and heterogeneity of display devices and interaction paradigms that can be found in an IS are raising the multiples challenges that the design and prototyping of hybrid games involve. Also, the novelty of ubiquitous technologies implies an added complexity to the design and development process, since they have begun to be used just recently and therefore they still lack stability and homogeneity. The biggest challenge lies in offering designers and developers appropriate tools to model and prototype applications. First, designers should be able to choose among different interaction methods; secondly they should be provided with a toolkit that supports those interactions and that is extensible to new interaction modalities that could appear in the future.

In this line of work, the AffectiveLab group launched the JUGUEMOS research Project (TIN2015-67149-C3-1R), a national coordinated project focused on the development of hybrid games in interactive environments. The realization of this Doctoral Thesis is framed within that project.

1.2 Thesis Objectives

Considering the context and the challenges previously outlined, the following objectives were defined:

1) To go deeper into the use of tangible tabletops in therapy with children with special needs, and to extend their use to other collectives that may benefit from their characteristics, such as adults with cognitive impairments. In order to do so it will be crucial to provide therapists and educators with tools that allow the adaptation of games and activities to their clients.

2) To develop a toolkit that facilitates the work of developers in the prototyping of hybrid games in interactive spaces, and that support different interaction styles, including (but not limited to) tangible interaction through tabletops. Cases of use to validate the usability of the generated tools as well as the potential of the developed toolkit will be carried out.

1.3 Thesis Structure

The structure of this dissertation is as follows.

- Chapter 2 presents a state of the art of:

- Hybrid games and toolkits aimed at their development, focusing on extracting specifications to develop our own toolkit.
- The use of the Tangible Interaction paradigm with children with special needs and adults with cognitive impairments.

- Chapter 3 briefly describes KitVision toolkit, developed during the author's Final Degree Project [Bonillo, 2014] having non-programming professionals in mind, together with its assessment, which was performed during the realization of this Doctoral Thesis.

- Chapter 4 presents different experiences carried out with KitVision to support therapeutic activities.

- Chapter 5 describes in detail the design and implemention of the JUGUEMOS toolkit, aimed at the creation of hybrid games for interactive spaces.

- Chapter 6 focus on the uses cases related to the use of the JUGUEMOS toolkit.

- Chapter 7 presents conclusions and future work.

- Annex 1 contains other experiences that were born thanks to the JUGUEMOS toolkit but in which the author was not directly involved.

- Annex 2 describes with more detail the study carried out to extract some design guidelines for children with Attention Deficit Hyperactivity Disorder (ADHD).

- Annex 3 presents in more detail the application of a design framework in one of the game prototypes developed during this Doctoral Thesis.

CHAPTER 2:

STATE OF THE ART

2.0 Chapter Introduction

In this chapter, the state of the art used as a base for this research is presented:

Section 2.1 presents a categorization of hybrid games in order to extract the main challenges that arise when developing this kind of games, together with an analysis of toolkits aimed at the creation of hybrid games [Bonillo et al., 2019b].

Section 2.2 focuses on tangible tabletop based hybrid games developed for users with special needs, and also on toolkits found in the literature aimed at the creation of activities by therapists or educators [Bonillo et al., 2017][Bonillo et al., 2019a].

2.1 Hybrid Games: Classifications and Toolkits

There is not a unique definition of "hybrid games" in the literature. According to De Souza e Silva and Delacruz [2006], hybrid games "*have three main design elements. First, they are mobile and location-based activities. Second, they are multiuser games and, therefore, social activities. Finally, they expand the game environment outside the traditional game space (the board or the screen) into the physical space, thereby creating new spatial perceptions, by merging physical and digital spaces, and new possibilities for social networks in both spaces*". Hinske et al. [2007] consider that hybrid games and mixed reality games are the same: "*Mixed Reality describes a reality somewhere on the continuous spectrum between the real and the virtual environments. Mixed Reality is combination of two worlds, the real and the physical (also sometimes referred to as a hybrid world)".* Finally, for Magerkurth [2012] hybrid games are: "*an environments that allows human users to utilize ubiquitous computing technology in order to provide novel interaction experience*".

However, it can be seen that despite these different definitions, there is an aspect of hybrid games on which the three works agree: they combine physical and virtual elements, taking aspects of the traditional games and combining them with current new technologies. Traditionally, games have been thought to be played in the physical space. The game evolves with the manipulation of physical objects (toys), establishing that way relations between players, objects, and players and objects. Current status of the game is also represented by the spatial distribution of toys or physical playing pieces in the game space. The emergence of ubiquitous technologies offers new possibilities to digitally augment the traditional game: first, this kind of technologies allows to identify and track physical playing pieces as they are manipulated by players; second, these new technologies allow the system itself to *"*intervene*"* in the play space. Thus, it is interesting to find an approach to retain the exciting elements brought by computer games, as well as simultaneously regaining the natural physical interactions embedded in pre-computer games.

Also, another of the main characteristics of hybrid games is that the technologies involved have to be seamlessly integrated in the game environment, which is augmented to enable players to interact with the game, to provide them with useful information via displays, and to immerse them in the game world. In this first subsection of the state of the art, we carry out an analysis of different types of hybrid games. The works presented here have been chosen because of their relevance, and because of the details of implementation they give, which will allow to extract the common characteristics of hybrid games.

2.1.1 Characteristics and challenges of the development of hybrid games

The hybrid games presented have been divided into four categories, depending on the augmentation carried out in the environment: *object augmentation* (**smart toys**), *table augmentation* (**tabletops**), *room augmentation* (**interactive spaces**), or *world augmentation* (**outdoor games**).

2.1.1.1 Object augmentation

In this first section, hybrid games whose interaction is based on the use of physical augmented objects are presented.

Caves & Creatures [Magerkurth et al., 2006] is a tabletop role-playing game that combines a tangible board and physical objects with a computer screen where the actions of the players are shown. Players physically move their characters on the board and use cards augmented with Radio Frequency Identification (RFID) to represent different items that can be traded with other players. RFID technology uses electromagnetic fields to detect and track tags attached to objects. The tags can be detected meters away from the RFID reader and they usually carry a local power source in order to operate. This kind of technology is commonly used in ubiquitous computing systems when it is necessary to know the position of certain objects or persons. Among the objects to be used, there is also a magic wand with a built-in accelerometer to recognize the movements that the players make to cast spells.

Martins et al. [2009] and Tanenbaum et al. [2010] propose storytelling digital augmented environments with *Noon* and the *Reading Glove* respectively. *Noon* is an interactive experience where players have to discover the secrets of a manor by manipulating different objects to trigger the memories they keep stored inside. Players wear a bracer with a built-in RFID reader to detect the different objects and the hand movements. The images and sounds that represent the different memories are displayed in a PDA encased in a hollowed-book, also carried by the players. Similar to the Noon game, the *Reading Glove* uses a wearable controller embedding a RFID reader to detect tagged objects. Players have to discover hidden memories inside 12 different objects to find out a story about a spy who has been betrayed. The story is narrated through video and audio feedback on a computer screen.

Don't Panic [Mora et al., 2015] is an augmented board game where four players have to collaborate to prevent panic from spreading in certain sectors of a city when random dangerous events take place. The cardboard where the game is played is a traditional physical object but the pieces used in the game are square-shaped augmented artifacts with an integrated LCD screen to show information related to the game. These artifacts have several functionalities: they detect other artifacts by proximity, they can display sounds, and represent the pawns controlled by the players, such as the dice to move the characters through the cardboard and the cards that trigger the game events.

BoomChaCha [Zhu et al., 2016] is a rhythm-based collaborative game where players have to defeat monsters using different toy weapons. The tracking of the toys and how they are manipulated is carried out integrating in the toys accelerometer sensors wirelessly connected to a computer via an Arduino microcontroller. That way, the computer wirelessly receives sensor data from multiple toys, and responds to players by sending commands to the toys' Arduino microcontrollers to light on LEDs attached to the weapons. Digital feedback is showed in a projection screen.

Park [2017] developed the *Hybrid Monopoly*, a new Monopoly-based hybrid board game that makes use of digital smartphones that can be combined with the non-technological game. In this version of the Monopoly, the playing pieces and board remain as physical elements, but a game calculator replaces the game's bank and the cards become digital elements appearing in the smartphone screen. RFID technology is once again used to detect the position of the playing pieces on the board. Three-multicolor LEDs and a LCD panel provide visual feedback to the player's actions, and audio instructions are given to the player through the smartphone devices.

Finally, Gatti et al. [2017] made use of haptic digital augmentation to create a hybrid version of the traditional Foosball game. In this version, goals are replaced by a set of hit sensors situated on either side of the table. By hitting the sensors with the ball, players can hinder the opponent's movements thanks to a haptic actuator attached to the clamps that applies friction when one of the players' sensors is hit.

2.1.1.2 Table augmentation

In this section, games whose interaction is carried out on interactive/augmented tables are presented.

PingPongPlus [Ishii et al., 1999] is a digitally augmented version of the classical ping-pong game considered one of the pioneers in the field of hybrid games. Digitally augmenting the ping-pong table required to develop a completely new ball tracking hardware, consisting of an audio based sensor capable of triangulating how the ball bounces on the ping-pong table. Graphic feedback is provided by projecting digital images on the ping-pong table, and by generating animated graphics related to the hits of the ball on the table. Several augmented ping-pong game modes were developed, enriching the traditional ping-pong game.

RoboTable [Krzywinski et al., 2009] is a tabletop system that allows users to manipulate robots intuitively. This time, instead of using RFID technology to detect the robot on the table, special printed markers are attached to the robot's base. Digital cameras installed inside the tabletop are in charge of detecting the robot's markers placed on the tabletop surface, and the reacTIVision software framework [Kaltenbrunner and Bencina, 2007] is used to recognize the markers of the robots. reacTIVision simplifies the tracking of conventional objects on interactive tables attaching ordinary printed markers on the base of the object instead of complex and expensive electronic components. reacTIVision uses the TUIO communication protocol [Kaltenbrunner et al., 2005], built on the Open Sound Control communication protocol (OSC) [Wright, 2005] in order to allow the transmission of messages which are sent when carrying out manipulations on the tabletop surface.

Other hybrid tabletop games also use reacTIVision. In the *Farm* game [Cerezo et al., 2015] children manipulate animal toys with reacTIVision markers attached to them in different ways: for example, when the child makes the cow and the hen "jump" on the tabletop, the image projected on the tabletop shows milk and eggs respectively, and when the pig toy is moved on the virtual bushes, it collects strawberries. Finally, *Uprising* [Dionísio et al., 2015] is a digitally augmented board game in which players control zombies and humans playing pieces on the tabletop surface to defend their respective territories. This game uses reacTIVision to detect the playing pieces on the tabletop, and also projects the image of the board on the tabletop surface.

2.1.1.3 Room augmentation

Here, games that are played in augmented rooms with convergence of different paradigms are commented.

The *Kidsroom* [Bobick et al., 1996] is an indoor environment that re-creates a child's bedroom where children become the protagonists of a story: *The Bedroom World*. The children have to go asking the different pieces of furniture of the room in order to discover a magic word that would allow them to travel to other worlds. Visual feedback is provided through wall projections that recreate the room environment and the different worlds the children can travel to, and audio feedback is reproduced via several speakers. The deployment of the game required to use a total of four cameras to track the children's position and movements in different angles, and a detection algorithm was implemented to recognize the actions the children perform while playing.

Touch-Space [Cheok et al., 2002] is an interactive room aimed to support mixed-reality based hybrid games where players have to walk around and interact with physical objects. In order to track the players' position in the room, *Touch-Space* uses a Real Time Locating System (RTLS) able to detect the position of the head and hands of the players. RTLS systems make use of wireless tags attached to objects or persons that send wireless signals to the sensors that compose the RTLS so that the system can triangulate their position. In *Touch-Space*, players also wear a Head-Mounted Display (HMD) to support video-see through augmented reality feedback, and the HMD has a small video-camera to track visual markers attached to different objects of the room. The position of the markers is tracked using the ARToolkit software [Kato, 2007]. In addition, the players carry a wand toy that gives visual feedback about the tasks that they have to perform.

Age Invaders [Khoo et al., 2008] is an interactive indoor game installation based on the Atari™ *Space Invaders* classic arcade game. In *Age invaders* the spaceship digital sprites were physically replaced by the players themselves. In a room, one team plays the defenders while the other plays the invaders. The floor is digitally augmented with audio and video projection, representing the star background and the missiles that each player shoots. Players use a hand controller to shoot the missiles. When a player is hit, the "explosion" is showed in a LED display that the players wear on their body. The tracking of the players' interactions during the game is provided by installing RFID readers in the players' shoes.

Another mixed reality example is *Treasure* [Guo et al., 2012], where players have to find objects marked with RTLS tags. In order to gather other physical information related to the objects, such as their orientation or certain changes produced in their surrounding environment, MOTE sensors are attached to certain objects. There are two different kinds of objects: target, the ones that the players have to find to win the game, and supporting, the ones that give hints to the player to find the target objects. *Treasure* has been designed so that it is possible to trigger different digital responses to the player's actions: for example, when they find an object an audio can be played, an image/video can be shown on the wall, or both.

The *Music Room* [Morreale at al., 2014] is an interactive indoor installation where music can be composed by dancing in the space. In order to detect the dancers' movements, cameras are embedded in the environment and a tracking software was developed by applying digital image algorithms. The information extracted from the camera image analysis is sent to a musical composition digital system using OSC. The composition system analyzes the data from sensors and generates music depending on the way people are dancing (close to each other, far from each other, fast, slow).

2.1.1.4 World augmentation

In outdoor games, players can be widely scattered in places from a campus to a whole city, or even the world.

Can you see me now? [Flintham et al., 2003] is a mobile mixed reality game in which online players play an adapted game of catch with real players (runners). Online players move in a virtual model of the city and runners have to “catch” the online player using a handheld map where the position of other runners and the online players is shown. Runners also wear Walkie-Talkies to communicate with each other. In this case, the whole city becomes the playground where players, online and runners, are collaborating.

Another example of outdoor game is *Treasure* [Chalmers et al., 2005]. In this game players have to collect virtual coins in the city with the help of PDAs where a map with the current positions of the coins and the players is displayed. Players compete to collect more coins and they can even steal coins from another nearby player. In both games, GPS sensors are used to track the position of the players, and visual and audio feedback is provided by the use of PDAs.

Finally, *Save the Safe* [Soute et al., 2013] is an adaptation of the traditional game of cops and robbers. In this version, children divided in robbers and cops carry a device with a LED that shows the color of the team and gives audio instructions. At the beginning of the game, the device of one of the cops vibrates, indicating that he/she has the key that the robbers have to steal to win the game. Only the cop with the key knows it, so the robbers must run after the different cops and approach their devices to the cops’ ones to try to guess who has the key, while the cops have to pass the key with their devices to prevent the robbers from stealing it. The devices used in this game embed different hardware components such as an accelerometer sensor to measure movements and a XBee module that allows RF communication to interconnect the different devices and measure distances between devices. Visual and audio feedback is provided by a vibration motor, speakers and LEDs.

2.1.1.5 General conclusions

All the examples that have been explained are summarized in Table 2.1 in order to show their characteristics more clearly. The second column indicates the way to interact with the respective systems, the third column relates to how the implementation has been carried out, and the fourth column shows the different kinds of outputs found in the games.

Table 2.1 Hybrid games classification based on deployment

	GAME	INPUT	IMPLEMENTATION	OUTPUT
	Caves & Creatures (2006)	Objects Gestural	**Communication**: TCP/IP, Bluetooth **Language:** C **Toolkit:** *Pegasus**	Computer screen Accelerometer
	Noon (2009)	Objects	**Communication**: RF	PDA Accelerometer
O **B** **J**	The Reading Glove (2010)	Objects	**Communication:** RFID **Language**: Max MSP	Computer (audio, images)
E **C** **T**	Don’t Panic (2015)	Objects	**Communication**: RFID, Bluetooth **Toolkit:** *AnyBoard**	LEDs
A **U**	BoomChaCha (2016)	Objects	**Communication**: TUIO, RF (xBee) **Language**: Processing	LEDs Projection screen Accelerometer

G M.				
	Hybrid Monopoly (2017)	Objects	**Communication**: Bluetooth, RFID **Language:** C++, Java	LCD panel LEDs
	Augmented foosball (2017)	Objects	**Communication**: Open loop control (Arduino)	Linear actuator LEDs Impact sensor
T A B L E A U G M.	PingPongPlus (1999)	Sound	**Algorithms**: Hit-detection, sound-based tracking system **Language:** C++	Projector
	RoboTable (2009)	Objects Gestural	**Communication**: Bluetooth **Language**: Java **Toolkit**: reacTIVision	Tabletop surface
	Farm (2015)	Objects	**Communication**: TUIO (OSC) **Toolkit**: reacTIVision, *ToyVision**	Tabletop surface Projection screen Speakers
	Uprising (2015)	Objects	**Communication**: TUIO (OSC) **Language**: Processing **Toolkit**: reacTIVision	Tabletop surface
R O O M A U G M.	Kidsroom (1996)	Embodied Gestural	**Communication**: RPC protocol **Algorithms**: Vision-based	Projection screens Speakers Lights
	Touch-Space (2002)	Embodied	**Communication**: Markers, RTLS **Toolkit**: ARToolkit	Wand for visual/audio information
	Age Invaders (2008)	Embodied	**Communication**: RFID, Bluetooth	LEDs Projection screens Speakers
	Treasure (Guo et al., 2012)	Embodied	**Communication**: RTLS **Toolkit**: *Sixth-Sense**	Projection screens Speakers MOTE sensors
	Music Room (2014)	Embodied	**Communication**: OSC **Algorithms**: Visual tracking	Speakers
W O R L D A U G M.	Can you see me now? (2003)	Embodied	**Communication**: Wifi, GPS	PDA Walkie-talkie
	Treasure (Chalmers et al., 2005)	Embodied	**Communication**: UDP, Wifi, GPS	PDA
	Save the safe (Soute et al., 2013)	Objects Gestural	**Communication**: RF **Language**: Processing, C++ **Toolkit**: *RaPIDO**	LED Speaker Accelerometer

After a detailed analysis of the different games, some conclusions can be extracted regarding their common characteristics:

- The development of hybrid games requires the integration of **a great variety of devices**, and there are some kinds of sensors that are commonly used depending on what to track: games where objects are augmented require RFID technology and visual printed markers that are later tracked by specialized software; when the game needs to "know" the position of the players in the system, RTLS technologies are applied in room augmented games while GPS sensors are used in world augmented applications; and when it is necessary to recognize the player's gestures, accelerometers sensors are integrated. Also, some games make use of actuator hardware, such as *BoomChaCha,* whose toys are reactive to users' manipulations by lighting LEDs in certain colors, and *Augmented Foosball*, where haptic actuators are embedded in the foosball's rods to apply force depending on the player's performance during the game.

- The hybrid games presented in Table 2.1 make use of different software toolkits in order to carry out certain parts of the implementation, such as reacTIVision and the ARToolkit to process camera digital image to track printed markers. Several programming environments such as Max MSP, Arduino, Processing and Eclipse are used to develop the game logic. In order to communicate distributed hardware components, different communications protocols are used, such as TCP, RPC, Bluetooth and OSC. Very often, the development of hybrid games requires to implement their own detection and tracking algorithms from scratch. Although in some works this could be due to the lack of existing software at the moment (*The Bedroom World* and *PingPongPlus*), there are relatively recent works that require hardware level coding from scratch too, such as *Robo Table*, *Music Room* and *Augmented Foosball*. In addition, among the 19 works analyzed, in 14 of them **the coding of the game has been made *ad hoc***, without using any specific toolkit that facilitates the task of dealing with the different paradigms involved in the game. The only 5 works that make use of existing toolkits are *Don't Panic* with *Anyboard*, *Caves & Creatures* with *Pegasus*, *Farm* with *ToyVision, Save the safe* with *RaPIDO,* and *Treasure* with *Sixth-Sense*, which will be analyzed in the next section.

- With the exception of *Augment foosball,* that does not provide visual output, and *Music Room*, that only uses audio feedback, the rest of the games employ a combination of audio and visual feedback. It can also be observed that there are multiple ways to show visual information (projection screens, controlled lights, tabletop surfaces, PDAs, smart-phones, monitors), and, unlike traditional games where the player's actions and the feedback obtained take place in the same space, in hybrid games the manipulations that the players carry out to interact with the application do not necessarily happen in the same place where the feedback is provided, but in their surroundings, and even in different devices at the same time. Also, giving feedback in different ways means that there are **multiple and heterogeneous displays** in charge of showing some pieces of information in order to make the game evolve.

After the analysis of hybrid games carried out from the point of view of the deployment process, it can be concluded that the creation of hybrid games is not something trivial, since it demands to deal with very different technologies whose software and hardware may greatly differ. For that reason, toolkits able to facilitate the whole development process of hybrid games or, at least, a part of it, are needed, which is what we are going to discuss in the next section.

2.1.2 Toolkits for the Development of Hybrid Games

The development of hybrid games relies on the development of ubiquitous computer technologies. As Weiser [1993] pointed out in his first work regarding this new paradigm: "*unlike Virtual reality, ubiquitous computing will integrate information displays into the everyday physical world. (…) And unlike current personal digital assistants, ubiquitous computing will be a world of fully connected devices, with cheap wireless networks*". Weiser also mentioned the multiple challenges that the development of ubiquitous computing would face up: "*this nascent research has already had a worldwide impact on all areas of computer* *science, from hardware Components to network protocols, interaction substrates…*". Twenty-five years have passed since these first reflections, but Weiser's vision regarding ubiquitous computing still seems futuristic. Davies and Gellersen [2002] already summarized some reasons for this situation that mainly consist of a lack of integration in existing systems. Ubiquitous computing requires a panoply of technologies to blend digital data into the physical world, but these technologies are already developed or in development. However, the number and heterogeneity of sensing techniques, interface devices, form factors and physical settings usually involved in ubiquitous computing represent a complex space from the perspective of the generalization of development tools [Melchior et al., 2011]. In order to deal with this complex situation, it is necessary to make an effort in the search and creation of architectures and tools that propose a standardization of the methods and techniques to deploy ubiquitous computing systems.

In addition, as outlined in the examples of the previous section, hardware configurations are usually purpose-built for each game, and software is written from scratch from low-level hardware code to high level game logic. This way two important questions remain open: how existing hardware and software design solutions can be re-used, and how higher level prototyping can support can be provided to designers so they can contribute to the implementation process, bridging that way the gap between the design and implementation processes. While many rapid prototyping tools are available for the standard platforms like personal computers and smartphones, tools for rapid prototyping of hybrid games are scarce. In the analysis of hybrid games carried out, it was seen that most part of the games had been developed ad hoc, but there were also some of them that used specific toolkits to deal with the creation of the games. Their review follows.

Pegasus [Magerkurth et al., 2006] is a software architecture for developing hybrid games based on tangible interaction. To integrate the different tangible and graphical components, each interaction device is associated with a software proxy in charge of communicating with the other devices to exchange information. PDAs are used to show information related to the game, and the authors have created an XML-based language to store the rules of the game. These rules can be modified in runtime, and the different devices can be connected or disconnected while the game is running.

Sixth-Sense [Guo et al., 2008] is an infrastructure initially aimed at the development of smart-artifact services but which is also used by the same authors to create hybrid games. Sixth-Sense is based on the OWL ontology to define relationships found in a typical smart home environment (humans, objects, and humans and objects). However, the ontology can be extended by adding other concepts related to games, such as a win/loss status.

AnyBoard [Mora et al., 2015] is a toolkit for the development of hybrid board games that facilitates the coding of the game logic and also provides tools to support the design of the games. In order to do so, AnyBoard proposes the Interactive-Token approach, based on the Token+Constraint framework [Ullmer et al., 2005]. The Token+Constraint framework provides designers with an abstraction language to specify any TUI. With this language, designers can define the different interactions of the systems in terms of relationships between elements of the game. This way, AnyBoard reduces the gap between the design and prototyping processes.

As commented already, ToyVision [Marco et al., 2012] also facilitates the prototyping of hybrid games for tabletop devices. In this case, ToyVision adopts the Tangible User Interface

Modelling Language (TUIML) [Shaer and Jacob, 2009], to provide a common tool between designers and developers. ToyVision provides designers with a GUI assistant that enables designers to draw the TUIML specification of a hybrid game for tabletop devices. This graphic is automatically translated into XML code, facilitating that way the process of coding the logic of the tabletop game.

Finally, RaPIDO [Soute et al., 2017] is a prototyping platform for outdoor games. In the games developed with RaPIDO, players make use of hand-made devices to interact with the game and the other players. RaPIDO devices are hand controllers which embed a RFID reader sensor in order to detect tagged objects, and an accelerometer sensor to measure movements; feedback is provided by a vibration motor, speakers and LEDS to provide audio and visual feedback. The communication between different controllers is provided by the Arduino microcontroller and the xBEE wireless module which also enables to measure the distance between them. Developers have access to a software API that allows to choose the functionalities of the device that they want to activate, and to program the behavior of the devices using the Arduino or C development environments. Therefore, RaPIDO enables the development of hybrid games in which interaction and feedback are provided by multiple identical hand controllers, which integrate different sensors and feedback hardware to be used in different ways.

In Table 2.2 a summary of the toolkits that have been commented in this section is presented. The first three columns show if the toolkits deal with the three challenges that we have found in the previous section: the integration of different devices (first column), the coding of the application (second column), and the management of displays (third column). The fourth column indicates the end-user the toolkit is addressed to, and the fifth column shows the interaction paradigm addressed by those toolkits: Tangible Interaction (TI), or embodied interaction (EI).

Table 2.2 Characteristics of toolkits

Toolkit	**Integration**	**Coding**	**Displays**	**Addressed to**		**Category**
				Designers	**Developers**	
Pegasus (2006)		✓	✓	✓	✓	TA
Sixth-Sense (2008)		✓			✓	RA
ToyVision (2012)		✓	✓	✓	✓	TA
AnyBoard (2015)		✓	✓	✓	✓	OA
RaPIDO (2017)		✓	✓	✓	✓	WA
JUGUEMOS	✓	✓	✓		✓	RA

It can be seen that independently of the category of the games (fifth column) neither of them addresses the integration of heterogeneous devices (first column), having decided to focus on the coding of the application (second column) and the management of displays (third column). This is probably due to the fact that this second group of toolkits are aimed not just at developers but also at designers (fourth column), and that therefore they preferred to focus on simplifying the creation of the game rather than on facilitating the integration of multiple devices, since these tasks usually go beyond the designers' skills.

ToyVision, a toolkit to create hybrid games for tabletop devices (third row of Table 2.2) had been developed in the AffectiveLab research group. Thanks to the *JUGUEMOS* Research Project (TIN2015-67149-C3-1R), an interactive space was installed in the Cesar-Etopía laboratories in Zaragoza, so it was decided to make the most of that environment to create a toolkit to develop hybrid games played in interactive spaces (seven row of Table 2.2). This new toolkit would be based on the previous experience, but would cover all kind of devices, not only tabletops. Due to this fact, it was decided to orient it to developers, not designers. This choice implies that designers do not have as much control and independence in the creation of hybrid games as they have in the previously cited examples, but we believe that the architectures on which our toolkits are based allow to lower the inevitable gap that exists between designers and developers, as it will be shown in this Thesis.

2.2 Tangible Tabletops and Users with Special Needs

Hybrid games seamlessly combine physical and virtual elements while making use of several paradigms in order to interact with the environment. By doing so, they allow a more natural way of interaction, which widens the possibility of using these systems with user groups affected with certain difficulties, such as children and adults with special needs.

2.2.1 Children with special needs

According to data from the World Health Organization (WHO), more than 2% of child population aged between 0 to 6 years old experiences pathological changes that can produce disorders in their development [Valcarce, 2006]. Developmental disabilities consist of a significant deviation of the natural evolution as a consequence of health or behavior events that compromise the biological, psychological and social development of a person, estimated to affect 5% to 10% of children [Shevell et al., 2003]. The developmental delay is a subset of developmental disabilities defined as a significant delay in two or more of the most common developmental domains (gross/fine motor, speech/language, cognition, social/personal, activities of daily living). The main problem is that there is no specific method to cure it, so any treatment plan would have to take every child’s uniqueness into account and would have to be designed to focus on the child’s individual needs.

Usually, regarding the corresponding developmental disorder, programs focusing on different scopes are used: aspects like comprehension, syntax development and grammatical elaboration are addressed in the linguistic area; work with several stimuli (visual, acoustic and tactile) is favored in the cognitive area; and, in the motor area, reflexes and movement of the different parts of the body are worked [Peñafiel at al., 2003]. Besides these traditional activities, new technologies are increasingly used to work with this group of children, such as interactive computer tools and games. The use of video games and digital devices is not new in cognitive stimulation, since it has been demonstrated that interactive games are stimuli that can help to improve the attention and planning skills, and may perform mediation functions encouraging children to explore, generate questions, and reflect [Gunter, 1998][Granic et al., 2014].

As already commented, hybrid games present certain advantages over desktop applications because of the natural ways interactions that they can offer. Tabletop devices have become quite popular in recent years for improving different cognitive skills [Piper et al., 2006][Zarin and Fallman, 2011]. A tabletop is a computer device whose physical appearance is very similar to a standard table. Its surface is virtually augmented by using projections of images and sounds coming from a computer application, and usually the interaction is carried out through movements of the fingers on the tabletop surface [Goh et al., 2012]. This manner of interaction has several advantages since the wide surface of the tabletop provides a broad space to work visual and motor skills, the audio-visual stimulation motivates the user, and the tabletop allows working with a bigger range of activities that cover one or more aspects of cognitive stimulation.

However, multi-touch interaction has some drawbacks for small children [Mansor et al., 2008]: if the child’s fingers are too small, the system may have difficulty in correctly detecting them, which may complicate the performance of some actions such as pointing to a virtual object or dragging it across the surface.

In those cases, Tangible User Interfaces (TUI) represent a natural interaction alternative where the interaction between the user and the application should be done by using physical objects of quotidian use [Ishii and Ullmer, 1997]. A tangible tabletop device can identify different objects placed on its surface, track the different user manipulations, and also show information related to such manipulations on the surface. By keeping objects on the physical side of the users, the emotional impact of the game is reinforced [Iwata et al., 2010] and important additional benefits emerge when applied to young children [Read and Markopulous, 2013] and children with special needs [Li et al., 2008][Hendrix et al., 2009][Alessandrini et al., 2014]. In fact, several comparison studies between tactile and tangible activities have been carried out showing that most children in the studies preferred tangible activities over tactile ones [Suárez et al, 2011]. This preference is related to high levels of stimulation and enjoyment, derived from three TUI properties: physical interaction, rich feedback, and high levels of realism [Zuckerman et al., 2015]. Besides, tangible interfaces enable more efficient and effective motor strategies [Antle and Wang, 2013], were considered more user friendly [Arnaud et al, 2016], and have been claimed as especially suitable for children with special needs [Falcão and Price, 2010].

In the last ten years, several examples of hybrid games that make use of the Tangible Interaction paradigm have been developed for children with special needs in order to help them work their affected capabilities. The work carried out by Hunter et al. [2010] is a group of activities to teach spatial concepts and sentence construction to children aged 4-7 years, by using *Siftables*: hybrid tangible-graphical user interface devices that allow wireless communication and that can detect other devices of the same kind. *TOK* [Sylla et al. 2011] is a tangible platform consisting of an electronic book with slots in which children can create their own stories by putting drawing cards in the book, in order to establish sequences or tales. *Reactable* is a tangible tabletop used by Villafuerte et al. [2012] to work with autistic children in the creation of complex music pieces, in order to offer them an alternative means of communication. The interaction with *Reactable* is usually carried out by using special objects called pucks (such as audio-filters, controllers, generators, etc.) but it also allows a direct interaction. *TangiPlan* [Weisberg et al., 2014] is a system composed of six tangible objects whose objective is to help children work their executive functions. Each object represents a task that the child has to carry out in the morning. The child situates the objects at the places where the tasks have to be performed and selects the time to be devoted to every task. *SitCap* [De la Guía et al., 2015] is a system that allows children with Attention Deficit Hyperactivity Disorder (ADHD) to work their memory, attention and associative skills by playing three different games with three levels of difficulty. In order to interact with the system, children use cards with RFID tags integrated inside that they have to approach to a mobile device. Finally, *the Interactive Fruit Panel* [Durango et al., 2016] is a tangible interface designed to help children with communication problems connect real objects (in this case fruits) to their graphical representation. The game consists of showing a real object or a miniature, which the child has to relate to some pictograms of the object. In this way, children can learn the required association between pictograms in order to have an alternative communication system. In addition to their communication skills, the activity also makes the children work out their concentration, visual activation and memory.

From the examples presented above it can be concluded that although there are several works that use tangible interfaces to work with children with developmental problems, the use of tabletops in this field is not widespread. Moreover, the works that make use of tangible tabletops usually focus on working just a specific developmental delay, without offering the possibility of working with children with different problems, so the activities developed are very difficult to adapt or modify. For example, some systems work, exclusively, with different language problems, while others allow to work more varied problems (spatial concepts, concentration, visual attention, memory, etc.) though it is not easy to modify the activities already created.

Our group, the AffectiveLab at the University of Zaragoza (Spain), had developed NIKVision [Marco et al., 2009], a vision-based tangible tabletop device designed for very young children that allows them to play with the computer manipulating conventional toys. In fact, thanks to ToyVision toolkit, several games were created and its potentiality for working with children was assessed [Marco et al., 2013a]. However, it was realized that to be useful for children with special needs it was necessary for the therapists and educators to adapt the games to each child. That was impossible for the therapists to do by themselves, as they usually do not have programming skills. This made it clear the necessity of new tools specially devoted to therapy as it will be explained in section 2.2.4.

2.2.2 Designing for and with children with special needs

When designing for children with special needs, several aspects have to be taken into consideration. McKnight [2010] sets fifteen guidelines that software designers should follow when designing their system. Even if several of those guidelines are valid for all kind of users (the relevant information has to be easily found, the instructions given have to be brief and clear…), there are certain guidelines that are especially meaningful for children with ADHD: to use calm and soothing colors instead of vivid ones, always use positive feedback, or minimize distractions. The same way, Börjeson et al. [2015] analyze different works in which design process with developmentally diverse children is carried out. The authors also present guidelines for how to prepare and perform design sessions with developmentally diverse children, regarding how to structure the sessions, how to motivate the children, the materials that have to be used or the instructions that have to be given.

Also, several works prove that letting children participate in the design process can provide good results. Druin [2002] assesses that there are four main roles that children play in the technology design process: *user*, when children simply use the developed technology; *tester*, when children use a prototype of the technology; *informant*, when children participate in certain stages of the design process; and *design partner*, when children participate in all the stages of the design process. The author strongly recommends to use the last one, since letting children participate in all the design experience allows them to experiment a new way of learning, and besides the collaboration between adults and children may result on innovative technologies for teaching, entertainment and learning. Read [2015] mentions as well the advantages of involving children in design and evaluation, even if there are some difficulties involved such as the process of recruiting children for the studies or to ensure that the children’s contribution are meaningful.

When working with children with special needs, participatory design with them acting as informants and design partners is possible as well, as long as both the nature and severity of the children’s disability are taken into account [Fails et al., 2012]. Some works that involve children with these characteristics in the design process have been found: *Memory Game* [Al-Wabil et al., 2010] is an educational game that helps children with learning difficulties work strategies for memory. The authors have involved the children in the selection of the characters and images that appear in the game. Also, Benton et al. [2014] present a framework to adapt participatory design to neurodiverse children. “Neurodiversity” is a term that applies to a subset of neurological conditions that include ADHD, autism, dyslexia, anxiety disorders and other cognitive disabilities [Amstrong, 2010]. However, what makes the neurodiversity approach is the consideration of the positive aspects neurodiverse people may have. For example, in the specific case of children with ADHD, due to their characteristics they are more likely to be highly creative and good multitaskers in stressful situations [Dalton, 2013].

Thanks to a collaboration with Atenciona, an association of ADHD families and professionals of Zaragoza, it was possible to test the activities that were created within this Thesis Project and carry out a participatory design experience, that will be presented in the Chapter 4 of this document.

2.2.3 Adults with cognitive impairments

The work with NIKVision had proved its usefulness to work with cognitive impairments such as attention, memory and reasoning with children with special needs. Therefore it was thought that it could be also interesting to support cognitive stimulation in adults. Cognitive deterioration is a natural consequence of aging, but it also can be caused by neuropsychiatricf diseases. In fact, it is estimated that 14% of diseases at a global level can be attributed to neuropsychiatric impairments [Prince et al., 2007] that produce a cognitive deterioration due to the disease itself or as a side effect of the medication prescribed. A way to help those adults to improve their cognitive skills, or at least to prevent further deterioration, is by using activities that help them work their most affected cognitive areas.

Applications for cognitive stimulation are based on the belief that keeping clients active can reduce or slow down their cognitive deterioration, by working their most affected areas and avoiding the disuse caused by the disease itself or by medication. Numerous studies support this practice [Hall et al., 2009][Reichman et al., 2010].

Two major approaches have been successfully applied to cognitive stimulation. Strategy training [Labouvie-Vief and Gonda, 1976] is a “top-down” approach which involves different techniques to improve performance over a range of different cognitive tasks including memory techniques, psychological support, goal management training, reasoning and complex coordination. In contrast, extended practice training [Edwards et al., 2005] is a “bottom-up” approach that may not involve a strategy for training cognitive areas but extensive repetition of skills to be stimulated. This second approach involves hundreds to thousands of repetitions of the skill to be stimulated. Therefore, the work of the therapist, most specifically of the occupational therapist (OT), is challenged to increase the client’s motivation for adherence to the therapy [Söderback, 2009], since such motivation for executing repetitive and boring exercises is often lacking.

Traditionally, the activities used by OTs in their sessions are mainly done using pen and paper. Examples of these traditional activities can be found in [Ball et al., 2002], where the authors present different cognitive training interventions: memory training, with exercises involving recalling a list of nouns, recalling a paragraph or recalling a shopping list; and reasoning training, with exercises involving abstract reasoning tasks such as letter series as well as reasoning difficulties related to activities involved in daily living. However, OTs often search for interactive computer tools and games as a means of obtaining immediate feedback and adding fun to the therapy. Computer-based activities are increasingly replacing the original traditional ones because they offer several additional advantages. They facilitate multimodal and multi-domain training, and allow therapists to set and/or gradually increase the level of difficulty of the activities [Gates and Valenzuela, 2010]. Nowadays therapists have at their disposal numerous tablet and smart-phone applications aimed at helping people with physical and/or cognitive impairments. However, it has been demonstrated that the use of a more natural form of interaction with the digital world can provide several added benefits. Marshall [2007] analyzes the potential of tangible interfaces when states: "*as interaction with tangible interfaces is assumed to be more natural or familiar than with other types of interface, they might be more accessible to young children, people with learning disabilities or novices, lowering the threshold of participation*". Therefore, natural interaction based applications may offer some extra benefits to therapy over computer-based applications.

A revision of tangible experience for adults with cognitive impairments follows.

In the context of tangible interfaces, *GenVirtual* [Correa et al., 2007] is an augmented reality-based musical game that aims to help people with disabilities. The game shows a sequence of virtual sounds and colors the client has to memorize in order to create a melody. The interaction with the system is carried out by placing the clients' hands or feet on the virtual object, and the difficulty of the game gradually increases, so the clients are forced to work their memory skills. *Abaris* [Kientz et al., 2005] is an automated capture application aimed at helping therapists during their sessions. The Abaris system replaces traditional pen and paper interaction by Anoto digital technology. This allows questionnaires filled in by the therapists to be stored in the application to automatically generate graphs of the data, thus easing the work of the therapists. Also, Abaris allows the whole session to be captured and is provided with software to record speech audio. The therapists can then access all the data and review sessions by accessing the Abaris interface in the computer. Finally, De la Guía et al. [2015] present a system aimed at clients with Alzheimer's and other dementias that is composed of two interactive and collaborative games, designed to support cognitive stimulation. The system has two forms of interaction: using a tablet or using a tangible interface composed of images with integrated tags. The interaction with the tablet is carried out with the fingers and the interaction with the tangible interface is done through a mobile device.

As mentioned, the application of tangible interaction in a tabletop device is particularly suitable thanks to the ergonomic features of the tabletop, for example the possibility of offering different viewpoints to several users working at the same time [Dillenbourg and Evans, 2011]. In the context of applications for tangible tabletops, *the E-CoRe system* [Kwon et al., 2013] aims to improve three cognitive processes (attention, memory and reasoning) by using a tabletop device with an application to simulate making cookies by manipulating different objects. The application has two stages: the baking stage, in which the users have to adjust the number of cookies, to select their shape and to set the oven temperature, and the finishing-touch stage, in which the users have to add syrup and toppings to their cookies. During the two stages the users have to follow certain instructions while remembering the steps that they have already done, so they are continuously working their attention and memory skills. Gamberini et al. [2006] have developed a tabletop together with the *Memo-game* activity, an application similar to the popular game of finding pairs. While playing the *Memo-game,* the users gain points when making pairs and lose points when they fail to pair two images correctly. However, they can recover the points that they have lost by playing additional mini-games. The aim is to improve cognitive functions like memory, reasoning, selective and divided attention, and classification. The users interact with the tabletop by using special pencils. Leitner et al. [2007] present a prototype of a tabletop for cognitive and physical rehabilitation. The authors also propose some activities based on manipulating cubes with different patterns drawn on them. To complete the task, the user has to align the cubes to form the same image as that shown on the tabletop surface. Finally, *Sociable* [2018] is a European Research project for cognitive training focused on people with cognitive disorders that uses a tactile tabletop to run a great variety of activities organized in categories: memory, attention, reasoning, language and orientation. They have developed tactile tabletop versions of popular games like *Finding pairs* or *Guess Who* together with several activities very similar to traditional puzzles.

All these systems are based on a tabletop device. However, not all of them use tangible interaction or, when they do so, they do not offer much variability in the physical objects that can be used. For example, the system developed by Gamberini et al. allows working different cognitive processes but uses only pens as replacements for the fingers. Also, even if Kwon et al. and Leitner et al. use different objects, the systems only address the development of one single activity with predefined objects, so the cognitive aspects covered and the objects used are very limited. Finally, despite the great variety of cognitive activities that appear in *Sociable* all of them are based on tactile interaction, so the advantages of tangible interaction are again lost.

For that reason, one of the objectives of this Thesis was to explore the use of tangible tabletops with adults with special needs (mostly cognitive). As in the case of children, it was clear that the existence of tools that allow the professionals to adapt the activities to every individual would be critical. In fact, there is no much work in that direction in the literature, as it is shown in the next section.

2.2.4 Toolkits for therapies

In the specific field of applications designed for therapy, the efficacy and use of the applications depends greatly on offering therapists the possibility to adapt the activities or even the therapy according to the clients' evolution and needs, allowing them to create and/or modify the activities without external aid. . For this reason, it becomes necessary to orient these systems to the End-User Development (EUD) paradigm, which tries to bridge the divide between design-time and use-time, allowing continuous adaptation of interactive systems that fulfill specific user-needs [33]. The EUD paradigm's main goal is to make systems that are easy to develop for the end-users, enabling the development of interactive applications without requiring coding and opening up in this way new possibilities for therapists to create their own applications for their daily work.

Lieberman et al. [2006] performed an exhaustive study in which they analyzed the first works that provided the foundations for the EUD paradigm as we know it nowadays. After their analysis, the EUD paradigm is defined as "*a set of methods, techniques, and tools that allow users of software systems, who are acting as non-professional software developers, at some point to create, modify or extend a software artifact*". The authors argue that due to the great diversity that exists in society and the presence of multiple professional areas and people with very different skills, the solution for creating systems that are really useful is to involve all these different professionals directly in the design and development process, making the final users take an active role so that they are able to change and modify the system itself to adjust it appropriately to their needs at any moment.

Several examples of EUD applications designed for therapy can be found in the literature, but if we focus on EUD applications for therapy that make use of the Tangible Interaction paradigm, the examples are scarcer. Table 2.3 shows current tangible toolkits that provide therapists with the means to develop their own activities.

Table 2.3 Features of different EUD tangible toolkits for therapy

		Kind of Therapy			
System	**Authors**	**Physical**	**Cognitive**	**Objects used**	**Graphic assistant**
Write-N-Speak	Piper et al., 2011		✓	Paper and Pen	✓
DIY-Toolkit	Moraiti et al., 2015	✓		Any (soft)	✓
TagTrainer	Tetteroo et al., 2015	✓		Any	✓
Moments	Lazar et al., 2017		✓	Any	✓
ConstrAct	Poutouris et al., 2017		✓	Cards/Fingers	✓

The five systems are first briefly described after which their main characteristics are analyzed in detail. *Write-N-Speak* [Piper et al., 2011] is a system that allows therapists to customize their own paper materials to work reading, writing, speaking and auditory comprehension with their clients. The clients interact with the customized paper materials by using a digital pen. *The DIY-Toolkit* [Moraiti et al., 2015] allows turning daily soft objects into smart devices that are able to recognize the manipulative actions that the clients perform on them, such as pinching, bending, pushing or squeezing. *TagTrainer* [Tetteroo et al., 2015] is composed of interactive boards on which clients manipulate objects with their hands to work arm-hand rehabilitation. *Moments* [Lazar et al., 2017] is a tangible system to work social skills that consists of a tablet mounted in a wooden frame that represents a painting. The tablet is able to read tagged objects. The therapists can create customized interactions and then the clients interact with the painting by using the tagged objects. Finally, *ConstrAct* [Poutouris et al., 2017] is an authoring tool addressed to educators that allows the creation of content and scenarios for ubiquitous educational mini-games based on multi-touch interaction or tangible interaction through cards. The system allows five game types to be defined: quiz (choose the correct answer to a question), sequence (place items in the correct order), classification (situate items in their most suitable place), “wrong item detection” (detect the items wrongly placed in a scenario), “execute a process game” (complete steps to carry out a task).

Regarding the kind of therapy that the toolkits work (third column), on the one hand, in the context of cognitive therapy, *Write-N-Speaks* has been designed to help adult people with speech-language difficulties, *Moments* allows people with dementia to work their abilities in social sharing, and *ConstrAct* allows the development of activities for children with cognitive disabilities such as limited reading skills or difficulties in problem solving. On the other hand, in the context of physical therapy, *the DIY-Toolkit* is oriented to clients that have difficulties manipulating objects, and *TagTrainer* supports arm-hand rehabilitation. Also, it is worth mentioning that all the toolkits offer immediate audio and/or visual feedback to the clients, not just to show them what is happening but also to increase their motivation when doing the therapy.

Focusing on the physical objects that these system use (fourth column), *Write-N-Speak* can work with a great variety of paper materials, but the clients only use an Anoto digital pen to interact with the system, for example by signaling the parts of the image that the therapist wants them to identify, or by pointing at the sentence that the therapist wants them to spell aloud. The *DIY-Toolkit* uses an encapsulated hardware that can be connected to conductive wool in such a way that when this wool and the hardware are placed inside an object, it becomes a smart device. These objects must be soft, since the clients have to be able to apply different physical manipulations on them. *TagTrainer* and *Moments* can work with any kind of object as long as they are marked, by using RFID tags in the first case and TopCodes tags in the second case. *ConstrAct* allows users to interact with the games by using their fingers (multi-touch) or physical printed cards.

Finally, it can be seen in the fifth column that all the toolkits provide therapists with a graphic assistant so that they can create their own activities. These graphic assistants follow the What You See Is What You Get (WYSIWYG) approach, allowing therapists to customize their own applications graphically. The editor mode of *Write-N-Speak* allows users to upload images and to trace dot regions on them that will later be detected with the Anoto pen. *The DIY-toolkit* graphic assistant allows users to define different gestures for each soft object, and also to relate them with a computer command such as a mouse click or a key on the board, allowing control of other applications with the created smart objects. *TagTrainer* provides a visual programming tool to define in which areas of the board the client is going to manipulate the object, and how he/she is going to do it (moving it up, moving it down, rotating it…). *Moments* provides the therapists with an Android application that allows the user to capture images, and record and replay audio to accompany the image. Finally, *ConstrAct* can add new questions to quiz games, designate new areas of interest in classification games and “wrong item detection” games, and establish the sequence of items or the steps to be carried out in sequence games and “execute a process” games.

After analyzing the different features of these toolkits, it can be concluded that even if there are some examples of EUD systems in the tangible context, the use of tabletops is still scarce. For that reason, one of the objectives of this Thesis has been to provide professionals with tools that help to introduce tangible activities in therapies with children and adults with special needs.

2.3 Contributions Related to Chapter 2

Bonillo, C., Baldassarri, S., Marco, J., & Cerezo, E. (2017). Tackling developmental delays with therapeutic activities based on tangible tabletops. *Universal Access in the Information Society*, 1-17.

Bonillo, C., Marco, J., Baldassarri, S., & Cerezo, E. (2019a). KitVision toolkit: supporting the creation of cognitive activities for tangible tabletop devices. *Universal Access in the Information Society*.

Bonillo, C., Marco, J., & Cerezo, E. (2019b) Developing Pervasive Games in Interactive Spaces: The JUGUEMOS Toolkit. In *Multimedia Tools and Applications* (***Minor revisions***).

CHAPTER 3:

THE KITVISION TOOLKIT FOR TABLETOP BASED HYBRID GAMES

3.0 Chapter Introduction

The author began to work in her Final Degree Project in the development of a tool (KitVision) aimed at non-programming professional that facilitated the creation of activities for NIKVision tabletop [Bonillo, 2014]. In the mentioned project the toolkit was designed and a first implementation was carried out, but it was during the Doctoral Thesis where the toolkit has been evaluated, improved and intensively applied to the creation of activities for children and adults with special needs [Bonillo et al., 2019a].

The aim of this chapter is to present the KitVision toolkit and the activities carried out to assess its usability.

Section 3.1 briefly describes the NIKVision tabletop that was used to develop the toolkit and the activities explained along the chapter.

Section 3.2 gives details about KitVision architecture.

Section 3.3 presents the evaluations of the toolkit carried out with end-users, including a year-long experience carried out in ASAPME, an association of adults with cognitive impairments.

3.1 NIKVision Tabletop

Five years ago, the Affective Lab at the University of Zaragoza developed NIKVision [Marco et al., 2013a], a vision-based tangible tabletop device based on the physical manipulation of traditional toys on a table surface. NIKVision was initially designed for very young children and children with special needs, for whom several games have been developed during the last few years [Marco et al., 2010]. Any toy can be used to interact with the tabletop on the condition that a printed marker (called fiducial) is attached to its base (see Fig. 3.1).

Fig. 3.1 Toys with attached fiducials

Once the fiducials have been glued to the toys, children can manipulate them on the tabletop surface (Fig. 3.2a), where images and animations related to the game currently running are displayed. Technically, NIKVision uses reacTIVision visual recognition software [Kaltenbrunner and Bencina, 2007] to track the position and orientation of the toys placed on the surface (Fig. 3.2c). Each fiducial attached to the toys is associated with a different number that allows to identify the different marked objects. Thus, involving any conventional object in a tangible tabletop activity does not require any technological knowledge: it is just necessary to print one of the fiducials included in the reacTIVision library and glue it on the toy base. An infrared light USB camera (Fig. 3.2b) captures video from underneath the table and streams it to the computer station which executes the visual recognition and game software. Active image projection on the table is provided by rear projection (Fig. 3.2d) through a mirror inside the table (Fig. 3.2e) while the audio of the activities is reproduced by the speakers (see Fig. 3.2f).

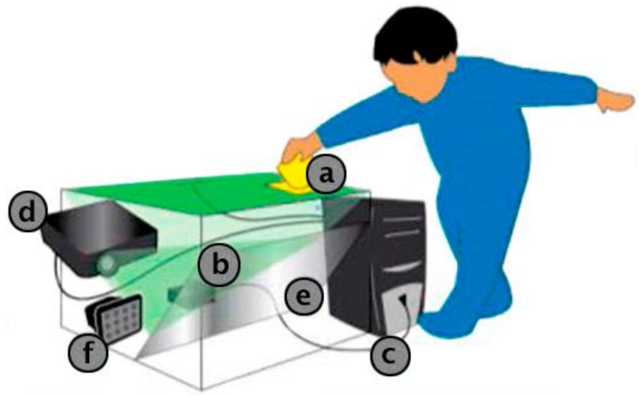


Fig. 3.2 NIKVision Tabletop scheme

3.2 KitVision Toolkit

As commented already, KitVision is a toolkit that was developed during the authors' Final Degree Project with the goal of allowing the easy development of tangible tabletop games. In order to simplify the creation process as much as possible, the hardware of the system is completely isolated from the coding of the game. reacTIVision [Kaltenbrunner and Bencina, 2007] is in charge of identifying and tracking objects on the tabletop surface, but the users do not have to deal with this program: they just have to attach printed markers (fiducials) to the objects they wish to use in the game and design it using a graphic assistant.

The architecture of the toolkit is showed in Figure 3.3. The marked **playing pieces** that are placed on the **vision based tableto**p are detected by reacTIVision thanks to the InfraRed (IR) video camera and the IR illumination placed inside the tabletop. reacTIVision analyzes the image coming from the tabletop IR video camera sensor and sends a message to the client application by using the **TUIO protocol** [Kaltenbrunner et al., 2005] when a physical object is placed, removed or moved on the tabletop surface. This client application connects with KitVision to inform it about all the manipulations, abstracting completely the detection of the physical objects from the coding of the tangible applications.

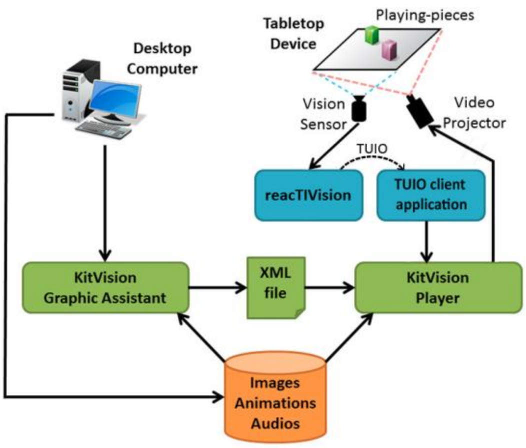


Fig. 3.3 KitVision architecture

KitVision is compatible with Windows and MAC systems, and it is composed of two main parts:

- The KitVision **graphic assistant**, which is used in a desktop computer to model the interface of the tabletop activities.

- The KitVision **player**, which is in charge of reading the XML files containing the KitVision activities that have been created with the graphic assistant. As it has been said, it also connects with the TUIO client to receive the manipulations of the objects that are placed on the tabletop device.

3.2.1 Graphic assistant

This component of the toolkit was developed in the context of the Final Degree Project of another student [Blasco, 2015], after the first version of KitVision was developed. Therefore, we will just give a general idea about how it works.

KitVision graphic assistant is a desktop application that facilitates the modeling of tabletop activities. The assistant uses a WYSIWYG (What You See Is What You Get) approach that allows the designers of activities to incorporate graphics, animation and audio, placing them on the screen in the same way that they will appear on the tabletop surface later.

In order to create an activity, it is necessary to first define certain elements:

- A **background**: the image that will appear on the tabletop surface (see Fig.3.4a);
- An **icon**: an image that represents the activity and that will appear on the screen of the tabletop allowing the user to select the activity (see Fig. 3.4b);
- The **areas**: positioning a playing piece in these square-shaped areas will have a specific meaning on the activity. Areas can be associated with the board, as used in board-games such as Ludo or Chess, or with a physical object, as used in bordless based games such as the Domino. An area associated with the board is defined in a fixed position on the screen, and that position does not change during all the activity (see Fig. 3.4c). However, an area associated with a physical object moves (and optionally rotates) with that physical object, so its position is variable.
- The **playing pieces**: every area of the game has a set of correct playing pieces and a set of incorrect playing pieces associated with it. As already mentioned, a playing piece is identified by the fiducial that is glued on its base, so, to assign the lists of correct and incorrect pieces to each area, we use the number of the fiducials.
- The **feedback**: graphic and/or audio elements which show the consequences of children's actions. For example, in Figure 3.4 the feedback is the face that smiles when the child situates a correct toy in the correct area and the face turns sad when the child does not do it right (see Fig. 3.4d).

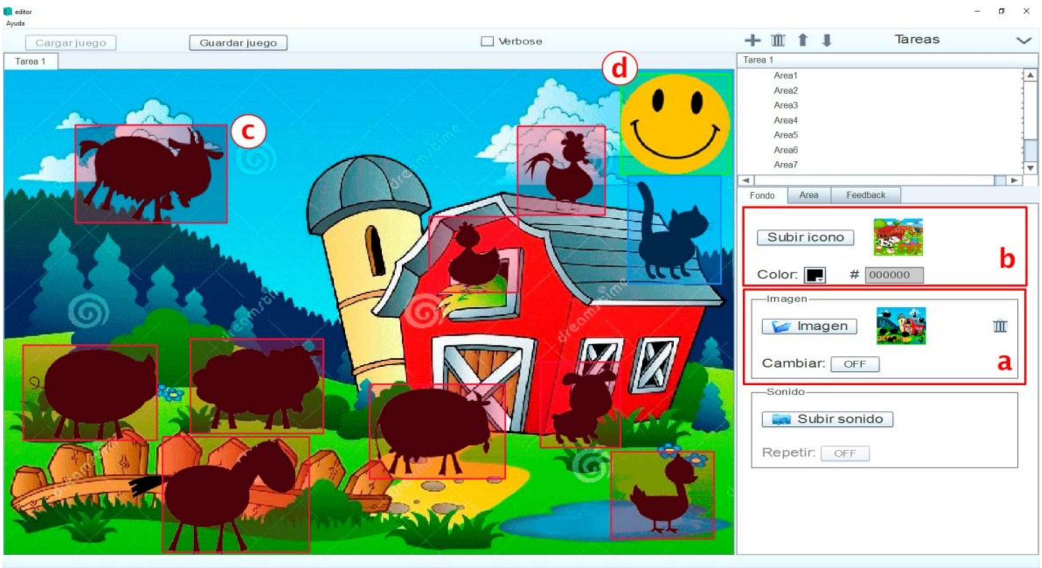


Fig. 3.4 KitVision Graphic Assistant

When the activity is finished, the graphic assistant automatically generates a file that contains the information of the activity and also gathers the resources that have been used (images, animation and sounds). All these files are stored in a folder that the player accesses to display and run them on the tabletop.

3.2.2 Player

KitVision player is the application in charge of loading and running the activities. As described in the previous section, the player reads all the files stored in a specific folder in the computer system. The first thing that the player has to do is to create a menu with all the stored activities (see Fig. 3.5 Left).

The way to interact with the tabletop is through two special objects called “selectors”. One of the selectors is used to select the activity that we want to run in the tabletop and the other allows to return to the initial menu while playing an activity (see Fig. 3.5 Right). These selectors have a special fiducial attached to their base in order to ensure that they are not going to be mistaken for toys when playing the activities.

When an activity is chosen, the player loads the file, recovers the graphic and audio resources that are needed for the selected activity, and displays the activity on the tabletop surface. The player is able to load the most popular image (BMP, GIF, JPG, PNG, etc.) and audio (WAV, MP3, etc.) formats, as well as SWF (Adobe Flash animation) animation.

Fig. 3.5 KitVision player. **Left**: menu shown on the tabletop. **Right**: Selectors.

Once the activity has been loaded, children can play by situating the different toys on the surface, since the player is also in charge of reacting to the manipulation of the toys thanks to the events that it receives from ReacTIVision.

3.2.3 Create an activity with KitVision

In this section we show the process of creating a tabletop game with KitVision, first in a general way, and next through a practical sample. Creating a tangible activity with KitVision involves three stages (see Fig. 3.6):

1. **Creating physical and virtual assets:** Physical objects have to be built, or conventional physical objects and toys can be adapted to be used in a tabletop activity. It is only needed to glue a printed marker on the base of the physical objects as it has been mentioned before. Virtual graphics and animations needed to build the activity can be created in any graphic design software package.
2. **Creating the activity with the graphic assistant:** The KitVision graphic assistant is used to create the logic of the activity. First, an image or animation is imported as a background (the image that will cover the entire tabletop surface). Then, interactive areas are created. These areas are 2D spaces where toys can be placed. Interactive areas can be associated to the tabletop surface or other physical objects (enabling it in this way to combine two physical objects, for example in domino-like games). For each interactive area, a list of correct and wrong toys has to be created. This way, each area has three different states:
    a) **Default**, when no physical object has been placed.
    b) **Correct**, when all the physical objects included in the correct list has been placed in the area
    c) **Wrong**, when a physical object included in the wrong list has been placed in the area.

   The therapist can associate a different image/animation and sound to each of these states. Finally, the feedback to the user is defined, in order to react to users' actions: default, correct action, wrong action, and activity completed. The feedback consists in a different image/animation and sound to each of these states, that will be displayed in an area of the tabletop surface.
3. **Testing the activity in the tabletop device**: Once the activity logic has been defined, the activity is ready to be tested in the tabletop device.

Once the general process of creating an activity with KitVision has been presented, a detailed example is presented in the next section.

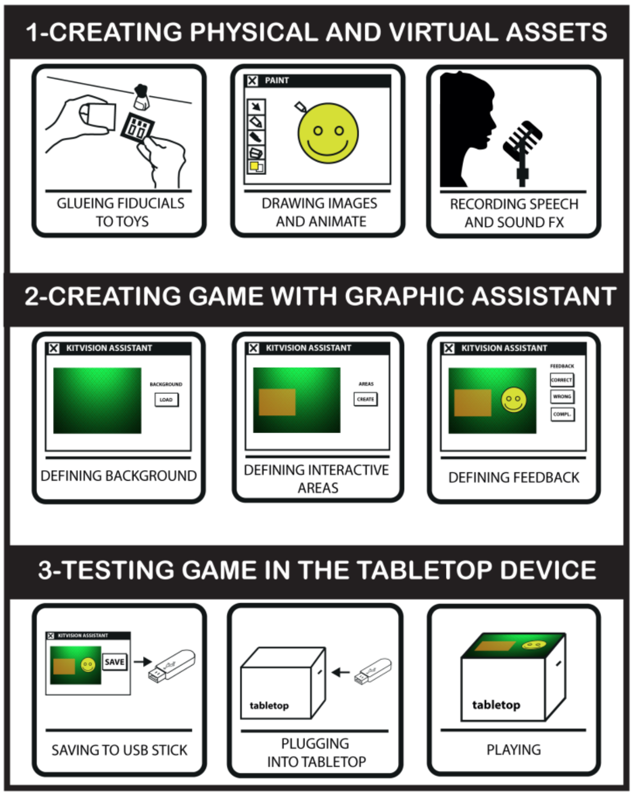


Fig. 3.6 The general creation process of an activity using KitVision.

Following is an example of the previous general process through the creation of a tangible activity based on the classic Tangram activity. Tangram is a puzzle activity in which users are asked to create different shapes by combining just seven geometrical shapes (see Fig. 3.7). From the point of view of the KitVision mark-up language, the Tangram has as many tasks as figures the user has to complete, the areas are the places where the geometrical shapes have to be situated in order to create the figure, and the physical objects are the seven geometrical shapes. Although the original tangram does not have any feedback in the tabletop activity it will be added to indicate the users if they have situated a shape correctly or not.

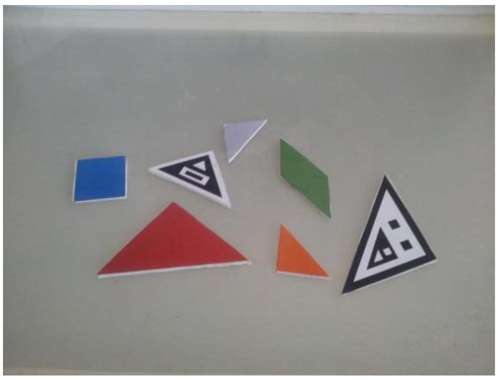


Fig. 3.7 Comertial Tangram pieces with marker glued on their base.

3.2.3.1 Creating physical and virtual assets

For the tabletop version, a comertial Tangram play set is used. Therefore, it is only needed to glue a different printed marker on the base of each piece. Using a image editor software (for example, Gimp), the graphics for the backgound and the images for the different shapes are created. Animations are created with the Adobe Flash software, since KitVision only supports the SWF format. For this activity, a cat character is drawn and animated in Adobe Flash. The cat includes animations for innactive, happy, sad and celebration which will be used when the user is not placing pieces, when they place a correct piece, when they place a wrong piece, and when all pieces are in their correct areas. Also, instructions to play the activity were recorded using an Audio editor software (for example, Audacity). Also, cat sound effects were extracted from a sounds effects CD and exported in MP3 format.

3.2.3.2 Creating the activity with the graphic assistant

The Tangram game logic is defined in a desktop computer with KitVision graphic asssistant installed. First, a new task is created. The task consists of composing a cat silhouette using the Tangram physical objects. Then, the background image and the icon are defined. Also, the instructions speech is imported and configured in the assistant to be played as soon as the activity launches. This way, when played in the tabletop, the user will receive a brief audio instruction about how the activity is played.

Then, the different interactive areas are created one by one. Also, for each area it is necessary to associate an image by default that relates it with a part of the cat silhouette (see Fig. 3.8). Next, the lists for the correct and wrong physical objects for every area are created. In the case of Tangram, for each area only one physical object is correct and the rest are wrong. KitVision graphic assistant understands a “*” character written in the wrong list as “*all physical objects different from the correct ones*”.

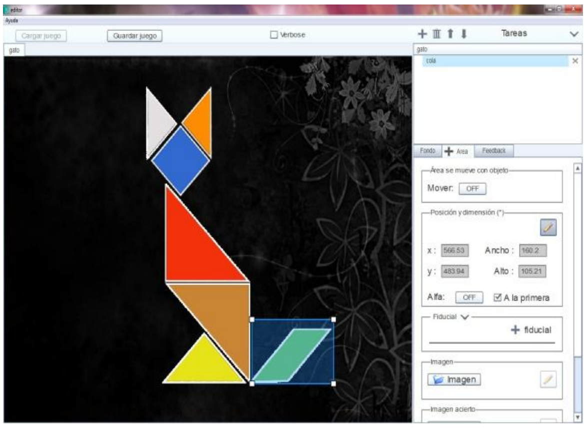


Fig. 3.8 KitVision graphic assistant: Cat shilouette with an an interactive area selected (the tail).

Once the areas are completely defined, the feedback is created. Cat animations are then imported and assigned to different events (see Fig. 3.9): Neutral (when nothing is happening), correct (when a physical object is placed on its right area), wrong (when a physical object is placed on a wrong area), and complete (when all physical objects are placed on its correct areas). As well as animations, cat sounds are assigned to each event in order to give audio feedback to users.

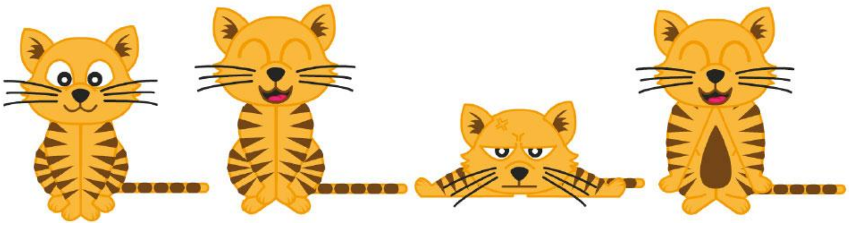


Fig. 3.9 Neutral, correct, wrong and complete feedback with a cat character.

With the feedback defined, the task is complete. More tasks can be created with different figures to be composed placing Tagram pieces. The different tasks will be played in the tabletop in sequence. The user can exit the activity at any moment by placing the "selector" on the tabletop as it has been explained in the Section 3.2.2.

3.2.3.3 Testing the activity in the tabletop device

In order to test the Tangram game in the tabletop device, the "save" button is pressed in the graphic assistant. When pressed, it asks the user to insert a USB memory pen in the computer, and anounces when the activity files have been succesfullly saved on the USB device. The activity is then tranfered to the tabletop device just by plugging the USB memory pen on the USB port of the NIKVision tabletop. The new Tangram game automatically appears on the KitVision player menu. The user just has to choose it by touching its icon, and the activity will start (see Fig. 3.10)

Fig. 3.10 Testing the activity on the tabletop.

The method of creating activities also makes it very easy to create different versions of the same activity with different levels of dificulties. For example, in the Tangram game it is possible to create a slightly more difficult activity by associating images with a uniform color to the areas. This way, the user will not have color clues to place each physical object.

3.3 Evaluating KitVision with End-users

In this section, we describe the evaluations performed to prove the usability of KitVision. Two different evaluations were carried out. The first was an in-lab evaluation that involved therapists, and its objective was to test the usability of the KitVision graphic assistant. The second was an evaluation carried out in a therapy center and whose objective was to evaluate the final use of the NIKVision tabletop and the toolkit in the OT's professional environment. This also involved the OT's therapy group.

3.3.1 In lab evaluation: testing KitVision usability

Three therapists (all of them female) participated in this evaluation session which was carried out in our own laboratory. We installed the KitVision graphic assistant in three different computers so that each therapist could work individually. In the laboratory there was also a NIKVision tabletop that the therapists could use to test their activities during the session. The three therapists knew about the NIKVision tabletop and some of the activities that we had developed for it. However, they had never seen nor used the graphic assistant before the session. Moreover, they do not use computer tools in their daily work.

3.3.1.1 Session preparation

The cognitive activity that the therapists had to do with the graphic assistant was predefined and consisted of designing a series puzzle. An incomplete sequence of geometric shapes is shown on the tabletop surface and has to be completed by placing the missing shape in its corresponding place. We prepared the virtual resources (see Fig. 3.11 Left) and physical objects (see Fig. 3.11 Right) for the therapists to use in the session. Of course, the therapists could themselves have chosen the resources they wanted, though since they were already investing part of their working time in going to our lab to test the graphic assistant, we decided to save them time and do this work ourselves.

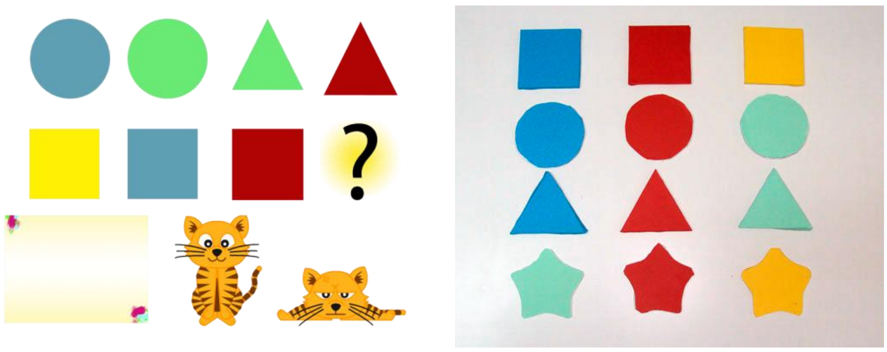


Fig. 3.11 Resources of the activity. Left: Virtual resources. Right: Physical objects.

Just as several commercially available software tools provide users with a “Help” section or with tutorials for solving users’ doubts, we prepared a 4-minute video tutorial to explain how to use the graphic assistant together with a document with this information. The tutorial was necessary because, as already mentioned, the therapists did not use technological tools in their daily work and felt more comfortable having some support in case they got lost during the process. Also, there were some terms that the therapists were not familiar with (such as fiducial or feedback) which the tutorial helped them to understand.

The process the therapists had to follow to create the tangible activity was divided into three tasks:

- To define the background of the activity;

- To create the different areas and images associated to them (in this case, the images of the geometric shapes);

- To define the visual and/or audio feedback of the activity.

3.3.1.2 Evaluation session

In this evaluation session, the therapists worked with their computers individually. First, we explained where to find the virtual resources and the objects they had to use for developing the activity. Then they watched the video-tutorial from beginning to end before starting using the graphic assistant. They could re-watch it as many times as they wished during the session. Three experts were present during the evaluation as observers, writing observation notes and supporting the therapists if they asked for help. The whole session was video-recorded, assigning one camera to each therapist so that the experts could later analyze the issues that the therapists experienced with the graphic assistant.

When a therapist finished the activity, they tested it on the tabletop. In order to do so, the activity that the therapist had created was saved in a USB which was then plugged into the computer connected to the NIKVision tabletop (see Fig. 3.12). If any mistakes were detected in the activity, the therapist returned to her computer to fix them before testing it again on the tabletop.

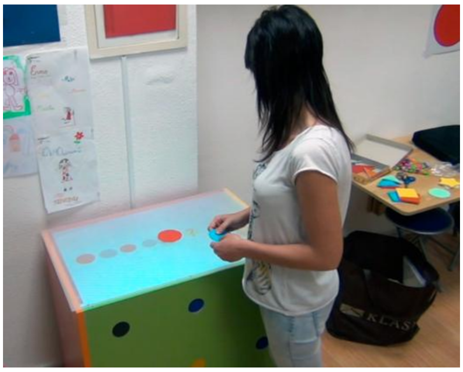


Fig. 3.12 Therapist testing her activity

After the session, the therapists had to fill in a questionnaire asking about their experience with the KitVision graphic assistant: if they thought it was easy to use, ways it could be improved, if the graphic assistant was missing any functionalities that could be useful for them in their professional environment, and if the documentation and video-tutorials had been useful for them. Although the three therapists were able to complete the task to create an activity, some issues regarding the use of KitVision arose which are explained in the following subsection.

3.3.1.3 Results

The three therapists were able to develop a fully functional activity that was tested on the tabletop. The time it took them to develop each step for creating the activity with the graphic assistant is shown in Table 3.1.

Table 3.1 Time it took the therapist to develop the activity

Step	Time (minutes		
	Therapist 1	**Therapist 2**	**Therapist 3**
Create the background	6	1	7
Create the areas	5	5	10
Create the feedback	5	5	3
Total time (minutes)	16	11	20

The observations carried out and the information extracted from the video-recordings revealed the following usability problems: (U1) Users confused the button for uploading an icon with that for defining the background, (U2) The “Erase” button is not intuitive, (U3) The “Modify” button is not intuitive. These problems are also reflected in the differences in time taken for each step presented in Table 3, as explained below.

Therapists 1 and 3 spent more than 5 minutes trying to define the background of the activity even though this step should not have taken them more than a minute, the time it took therapist 2. This was due to the fact that the option for defining the icon for the activity was not well differentiated from the option for defining the background. This confused therapists 1 and 3 since they thought that they were defining the background instead of the icon, making them waste unnecessary time (**U1**).

Therapist 3 spent five more minutes than the other two to define the areas because she accidentally deleted the task on which she had been working and had to re-do it. This indicated that the option of the graphic assistant for deleting tasks and the option for deleting areas were not sufficiently distinguishable, since therapist 3 mistook one for the other (**U2**). Also, the icon for editing areas that appears right next to the defined area proved to be inadequate since the therapists did not identify it as such. In fact, every time that they needed to modify an area, they deleted it and started again, until the experts told them how to use the modify command (**U3**).

Finally, therapists 1 and 2 took more time than therapist 3 to define the feedback, since the first two therapists used both visual and audio feedback while therapist 3 decided to use audio only.

Besides these usability problems, other useful insights were extracted from the questionnaires.

All three therapists commented that to be able to create activities for the tabletop, it would have helped to have a better understanding of the characteristics of the tangible tabletop activities beforehand. They referred to the need to define the activities following a hierarchy: first the tasks, then the areas, and then the objects to be placed on those areas. We must think about the possibility of adding some documentation regarding the structure that the tangible activities follow.

As regards the documentation provided, one of the therapists noted that: “*The video tutorial has helped me a lot. I’ve used it almost all the time while creating the activity*”. In fact, during the session the observers noticed that two of the therapists watched the video-tutorial not once but twice at the start of the session, to be sure about how to construct the activity. Also, while creating the activity, every time that the therapists had doubts about what to do they re-watched some parts of the video-tutorial. However, the paper documentation was not much used, and one of the therapists commented that: “*For me, the video-tutorial is easier to understand because it directly shows how the commands work, and the correct order to use them*”. This last comment made us think that it would probably have been easier for the therapists to have been provided with short videos showing the different steps that have to be taken in order to create the activity (a video that shows how to create the background, another one that shows how to create the area, etc.) instead of a full video with all the steps. This would also save time for the therapists, since they would not need to waste time searching the video for the specific step that they wanted to consult.

Finally, the three therapists were satisfied after using KitVision: “*while doing the first task I thought that it was complicated, but when I’ve had to repeat it I’ve seen that it has taken me* *much less effort to do it*". They also said that it would definitely be a good supplementary resource for their therapies and that even if the activities made with KitVision were apparently simple, they thought that the tool was flexible enough to develop activities that would be useful in their therapies.

3.3.1.4 Fixing usability problems

After analyzing the in-lab evaluation results, we concluded that we had to re-design the way the different options of the graphic assistant were presented (define background/icon, delete task/area, edit area), since some of them were not intuitive enough and led to rather annoying mistakes such as completely deleting a task.

In order to fix the detected usability problems, the modifications described in the following were made to the graphic assistant before continuing with the evaluation of the toolkit.

To resolve U1, we decided to present the command for setting the icon in the same way as for the background and the sound that played when starting the activity, so that the end-users could identify all three elements more clearly. Even if the solution seems simple, the fact that the icon button was not surrounded by a square indicating that it related to the icon led the therapists to believe that the "Subir Icono (Upload icon)" button was related to the "Imagen (Background)" button, and used the first button to define the background (see Fig. 3.13).

Fig. 3.13 Modifications in the graphic assistant regarding U1 (left: before, right: after).

To fix U2, we decided to add a button similar to the one for removing tasks whose functionality was to erase the area, and place it next to the "Modify" button. We also added a clarifying text saying "Erase area", so that end-users would not mistake the button to delete tasks with the button to delete areas (see Fig. 3.14).

Finally, regarding U3, we added a text saying "Modify area" right next to the pencil to clarify the functionality of the button (see Fig. 3.14).

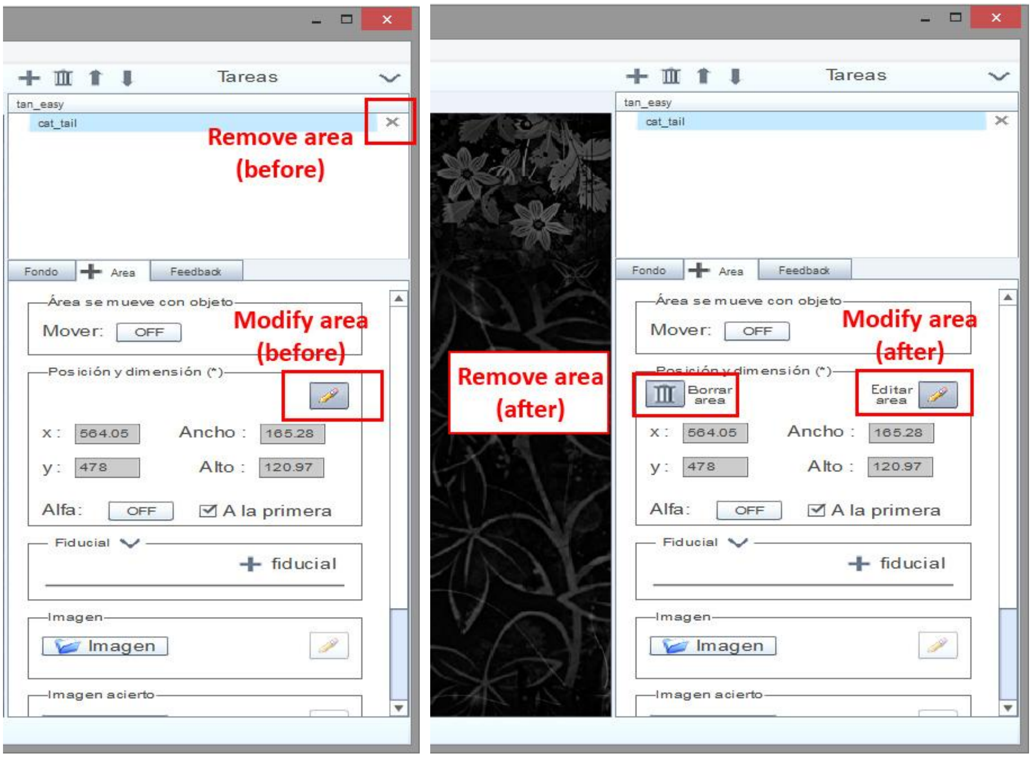


Fig. 3.14 Modifications in the graphic assistant regarding U2 and U3 (left: before, right: after).

With the usability problems fixed, a second evaluation was carried out.

3.3.2 Testing KitVision in the ASAPME therapy center

Thanks to a collaboration project with ASAPME, a local association working with adults with mental diseases, we were able to carry out an in-the-wild evaluation in a therapy center [Bonillo et al., 2019a]. This was our first field-testing of the installation of our KitVision toolkit (tabletop, player and graphic assistant) in such a center. The objective here was to evaluate the suitability of KitVision in terms of enabling an OT to create a new tangible activity in her workspace and use it with her clients in order to know their reactions, degree of satisfaction or suggestions.

3.3.2.1 Session preparation

An OT from the ASAPME center participated in this evaluation. The daily work of this OT is doing activities with her group of clients in order to work their affected capabilities. During our first meeting she showed us the pen and paper activities she generally uses. She then chose one of these activities to be translated into a tangible tabletop activity. In this activity, a composition of colorless geometric figures (squares, circles and triangles) is given to the client together with a set of instructions. The instructions give the clients hints about what color to use to color the figures. The instructions are usually inter-related so the client must read all the instructions to deduce the color of the figures.

The OT designed how the activity would be translated to the tabletop device. She designed the game as a set of tasks with increasing difficulty. Squares, circles and triangles were the tangible physical objects. The client would receive the instructions from the computer, and he/she would arrange the pieces on the tabletop in the correct spatial distribution following the instructions. The tabletop would give feedback when a physical object was correctly or wrongly placed.

3.3.2.2 Evaluation session

A NIKVision tabletop was installed in the room where the OT usually conducts her therapy sessions. The OT used the KitVision graphic assistant to model the new game in a conventional desktop computer. Prior to using the graphic assistant, the OT viewed the short video-tutorials showing how to use it. This time she was not provided with any other documentation, since the previous evaluation showed that this was not necessary. The OT then started to develop the game.

The task of developing the tangible tabletop game was divided into the following steps:

- Defining the background.

- Defining the interactive areas of the game.

- Designing the feedback of the activity, giving visual and audio responses to the user's actions with the graphic assistant.

- Preparing the objects to be used in the activity and adding reacTIVision fiducials to the physical objects. The virtual assets (basically the background image) were given to the OT.

It took the OT less than 15 minutes to create the activity with the graphic assistant, and another 20 minutes to adapt the objects. Among those first 15 minutes, the OT spent 5 recording the audio of the feedback herself, on the grounds that her clients were used to her voice and hearing a different person giving instructions could confuse them. The other 10 minutes were devoted to use the graphic assistant to create the two tasks that composed the activity. The time spent by the OT in creating the activity with the assistant was quite similar to the previous in-lab evaluation, but in that case all the virtual resources had been provided. On the other hand, the preparation of the objects took some time since she had to choose the fiducials for the objects, to verify with reacTIVision the number associated to the fiducials, to glue the fiducials to the base of the objects, and to verify again with reacTIVision that the objects were correctly identified. This process of creating the toys was not included in the previous in-lab evaluation because at that time we just wanted to detect usability problems of the graphic assistant. However, in this case we wanted the OT to carry out the complete process of creating a tangible tabletop activity, which also includes adapting the objects required for the activity.

No other usability problems arose from our observations, but the OT mentioned that she missed a "copy and paste" option in the graphic assistant. This was because the tasks of the activity were quite similar, so to replicate a task and perform the opportune changes would take less time than creating a new task from scratch. The game was tested on the NIKVision tabletop device and worked correctly (see Fig. 3.15).The OT's clients were now able to test the activity.

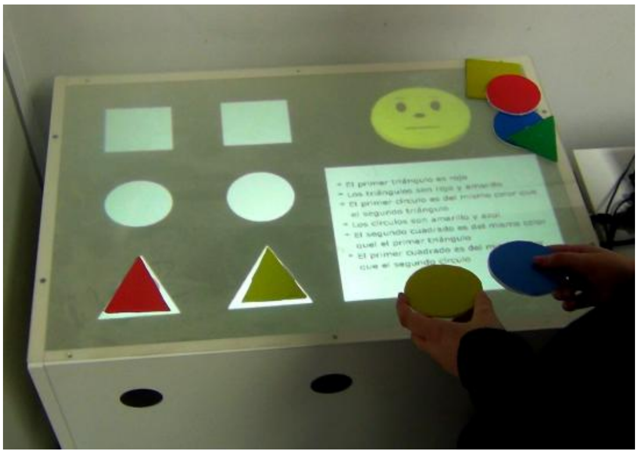


Fig. 3.15 Therapeutic tabletop game

3.3.2.3 Testing the tabletop activity with clients

Once the activity was created, we decided to test it with the OT's group of clients, since the ultimate goal of the end-users creating their own activities is that their clients are able to use them. The ASAPME therapy group was composed of four adults (all of them males) aged 25 to 45 years with different mental health impairments: schizophrenia, schizophrenia and intellectual disability, frontal lobe syndrome, bipolar disorder, organic mental disorder with impulse control disorder and intellectual disability, anxiety disorder and physical disorder.

The session was attended by the OT, who helped the clients while they tested the activity, and two experts, who acted as observers and were responsible for taking notes of the participants' comments. The session lasted one hour and took place in the room where the clients usually do their therapeutic activities and where a NIKVision tabletop was installed.

All the participants worked on paper with the non-technological version of the activity and, in turns, they also played with the tabletop version. One client refused to test the tabletop version of the activity but the other three completed the tabletop game with no problems, although they needed different times. More cognitive affected clients required half an hour, while less affected completed the game in ten minutes. After the session, the group discussed for 15 minutes with the experts and the OT their opinions and perceptions of the two versions of the activity.

We started by asking the clients which activity they liked most: the non-technological or the tabletop version. The tabletop activity was in general well received by the clients who played with the tabletop device, all of whom chose the tabletop version of the activity over of the paper one, but they also expressed some personal perceptions. One of the clients pointed out that, although it was more fun to do the activity on the tabletop, he preferred to read the instructions on paper since looking at the tabletop screen for a long time tired his eyes. Another client said that he preferred to do the activity on paper because when playing with the tabletop version, it occasionally gave him wrong feedback, saying that the physical object was wrongly placed while an instant later it said that it was correct. This event was due to a technical problem with the tabletop hardware which has already been fixed for future tests. However, when we asked the client what he would choose if the feedback problem was solved, he said that he would choose the tabletop activity instead of the paper one. This was because it was more fun and it was easier to know if he had chosen the correct color figure thanks to the sound, while in the paper activity he had to ask the OT and later erase and re-color if he had selected the wrong color. Finally, another client told us that he preferred the tabletop activity but that he did not like the “wrong” sounds: he preferred that a sound was only reproduced when he did something right and that nothing was reproduced when he did something wrong.

The OT later pointed out that some clients are motivated by positive feedback, but can easily be frustrated by negative feedback; therefore, this is an important aspect to be considered in the future when designing tabletop activities tailored to client preferences. Also, the OT explained that the client who refused to use the tabletop did not do so because he disliked the device, but that he automatically rejected people that he did not know (in this case the experts) and consequently everything that had to do with them (the tabletop).

After carrying out this second evaluation, the OT expressed her interest in having a NIKVision tabletop permanently installed in the association’s premises so that she could integrate the use of KitVision and the tabletop into her daily work routines.

3.3.3 Integrating KitVision in the Occupational Therapist’s Daily routine: a One Year Experience

A new tabletop was built for the ASAPME association. It was a bit of a challenge as it was the first one to be used by adults. Besides, the OT wanted her clients to be able to do the activities on the tabletop together, so it had to be wide enough so that at least two people could work on it comfortably (see Fig. 3.16).

Fig. 3.16 Tabletops comparison. **Left**: Original tabletop (75 x 50 cm). **Right**: ASAPME tabletop (112 x 75cm)

The tabletop was installed and for the period of a year, the OT was autonomously using the NIKVision tabletop together with the KitVision toolkit on a daily basis, creating activities with her clients and testing them in weekly group sessions. During that time, she contacted us occasionally through email with enquiries about the creation of activities. For example, she once had problems when defining the icon of an activity because she was using the wrong image format, and on another occasion she forgot to add the feedback that indicated that the task was completed and consequently the game ended immediately without giving her time to explain the result of the activity to her clients. However, it is worth mentioning that, with the exception of one occasion when an expert had to go to the ASAPME association to fix a software problem in the computer installed inside the tabletop, the OT did not need any assistance to work with the tabletop and the KitVision assistant, and she was able to create completely new activities with total autonomy.

After the first year using KitVision in ASAPME, we had an interview with the OT to learn about her experience, views and feelings. At the beginning of the interview, the OT showed us the five activities that she had developed during that time. Table 3.2 summarizes information about the activities: the name and type of activity and also the different elements used, including the number of tasks, areas and objects that compose each activity, in order to assess their complexity.

Table 3.2 Summary of activities developed by the OT

Name	Type of activity	Elements used			
		Number of tasks	Number of areas	Number of objects	Feedback
Pair the Birds	Attention	1	12	12	✓
Remember the Names	Memory	5	20	6	✓
Choose the Cat	Reasoning	3	6	5	✓
Choose the Shape	Reasoning	3	6	5	✓
Complete the Sequence	Reasoning	3	6	5	✓

To work attention the OT created the *Pair the Birds* activity, consisting of matching a set of bird drawings with corresponding drawings shown on the tabletop surface. In this activity, the OT developed just 1 task with 12 different areas (see Fig. 3.17 Left).There were 12 objects corresponding to the bird pieces that the clients have to place on the area showing the same drawing (see Fig. 3.17 Right). This was the first activity the OT developed. She forgot to select an icon for the activity and preferred to compress everything in a single task instead of trying to define more than one.

Fig. 3.17 OT’s activity *Pair the Birds*. **Left**: Activity running on the tabletop. **Right**: Physical objects.

To work memory the OT created the *Remember the names* activity, whose level of difficulty increases in each iteration. The tabletop shows a set of people with different names that the client has to memorize (see Fig. 3.18 Top-Left). After that, the tabletop shows the same image but the names of the people are no longer there. The objects used in this activity are 6 different names (see Fig. 3.18 Bottom-Left) and in each task the client has to select those belonging to the people shown on the tabletop (see Fig. 3.18 Bottom-Right). Again, the OT forgot to assign an icon for this activity even though this time she was bold enough to define a total of 5 tasks for the game.

Fig. 3.18 *Remember the names* activity.

Finally, to work reasoning the OT developed three activities. In the first one, the client has to choose what cat is the same as the one that appears inside the square (*Choose the cat* activity), while in the second and third activities (*Choose the Shape* and *Complete the Sequence* activities) the client has to choose the shape that completes the sequence (see Fig. 3.19 Left). This time, the OT remembered to set the icon for the three activities. All the reasoning activities were composed of the same number of tasks, areas and objects (see Table 3.2). However, in this case it is worth mentioning two aspects that differentiate the three reasoning activities from the memory and attention ones. The first aspect is that, since a good part of the activities that the OT used in her therapies consisted of choosing the correct answer between a set of options, she created a set of 4 objects (see Fig. 3.19 Right) that she called "Option pieces" that could be used in any activity requiring selection of an option. This meant that when she developed more reasoning activities, she would save time because she already had the objects created.

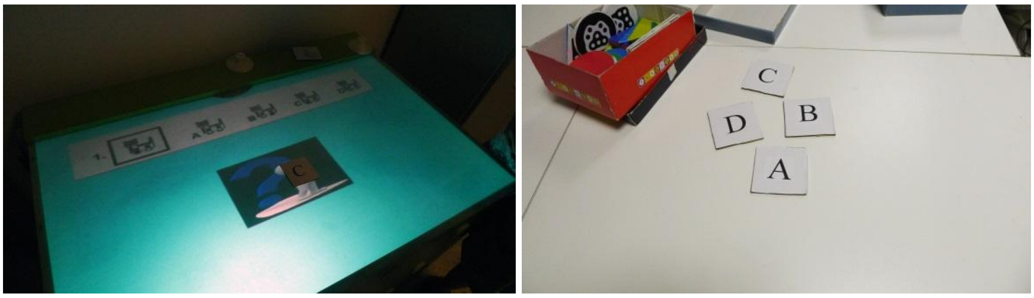


Fig. 3.19 Reasoning activities. **Left**: *Choose the Cat* activity. **Right**: "Option pieces"

The second aspect consists of a method the OT came up with to "force" her clients to discuss the result of the current task before beginning to do the next one. In order to do this, she created a special object called the "OK object" that she controlled and that was required for ending the task (see Fig.3.20 Left). Thus, even if the client completes the activity successfully, the next task does not begin until the OT places the special object on its corresponding area (see Fig. 3.20 Right), giving her time to ask the client questions about the solved task, such as why he/she had chosen that answer instead of the others. For this reason the 3 reasoning activities have 2 areas: one for the client to place the "Option piece" while the other is for the OT to place the "OK object" so that the client can continue with the following task once the OT is satisfied with the client's answers to her questions.

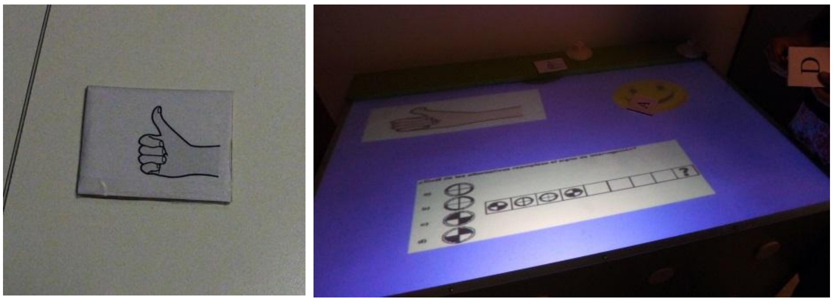


Fig. 3.20 Use of the OK object. **Left**: "OK object". **Right**: Task with the OK area.

In terms of the number of tasks, areas and objects, the *Remember the Names* activity was the most complex (see Table 3.2). However, considering the way the OT addressed the use of sharing objects for the reasoning activities and also the use of the special object to have full control of the game, it is safe to conclude that the reasoning activities are the most complete and show the flexibility of KitVision and its capability of supporting the work of the OT and the needs of her clients. The *Pair the birds* activity (the first one the OT developed) was the simplest of the five.

Once the OT had explained her activities, the experts conducted an informal interview to ask her about the methodology that she used with her clients, and whether she had missed anything in the graphic assistant.

As regards the methodology, the OT explained that the first thing she does when new people join her therapy group is to show them the tabletop and the activities created so far, so that they can test them and see how they work. The OT said that she always asked her clients for opinions when she created an activity: "*I ask them if the activity was too easy or too complicated or if they wanted to change something in the design, such as the drawings that appear in it*".

Concerning KitVision's graphic assistant, the OT simply commented that when creating the activities, instead of starting from scratch she always uploaded in the graphic assistant an activity that she knew for sure already worked and then made the modifications needed to create the new activity, such as changing the background, adding new areas or assigning the right fiducials to the objects: "*That way, I'm sure that I'm not going to forget to add anything, such as the sounds or the feedback*". She also said that this method helped her to create the activities faster.

Once the usability of KitVision toolkit was assessed, more experiences were carried out with different target users, as it will be shown in the next chapter.

3.4 Contributions Related to Chapter 3

Bonillo, C., Marco, J., Baldassarri, S., & Cerezo, E. (2019a). KitVision toolkit: supporting the creation of cognitive activities for tangible tabletop devices. *Universal Access in the Information Society*.

CHAPTER 4:

USING KITVISION TO SUPPORT THERAPEUTICAL ACTIVITIES

4.0 Chapter Introduction

In this chapter we are going to present different experiences in which KitVision toolkit was used to support the creation of therapeutical tabletop activities for different user groups:

Section 4.1 describes an experience carried out in the Romareda nursing home, with elderly people.

Section 4.2 explains the development of activities and evaluations that were performed in ENMOvimientTO and the Aragonese Institute of Social Services (IASS) centers, with children with developmental delays.

Section 4.3 covers the development of activities and evaluations carried out in Atenciona, an association for ADHD children.

Finally, section 4.4 explains a participatory design experience that took place also in Atenciona, with ADHD children.

4.1 Tangible Tabletop Activities for Elderly People

Thanks to a collaboration with the Aragonese Institute of Social Services (IASS), a NIKVision tabletop was installed. First, NIKVision activities previously created were tested to see client reactions and user experience. Afterwards, new activities specially devoted for them were created with KitVision toolkit, to explore its usefulness in the therapy of elderly people. This evaluation was made in the context of a Final Degree Project [Nebra, 2016].

4.1.1 First evaluation

The Romareda therapy group was composed of thirty seven people (23 women and 14 men) aged 63 to 99 years with different mental health problems. The clients were divided in turn in two subgroups:

- **Cognitive Problems**: the people belonging to this group suffered from attention and memory problems. They had also hearing and eyesight impairments, and got easily tired and distracted. During their regular therapy sessions, they did activities like finding the differences or similarities between images and puzzles.
- **Dementia**: the people belonging to this group need the constant help of the therapist in order to do their therapeutic activities, which consisted mostly of working with geometrical figures to identify their shape and color. They presented problems of concentration, memory, autonomy and self-control, so sometimes they could even be violent with the therapist in charge of them.

4.1.1.1 Methodology

During the first session, the clients tested individually activities that had already been created as a part of the Final Project of the PhD student [Bonillo, 2014] and, also, the activity that the OT of ASAPME created (Section 3.3.2). With this evaluation we wanted to have a first measure of the user experience while doing the activities on the tabletop.

After discussing with the OT of the Romareda nursing home the best method to apply to the evaluation with her clients, she proposed to observe them and then to ask them some questions related to the tabletop, the activities and the objects at the end of the session. For example, which activities they had liked the most, which activity had been the easiest one, if they preferred to use flat objects or 3D objects, if the audio feedback could be heard clearly…

Several people took part in the evaluation session: the OT of the Romareda nursing home, who helped the clients while they tested the activities, and two experts, in charge of observing, taking notes and providing the clients with the toys to be used.

The evaluation session took place in one of the rooms of the nursing home, where a NIKVision tabletop was installed. The clients were called one by one in order to test the tabletop activities. Every individual session lasted half an hour. Meanwhile, the rest of the clients remained in the room where they usually did their traditional therapeutic activities. The therapist was in charge of explaining very briefly the activity to be performed to the clients. In case they did not understand the therapist provided them with more information. In the meantime, the NIKVision expert took notes about the clients' behavior while testing the activities. We specially wanted to see if the clients understood intuitively the use of the tabletop, if they were able to deduce the objects that they had to use, and if the activities were easily understandable and easy enough for them.

4.1.1.2 Activities evaluated

With the exception of the *Syntagmatic Relations*, which was developed during the evaluation of KitVision in ASAPME, the rest of the activities were created in the context of the author's Final Degree Project [Bonillo, 2014].

Memory activities

In the *Shopping list* activity the surface shows an image with a list of several groceries for five seconds. The image is then replaced by an image of a shopping bag. The user has to remember the contents of the list and select the correct items to place them on the bag. A total of twelve objects are used: water, onion, peas, egg, milk, apple, orange, pepper, tomato, carrot, orange juice and grape juice. When the user places a correct item on the shopping bag, a smiley face appears in the upper corner, though if the food was not on the list the face turns sad (see Fig. 4.1 Left).

In the *Trips* activity the surface shows a map of Europe, and at the same time a recording of an itinerary with different means of transport is played. The user has to remember the route and place the means of transport on the correct countries. We use three transport objects: train, plane and boat. When the user places the transport object on its correct country, a smiley face appears in the top corner. A sad face appears when the user places the object on a wrong country (see Fig. 4.1 Right).

Fig. 4.1 Memory activities. **Left**: *Shopping list*. **Right**: *Trips*.

Attention activities

Three activities were developed to work the three types of attention: *How many are there?* (divided attention), *Find the symbols* (selective attention), and *Tangram* (sustained attention).

In the *How many are there?* activity the surface shows an image with numbers between 0 and 9. At the same time, a recording is played telling the user the number that he/she has to find. The user has to place physical pieces on all the numbers heard while another recording reproduces a sequence of hits. For example, the recording plays four hits followed by a pause followed by eight hits followed by another pause. In this case, the user has to say aloud how many hits he/she has heard during the pause while at the same time searching for the numbers on which to place the physical objects. For this activity the objects needed are several pieces of the same kind that the player uses to mark the selected objects. The feedback consists of the appearance of a green tick or a red cross on the corresponding number depending on whether it is correct or not (see Fig. 4.2 Top).

In the *Find the symbols* activity the surface shows a map with symbols of gas stations, restaurants, hotels, pharmacies and the user is asked to mark those of a certain type. This is an example of an activity that does not require different objects since the user uses simple physical objects to select the symbols. The feedback consists of the appearance of a green tick or a red cross on the corresponding number depending on whether the symbol is correct or not (see Fig. 4.2 Bottom-Left).

The *Tangram* activity has two levels: an easy one, where the user can see the position of each of the seven pieces that compose the figure, and a difficult one, where only the outline of the figure is shown. The objects in this activity are the seven pieces of the Tangram. The feedback consists of an animation of a cat that does not move while the users do nothing, that applauds when placing a correct piece and that gets sad when placing an incorrect one (see Fig. 4.2 Bottom-Right).

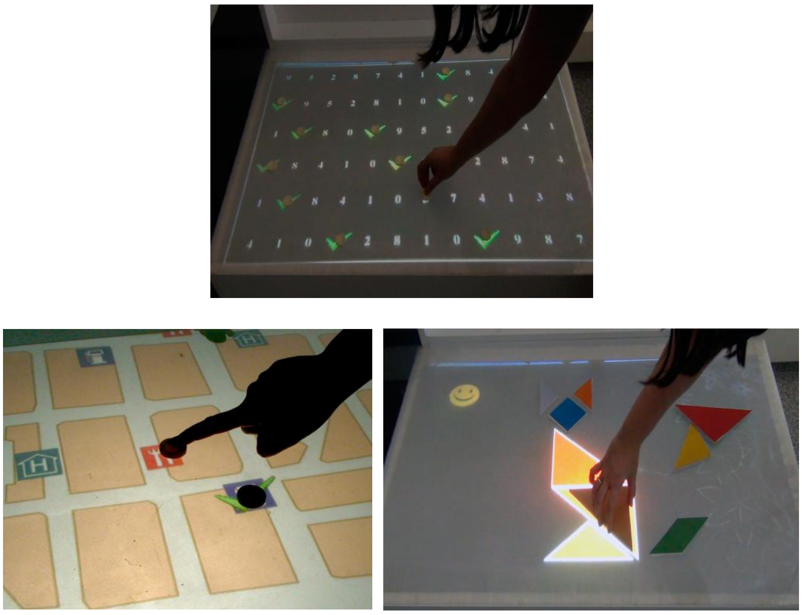


Fig. 4.2 Attention activities. **Top**: *How many are there?* **Bottom-Left**: *Find the symbols* **Bottom-Right**: *Tangram*.

Reasoning activities

In the *Analogies* activity, the user has a set of pieces. Each piece is composed of two pictograms. Each pictogram can be paired with another picto from a different piece. This is an example of an activity with associated areas: each of the pieces has two associated areas (corresponding to its two pictos) that move along with the piece. The goal of the activity is to compose a chain by pairing the physical objects with the correct pictos. The feedback during the activity in this case is only a sound, differentiating when two pieces are well paired or not (see Fig. 4.3 Left).

In the *Complete the sequence* activity, the surface shows a sequence formed with domino pieces in which some of the pieces are missing. The user has to select the correct missing piece to complete the sequence. The objects in this activity are a set of domino pieces. The feedback consists of a face in the top corner of the screen that smiles when the user places a correct piece and frowns when the user places a wrong one (see Fig. 4.3 Right).

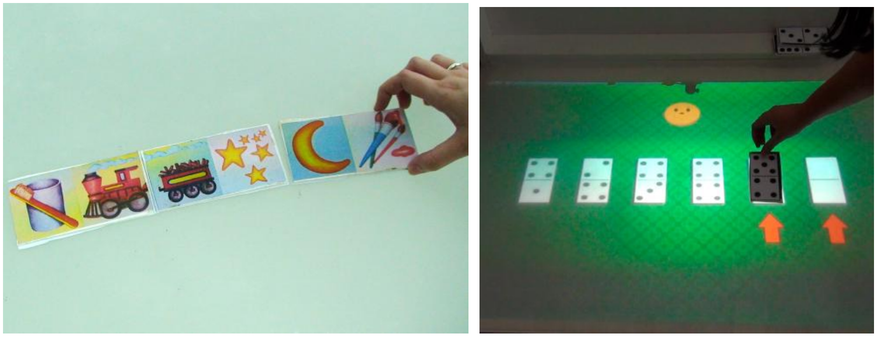


Fig. 4.3 Reasoning activities. **Left**: *Analogies*. **Right**: *Complete the sequence*.

4.1.1.3 Initial results

Before the session the OT decided the activities that every client would test, together with their level of difficulty. Regarding the Dementia group of clients, they tested the easiest level of the *Tangram* activity and the *Find the symbols* activity, since the therapist considered that they would be unable to understand more complicated activities. With the other group of clients, the chosen activities depended more on the characteristic of every clients. For example, the clients that had reading difficulties did not test the activities that required reading (*Shopping list* and *Syntagmatic Relations*). Likewise, with the clients with serious hearing impairments we could not test the *Trips* and *How many are there?* activities, since it was necessary to hear the itinerary in the first case and the hits that are played in the second case to complete the activities.

To know about the perception of the users while using the tangible activities, the clients answered some questions in order to gather their opinion about the tabletop and the activities. However, a problem was detected with this method of evaluation, which was that since some of the clients suffered from memory loss, when they were asked their opinions about the tabletop experience at the end of the session they had problems trying to remember all the activities that they had already done. Indeed, some of them were just able to comment the last activity they had tested. Consequently, for future evaluations instead of asking all the questions at the end of the session it would be better to ask the clients just after every activity. This change will surely increase the time of the session but the information obtained will also be more reliable.

Regarding the notes we took, it was observed that the time of the initial image that appeared in the memory activities was too short and the most difficult levels of certain activities were practically impossible to be completed by any of these users. More specifically, the Dementia group had serious difficulties completing just the easiest level of the *Tangram* activity, since they were used to doing activities in which they just needed to recognize geometrical figures but without having to place them in a specific place.

Thus, we could extract some conclusions in this evaluation:

- Several clients did not understand intuitively how to interact with the tabletop. In fact, even after seeing the NIKVision expert select the activities in the tabletop menu, they still thought that it was just a conventional table so it was necessary to explain to them how the tabletop worked. After the explanation, most of them were able to identify without any help the objects they had to use in order to complete the activities.

- Practically **none of the clients paid attention to the feedback**. The clients ignored the audio that sounded just at the beginning of the activities and that explained how the activity had to be done, since the clients were used to hear the instructions directly from their therapist and consequently they did not identified the audio that was sounding from the tabletop as such. Also, they did not understand either that the neutral, happy and sad faces that appeared on the activities were indicating the result of their actions on the tabletop. They just saw them just as mere decoration of the activity.

- The clients had difficulties recognizing some objects. For example, in the *Shopping list* activity all the clients mistook the apple toy with a pepper toy, since the apple toy was red and most of the clients were used to see green apples. Also, in the *Analogies* activity there were some pictures that they did not understand, so the therapist suggested that for future activities it could be better to use real images instead of pictures, since probably that way the clients would be able to recognize them more easily.

- Clients with wheelchair had difficulties to complete some activities. Among the 37 clients that we evaluated, 18 used a wheelchair. This meant that these clients had to resolve the activities laterally in order to be able to do the activities on the tabletop. Besides, the clients who also had bad mobility in their upper limbs had difficulties when completing the activities that required to place the objects in the superior (or even center) zones of the tabletop. Consequently, it would be necessary to create new versions of certain activities so that the interactive areas are closer to the border of the tabletop so that these clients could interact with them more easily and comfortably.

- Finally, almost all **the clients needed a practical example of the activities** to know how to complete them. For that reason, we concluded that it could be necessary to add an initial task just at the beginning of the activities that explained how to complete them.

4.1.2 New activities

The results of this evaluation provided us with valuable information to take into account in order to create three new activities, specially designed for the nursing home clients. One of them was devoted to work upper-half motor skills. It was the first of this kind designed for the NIKVision tabletop and created with KitVision toolkit.

4.1.2.1 Clothes activity

Aim of the activity: This first game is based on the daily task of getting dressed and has three different levels of difficulty:

- **Easy**: the background shows a body part (hand, feet, head…) together with the silhouette of two pieces of clothing. One of them corresponds to the body part while the other do not. The user has to select the correct one and place it on the right body part (see Fig. 4.4 Top-Left).
- **Medium**: this time instead of a body part, the background shows the whole body of a person (man or woman). The user has to select the clothing that corresponds to the gender of the person: for example, heels or skirt to the woman, and shoes and pants to the man (see Fig. 4.4 Top-Right).
- **Difficult**: in this level, the users have first to complete a word related to the weather with the vowels missing: “Sun”, “Rain”, and “Snow” (see Fig. 4.4 Bottom-Left). After that, the background shows a person together with four different pieces of clothing. Also, through a window the weather that the users have just completed can be seen. Then, taking it into account they have to choose the most adequate clothes to wear: for example, if it is sunny they have to choose the sunglasses and the fan (see Fig. 4.4 Bottom-Right).

All the activities begin with an audio that indicates the objective of the task, together with a positive audio feedback of the answers of the user. Each audio can be heard again touching the corresponding button of the navigation menu, situated on the top-right corner (see Fig. 4.4a). This menu also has a direct access to the screen with the choice of the difficulty level (see Fig. 4.4b), and also a button to go on to the next task (see Fig. 4.4c).

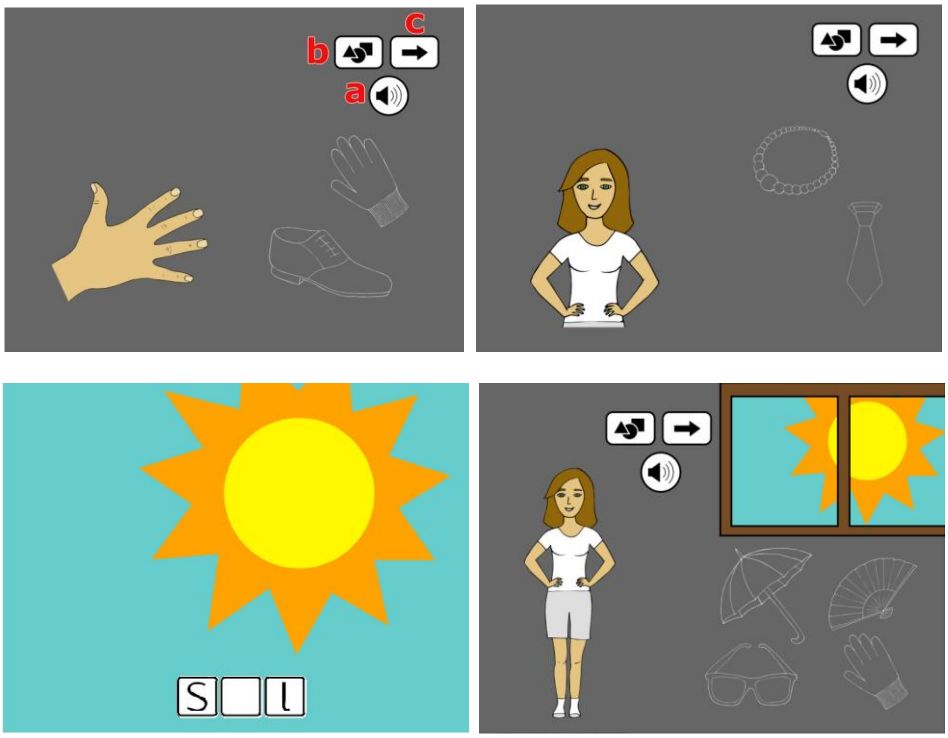


Fig. 4.4 *Clothes* levels of difficulty. **Top-Left**: Easy. **Top-Right**: Medium. **Bottom**: Hard.

Virtual and physical elements: The virtual elements consist of the different background that shows the body parts. Users interact with the tabletop by using different objects with realistic drawings of pieces of clothing and letters (see Fig. 4.5).

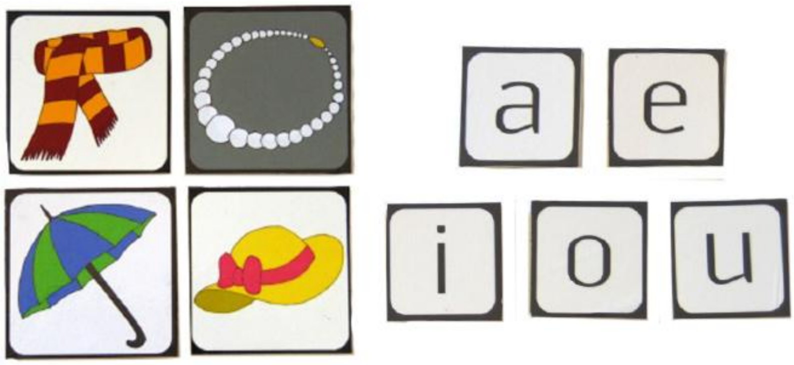


Fig. 4.5 Objects of the *Clothes* activity

Therapeutic goals: this game allows the consolidation of the semantic memory in the field of the clothing, together with the weather. Also, it allows to work the relation between analog elements thanks to the association of the clothing with its corresponding body part, and the relation between different elements when you have to choose clothes depending on the genre and on the weather. In the most difficult level, language is subtly worked thanks to the words that have to be completed to advance in the game. Fine motor skills are addressed when users have to pick up the two-dimensional objects to place them on the tabletop. Finally, the audio feedback (changing between man and woman depending on the task) enhances the short-term memory and complements the information showed on the tabletop.

4.1.2.2 Shapes activity

Aim of the activity: In this game users have to select the shapes indicated by the game and situate them on the box displayed on the tabletop. There are two different levels of difficulty (easy and hard) and a multi-player levelthat combines tasks that appear in the easy and medium levels.

- **Easy**: this level is focused on the work with a single type of shape (circles or squares) but with different sizes and colors, increasing the number of toys involved with each task (see Fig. 4.6 Top).
- **Hard**: in this level the users work with the two types of shapes. In this level, the number of correct answers increases (see Fig. 4.6 Bottom-Left).
- **Multi-player**: in this case, all the available toys are divided in two so that each player has half of them. Also, the division is made in a way that the solution contains toys belonging to both users, so that they have to collaborate to complete the task (see Fig. 4.6 Bottom-Right).

The use of feedback and the navigation menu is the same as in the previous game.

Virtual and physical elements: the virtual elements of this game consist of the background showing the box and the different geometrical figures involved in the task. Users interact with the tabletop by using geometrical shapes (see Fig. 4.7).

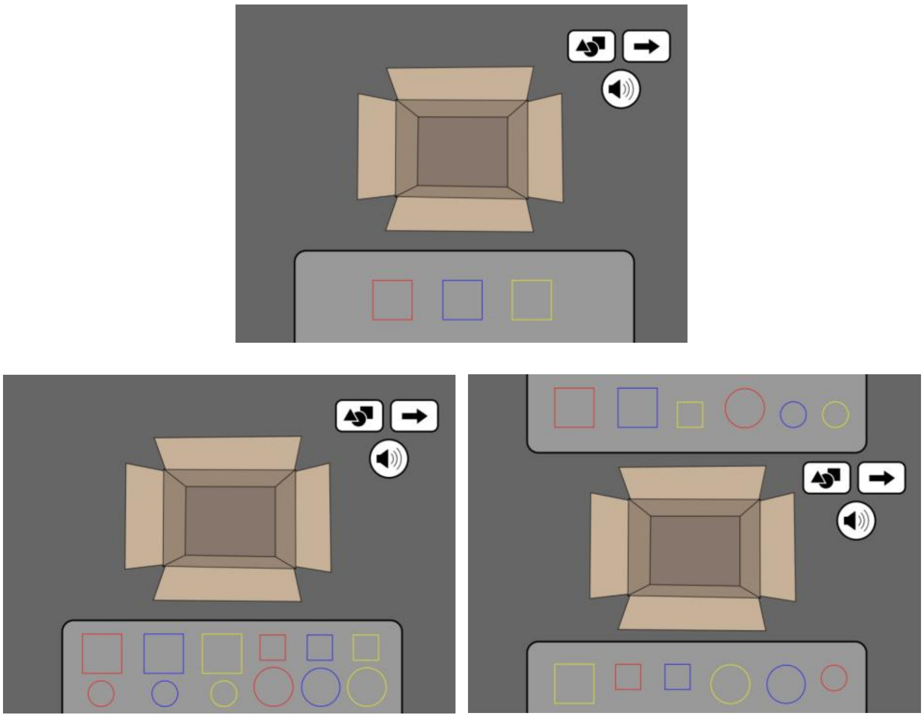


Fig. 4.6 *Shapes* levels. **Top**: Easy. **Bottom-Left**: Hard. **Bottom-Right**: Multi-player

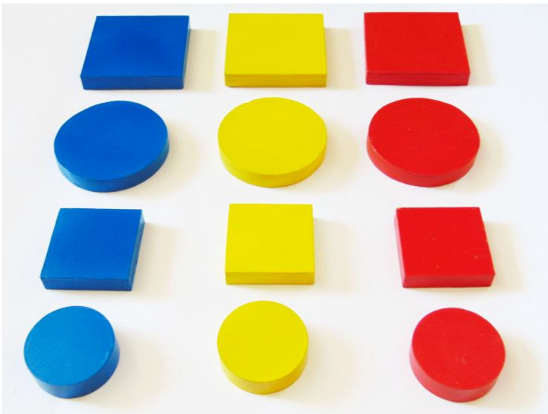


Fig. 4.7 Objects of the *Shapes* activity

Therapeutic goals: this game allows to work the association between physical elements with the concepts they represent, together with the inductive reasoning that allows to carry out the process of thinking from the specific concepts to the general concepts. In the multiplayer level, the game fosters the communication between the people that are playing and cooperation, since they need to work together to complete the task. The use of two-dimensional toys enhances, again, fine motor skills. Finally, short-term memory is reinforced thanks to feedback completing once again the visual information displayed on the tabletop.

4.1.2.3 Roads activity

Aim of the activity: the last game is focused on upper-half motor skills. Users have to move the object on the tabletop surface by following a virtual road, and also by avoiding physical obstacles in the most difficult levels. Again, this game has three different levels of difficulty:

- **Easy**: the different tasks just have a single road and there are not any obstacles. The roads are rather straight, without many bends (see Fig. 4.8 Top).

- **Medium**: obstacles begin to appear and each task has two different roads to choose. An audio plays saying which road (red, green or blue) the user has to follow, and the user has to select it with the corresponding object (see Fig. 4.8 Botton-Left).
- **Hard**: in the most difficult level the two roads interjects so that the user has to pay attention and continue for the correct road. Also, in the last tasks both roads are of the same grey color, to increase the difficulty even more. Obstacles are placed in all the tasks (see Fig. 4.8 Botton-Right).

In this case, an audio was added as feedback to indicate the user when he/she is deviating from the path.

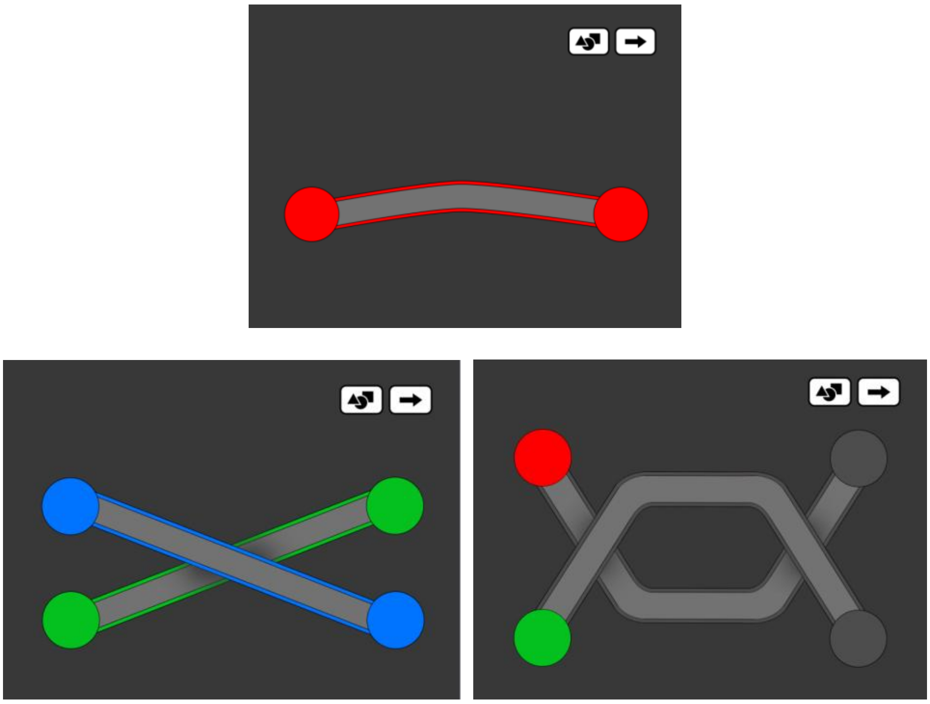


Fig. 4.8 *Roads* levels of difficulty. **Top**: Easy. **Bottom-Left**: Medium. **Bottom-Right**: Hard

Virtual and physical elements: the virtual elements are the backgrounds showing the different paths. The objects with which the users interact are different handles designed to work different kinds of "grabbing" actions (see Fig. 4.9 Left). The obstacles used in the most difficult levels are also physical (see Fig. 4.9 Right).

Fig. 4.9 Objects of the *Roads* activity. **Left**: Objects fostering different "grabbing" actions. **Right**: Obstacles.

Therapeutic goals: the game allows the development and maintenance of procedural memory in the use of tridimensional objects with different handles, representative of different daily situations. Fine motor skills are addressed, specially the movement of the upper limbs. Also, spacial orientation is worked, together with divided and sustained attention since in the most difficult levels the user has to focus his/her attention on one of the two different paths, and to concentrate to follow it correctly. In general, hand-eye coordination is worked, fostering this skill that enables the eyes to guide the hands in accurate movement.

4.1.2.4 Final evaluation

For this final evaluation, we made sure to ask for the clients' opinion of the activity just after they performed it.

In the *Clothes* activity the clients were able to recognize the pieces of clothing and divide them according to genre. They took their time placing the objects on their corresponding place (pants/skirt on the man/woman's legs, or shoes/heels on the man/woman's feet). They understood the audio instructions but they usually needed to hear it more than once. They have more difficulties with the Hard level of difficulty where they have to complete the words related to the weather, since they focus on what the audio is saying to discover the word that they have to complete, and sometimes the audio does not say it directy (for example, the audio says "it's raining" but the word they have to complete is simply "rain").

In the *Shapes* activity the clients had more difficulty with the Medium level of difficulty where they had to place on their on, performing better on the collaborative level since the number of pieces they had to manipulate was lower. A good interaction between players was observed, and some times they even helped each other to be able to complete the exercise. One thing that was necessary to improve for the next version of this activity was the size of the virtual box: it should be bigger so that clients did not have to waste too much time in reorganizing the pieces so that all of them fitted well inside.

Finally, in the *Roads* activity the clients reacted well with the different way of grabbing. They were able to follow the roads, presenting the expected difficulties in the last level of difficulty when the roads overlapped. They also managed to overcome the physical obstacles while playing. However, the audio feedback was a little slow to sound when they stepped out the road, and also it was decided to widen the roads for the next version of the activity.

In general, the evaluation was positive and, in spite of the few mistakes detected in the design of the activities, it was observed their adequacy to the target group they addressed.

4.2 Tangible Tabletop Activities for Children with Developmental Delays

Thanks to a collaboration with ENMOvimientTO, an occupational therapy center specialized in the early identification of delays and disorders in children aged 0-16 years, we could realize the potential of NIKVision tabletop and activities for children with developmental delays [Bonillo et al., 2016a] [Bonillo et al., 2016b].. Afterwards, we carried out a longer collaboration with one of the centers of the Aragonese Institute of Social Services (IASS), which allowed to go deeper in the design and evaluation of tangible tabletop activities for this kind of children [Bonillo et al., 2017]. The experience made it necessary to add new functionalities to KitVision toolkit, and ended with a NIKVision tabletop permanently installed in the center.

4.2.1 The ENMOvimienTO experience

A collaboration with the ENMOvimienTO therapy center was carried out in the context of a Final Degree Project [Llorente, 2015]. The aim of the collaboration was to design a set of activities for the children attending the center. The therapeutic goals of the activities were set by their occupational therapist, taking into account the most common impairments of their clients. The activities were implemented by the student of the Degree of Product Design, making use of KitVision toolkit, for the NIKVision tabletop. A description of the activities follows.

4.2.1.1 Bees

Aim of the activity: In this activity, the tabletop surface shows an animation of a tree full of hives with several bees flying around. The animation also shows a beekeeper standing under the tree. After some seconds, the bees stop flying and each one of them disappears into a different hive. Among the bees, there is only one that carries honey. The player has to pay attention, following with the eyes the bee with honey, and place the honey pot toy under the hive where the bee disappeared.

Virtual and physical elements: In this activity, the virtual elements are the scene, the bees that move around it and the beekeeper character that gives feedback to the user (see Fig. 4.10 Left). The honey pot toy that the player has to put under the hive is a physical tangible object (see Fig. 4.10 Right).

Fig. 4.10 *Bees* activity. **Left**: Background-animation shown on the tabletop surface. **Right**: Physical honey pot toy to interact with the tabletop.

Therapeutic goals: The wide surface display allows to exercise long visual tracking, helping to train the ocular muscles. Also, visual attention is considered, since the difficulty not only increases with the speed of the bee carrying the honey, but also with the growing number of distracting elements (number of bees without honey that move in the display). For those reasons, this activity is useful for children with psychomotor delays, to develop the fine motor skills of the upper limbs, and for children with an attention deficit, since only if the child is paying attention, he/she could complete the activity.

4.2.1.2 Plumber

Aim of the activity: In this activity, the tabletop surface shows an animation of a pipe composed of segments of different colors. Some of those coloured segments present water leaks of the same colour: red or blue. The aim of the activity is that the child places his/her hands over the segments of the pipe that have water leaks with the glove of the corresponding colour to close the circuit.

Virtual and physical elements: The virtual elements are the scene with the pipes that must be covered by the user and the plumber character that gives feedback to the user (see Fig. 4.11 Left). The physical objects are the gloves of different colors that the child has to wear on his/her left and right hands (see Fig. 4.11 Right).

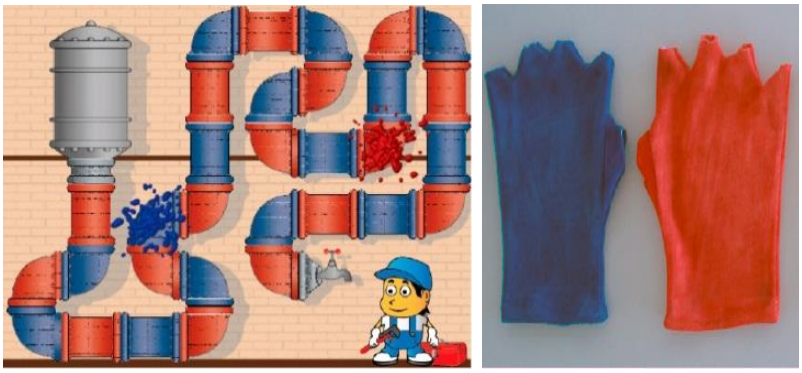


Fig. 4.11 *Plumber* activity. **Left**: Virtual scene shown on the tabletop surface. **Right**: Tangible coloured gloves to interact with the tabletop.

Therapeutic goals: This activity helps to develop upper limb coordination skills, bilateral coordination (simultaneous use of both hands) and management of contralateral space (crossing of the body centre line with both hands). Therefore, it is useful to work with children with psychomotor delay, especially to train gross motor control.

4.2.1.3 Fishing

Aim of the activity: In this activity, the tabletop surface shows an animation of a pond with a pier where a cat is standing. The player has to use a rod to catch the fish in the lake and give them to the cat (place them on the pier, next to the cat). The aim of the activity is to give the cat the fish that it likes. However, the cat does not eat all the fish: the ones it likes are those whose shapes appear drawn on the pier, next to the cat.

Virtual and physical objects: The virtual elements are, again, the scene consisting of the pier and the lake, and the cat character that gives feedback to the user (see Fig. 4.12 Left). The tangible elements are the fishing rods of different length and the fish toys of different shapes and colours placed on the tabletop surface (see Fig. 4.12 Right).

Fig. 4.12 *Fishing* activity. **Left**: Background-animation shown on the tabletop surface. **Right**: Physical rod and fish toys to interact with the tabletop.

Therapeutic goals: In this activity, the most efficient posture to grasp the fishing rod is by shoulder co-contraction and smooth movement of the wrist and the fingers. This activity is useful to work with children with psychomotor delays, to train fine motor skills.

4.2.1.4 Evaluation

In order to locate usability problems we used a video analysis usability method consisting of a simplification of DEVAN [Vermeeren et al., 2002], so all the sessions with the children were video recorded for that purpose. After the evaluation, a usability expert reviewed the videos and labeled them using five categories of usability events: weird situation observed, adult intervetion needed, playability error detected, incorrect action, correct action. If an event occurred/happened in more than 50% of the cases, it was considered a “critical point”, meaning that a correction in the game had to be made in order to prevent that event from appearing again. Otherwise, the event could be considered an “isolated case” and be ignored.

Regarding the first evaluation, Table 4.1 shows the critical points that were found when the children tested the developed activities.

Table 4.1 Therapeutic goals of the activities

Activity	Times	Event	Explanation
Bees	7	Error	While the bee is still flying, the child begins to move the honey pot toy over all the hives, so that he is able to complete the activity without paying attention to the bee.
	6	Error	After an incorrect action, the child chooses the correct hive but the wrong sound that was reproduced with the first incorrect action keeps playing, confusing the child.
	5	Adult	Instead of putting the honey pot toy under the hive, the child places it over the hive.
Fishing	7	Error	The child does not return the fish to the water once the task is completed, so when the next task begins there are already some fish placed on the pier that can make the audio feedback play even when the child has not done anything yet.

As shown in the table, in the *Bees* activity there were three critical points that had to be fixed:

1. The first critical point was resolved by deactivating all the areas in which the child can place the honey pot while the animation of the flying bees is being reproduced. That way, even if the child tries to guess the correct hive by probing all of them he does not get any kind of response and consequently he is forced to pay attention to the bee in order to see what hive is the correct one.
2. In order to solve the second critical point, it was decided to give priority to the cor-rect feedback. That way, the moment the child performs a correct action the other sounds that could still be reproducing/playing stop and just the correct sound remains, eliminating the possibility of confusing the child with contradictory feedback.
3. Lastly, regarding the third critical point we considered to modify the game so that the child could place the honey pot over the hive instead of under it. However, during the evaluation we also observed that some children immediately realized what they had done wrong when

seeing the animation of the honey falling from the hive, so in the end it was decided not to change the game.

Also, the evaluation showed that most of the children could complete the activity without any problem. Therefore, we decided to increase its level of difficulty for the next evaluation by adding more distractors to the animation (more bees that carry no honey) and by increasing the speed of the bees.

The *Fishing* activity had just one critical point that could be easily fixed by add-ing an intermediate task in which the child has to return the fish to the water. That way, the possibility of a task being affected by the fish that the child has placed in the previous task disappeared.

Finally, regarding the Plumber activities, no critical points were found.

4.2.2 The IASS experience

After the ENMOvimienTO experience we contacted with the "Centro Base I" of the Aragonese Institute of Social Services (IASS), which works with children with developmental delays that, because of their age or characteristics, do not attend school yet. We showed the therapeutic NIKVision tabletop and activities. The IASS therapists confirmed the advantages of using tangible activities with their clients. The first step was to decide the set of tangible activities for NIKVision that could be useful for the most common problems treated in the "Centro Base I". The therapists indicated their main therapeutic goals: visual attention, psychomotor skills, bilateral coordination and cognitive skills. The *Bees*, *Fishing* and *Plumber* activities fitted well in these goals (see first three rows of Table 4.2).

It was decided to design three other NIKVision activities (last three rows of Table 4.2) to complement the other ones and to carry out an evaluation, in order to adapt the activities to their children and detect usability problems.

Table 4.2 Therapeutic goals of the activities

Activity	**Therapeutic Goal**			
	Visual attention	**Psychomotor Skills**	**Bilateral Coordination**	**Cognitive skills**
Bees	✓	✓		
Fishing	✓	✓		
Plumber		✓	✓	
Pac-man		✓	✓	
Silhouettes	✓			✓
Supermarket	✓			✓

4.2.2.1 Additional NIKVision activities

Besides the activities that resulted from the experience in ENMOvimienTO, others activities that had already been developed for NIKVision were also used.

Pac-man

Aim of the activity: This activity consists of a maze with obstacles and pac-dots (represented by white dots), in which the pac-man must eat the pac-dots without colliding with the walls. Meanwhile, a ghost roams the maze, trying to catch the pac-man. The activity finishes when the pac-man eats all the pac-dots without being caught by the ghost.

Virtual and physical elements: The virtual elements are the maze and the pac-dots (see Fig. 4.13 Left). The physical elements are the two characters involved in the activity: the pac-man and the ghost that runs after it (see Fig. 4.13 Right).

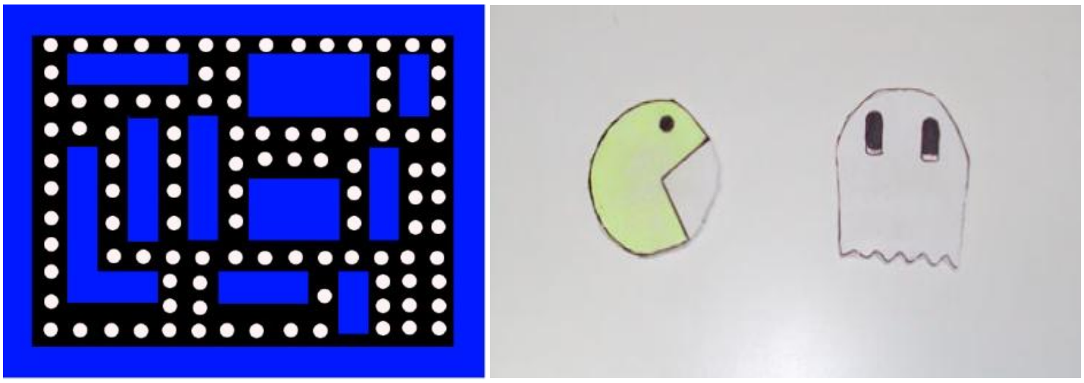


Fig. 4.13 *Pac-man* activity. **Left**: Virtual maze and pac-dots. **Right**: Tangible pac-man and ghost.

Therapeutic goals: Since the player has to move the pac-man over the surface without colliding with the obstacles, this activity allows to train fine motor skills, especially of arms and hands. Moreover, in order to eat the pac-dots and not to collide with the walls, it is better to move the pac-man continuously and slowly. Therefore, this activity is also useful to train children with attention deficit disorder since the activity requires patience to follow the path slowly without leaving it.

Silhouettes

Aim of the activity: This activity consists of a farm scene, with several animal silhouettes spread out in the environment. The player must place the toy of each animal over the corresponding silhouette. If the animal is the correct one, the sound of that animal is reproduced.

Virtual and physical elements: The virtual element in this activity is the farm scene with the silhouettes (see Fig. 4.14 Left). The tangible elements are the toys of the different animals that must be correctly placed on the silhouettes (see Fig. 4.14 Right).

Fig. 4.14 *Silhouettes* activity. **Left**: Virtual farm scene. **Right**: Tangible animal toys.

Therapeutic goals: This activity allows to treat simple speech delay, encouraging children to imitate the sounds of the animals, improving the ability to articulate words. Also, in some cases of generalized developmental disorder, the task of association between real objects and silhouettes can help to train cognitive skills.

Supermarket

Aim of the activity: In this activity, the player must help the character to do the shopping. Not all the food can be put into the shopping basket, only those whose pictograms appear on the right part of the scene. The aim of the activity is to choose all the correct food toys and to put them into the basket.

Virtual and physical elements: In this activity, the virtual element consists of the scene with the character, the pictograms of the food [products] and the shopping basket (see Fig. 4.15 Left). The tangible elements are the food toys that the player must put into the virtual shopping basket (see Fig. 4.15 Right).

Fig. 4.15 *Supermarket* activity. **Left**: Virtual scene with the character, the shopping basket and the food pictograms. **Right**: Tangible food toys.

Therapeutic goals: This activity is aimed at children with generalized developmental disorders, since it is necessary to establish a relationship between the pictogram elements with the more realistic physical corresponding objects (tangible toys). Therefore, the activity is useful to work with children with cognitive delays.

4.2.2.2 First evaluation

To carry out the evaluation, a NIKVision tabletop was installed in the "Centro Base I", in Zaragoza (Spain). The evaluation sessions were conducted over one week, during the therapist consultation hours with children attending the Center.

Five therapists (1 speech therapist and 4 psychomotor therapists) participated in these evaluation sessions. The children that used the different developed activities were selected among the clients by each therapist, considering for whom the tabletop therapy could be more useful. A total of 12 children (7 boys and 5 girls) aged between 2 and 5 years participated in the evaluation.

During the sessions, that lasted an average of 20 minutes, direct expert observation was used. The therapist selected the more suitable activity according to the disorders of each client and, while the child played, the expert monitored the session taking notes, writing problems, suggestions, etc. At the end of the session a brief informal interview with both the therapist and the child was carried out, in order to know their opinion about the session and the activities played.

Each child played at least five activities, the most played being those related to the fine and gross motor skills (bees, plumber and fishing) since this is the most common disorder treated in the center. The silhouette activity was also played by most of the clients (all except one), though in this case it was not selected because of its therapeutic goals. Instead, it was chosen due to its ludic component since it allows children to relax after completing other more cognitive-demanding activities.

After analyzing the data of the assessment sessions, some relevant issues were detected.

In the first place, regarding the use of the activities some general problems emerged. Some of them were usability problems though others were more related to the content of the activities. For example, some activities seemed to be too brief, others did not give enough variability and, in some cases, the difficulty curve between different levels was too steep. Another important problem detected was that several tangible elements were too fragile and could be easily broken. Therefore, the activities were re-designed in order to take all these issues into account (see Section 4.2.2.3).

Secondly, the therapists detected that none of the activities tackled severe speech delays. Although some activities like *Silhouettes* or *Supermarket* could help to treat simple speech delays, making children repeat the animal sounds or the names of the foods, these activities were not especially focused on treating speech disorders. Therefore, it was decided to create a new specific activity aimed to children with severe speech delays (see Section 4.2.2.4).

Finally, the therapists also expressed their difficulty to take notes while the client was doing the activities with the tabletop, since during the session they also had to select the corresponding activity, give the toys to the child, explain some activities, help the child if necessary, and so on. Moreover, at the end of the session they had to write down the results of the activities in order to follow and evaluate the progress of each client. To solve this problem and in order to facilitate the therapists to work with the tabletop in an autonomous way, it was decided to modify the KitVision software so that it could include a new functionality, i.e. a logs management system (see Section 4.2.3).

4.2.2.3 Improving the activities

The problems detected in the assessment sessions were analyzed and solved by re-designing the activities and making different changes on the virtual and physical elements. Then, a second assessment with the same methodology and the same children was carried out. The results of this new evaluation showed that the therapists were very satisfied with the new adapted activities.

A thorough analysis of the results of the assessment session showed the following specific problems in the activities:

1. Some activities were too brief. In these cases the activity was completed very quickly, except in the case of clients with severe cognitive disorders:
    a. The silhouette had only one task
    b. The supermarket only asked for three foods
2. Some activities did not offer enough variability:

   a. The paths followed by the bees did not change, so some kids could remember the result
   b. In the supermarket the kids could remember the foods asked in a precedent session
3. The difficulty curve between different levels was too steep:
   a. The bees activity had two levels (easy and difficult), with a great gap between both of them.
   b. The cat asked for different fishes during the game, though only at the beginning, so children often used to forget the aim of the activity.
4. Some tangible elements were too fragile and could be easily broken.

The changes and improvements made for each activity in order to address the previous issues are reflected in Table 4.3.

Table 4.3 Improvements made in the activities

	Problem
Bees	
The path followed by the bee was modified to change randomly	2
A new intermediate level was introduced	3
The honey pot toy was changed by one made of wood and vinyl (Fig. 4.16a)	4
Pac-man	
The color of walls and obstacles was changed to make them more visible	Access.
New toys for the pac-man and the ghost were made (Fig. 4.16b)	4
Fishing	
A button that allows to repeat the audio instructions about the fish wanted by the cat was included in the scene	3
New fish toys were made (Fig. 4.16c), however the fishing rods did not require any changes since they were made of wood	4
Silhouettes	
Silhouettes of more animals were included in the scene: a cock, a goat and a cat	1
In order to have all the silhouettes with the same design, new toys were made for all the animals (Fig. 4.16d)	4
Supermarket	
Two new versions of the supermarket activity were created using the KitVision software: - **Memory** supermarket: Once all the food products are required (the number can vary), the food pictograms disappears of the scene and the child has to remember the asked food - S**equence** supermarket: this version is similar to the previous one, though the child has also to remember the order in which the food was required	1 / 3 1 / 3
New food toys were made for this activity (Fig. 4.16e)	4

Since one of the problems detected in most of the activities was the fragility of the toys, after studying different alternatives it was decided to make new ones using wood and vinyl. The new toys are more robust (see Fig. 4.16), so that the therapists do not need to be controlling the children all the time to prevent them from breaking the toys.

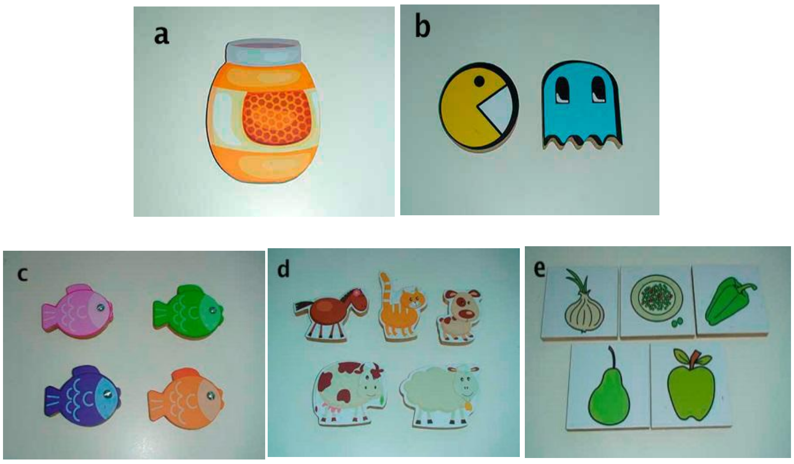


Fig. 4.16 New toys for the activities: **a)** *Bees*. **b)** *Pac-man*. **c)** *Fishing*. **d)** *Silhouettes*. **e)** *Supermarket*.

After finishing the re-design and implementation of the activities, new sessions to assess the changes and improvements were conducted in the center. In the assessment sessions 8 children (4 boys and 4 girls) aged between 2 to 5 (see Table 4.4) participated and 4 therapists (1 speech therapist and 3 psychomotor therapists) attended them. We made sure to test the activities that had suffered more changes, i.e. *Silhouettes* and the different versions of *Supermarket*.

Table 4.4 Details of the second evaluation session of the improved activities

	Gender	**Age**	**Actitivy**				
			Bees	**Pac-Man**	**Fishing**	**Silhouettes**	**Supermarket**
1	M	2				✓	
2	F	2				✓	
3	M	4		✓			✓
4	F	5	✓		✓	✓	
5	F	3	✓			✓	✓
6	M	5	✓			✓	
7	M	3			✓		✓
8	F	4		✓			✓

Regarding the results of this new assessment, the psychomotor therapists were very satisfied with the improvements introduced in the activities, especially with the new versions of the supermarket, the robustness of the new toys, and with the inclusion of a button that allows to repeat the instructions in the fishing game. All therapists showed their interest in having a NIKVision tabletop permanently installed at their place.

4.2.2.4 Creation and assessment of a new activity: speech therapy

The results of the first evaluation carried out in the Center revealed that, among the initial six activities, there was not any that directly aimed to work language disorders. Therefore, it was decided to design and implement a seventh activity that handled this particular issue.

Speech-language therapy addresses the evaluation and treatment of language, voice and communication disorders. It focuses on improving oral and written communication of the clients that suffer from hearing, phonatory or cognitive impairments that cause difficulties in the acquisition and development of the language.

In order to create a new activity for treating this disorder, a study of other existent applications was carried out. On the one hand, in the context of tactile interaction applied to speech therapy, there are several applications dedicated to the treatment of different language impairments. On the other hand, when working with tangible interaction, the most common method of therapy used is through "storytelling", the interactive art of using words and actions to show images and elements of a story encouraging the listener to use his/her imagination [Schneider et al., 2006]. The main characteristics of storytelling are as follows:

1. It is interactive;
2. It makes use of words;
3. It makes use of actions such as vocalization, physical movements and/or gestures;
4. It presents a story;
5. It encourages listeners to stimulate their imagination.

In the context of tangible interfaces applied to storytelling, the works of Cristina Sylla et al. set the basis of our work: *TOK* [Sylla et al., 2011] is a tangible platform with book appearance, in which the kids can create their own stories by using drawing cards, and putting them in order to establish sequences or tales. Also, *t-books* [Sylla et al., 2012] is a evolution of *TOK*, consisting of an electronic book with slots and a set of drawing cards that children can put in the book for interacting and exploring the narrative. According to the cards selected by the children, different animations and audio are executed in the computer. Lastly, *t-words* [Sylla et al., 2013] ("tangible words") is an interface set up by rectangular blocks in which the children can record audio and later listen to it. The blocks can be connected together, in order to reproduce the audio sequentially. In this way, the rearrangement of the blocks allows to reorder the audio that was previously recorded.

After analyzing these works and verifying their similitudes with the way children manipulate physical objects when interacting with NIKVision, it was decided to create a tangible tabletop activity based on storytelling. The final design of the activity and the cards can be seen in Figure 4.17.

Aim of the activity: The story chosen for the activity was *The Wonderful Wizard of Oz*. A set of sentences related to the story are presented to the child. In the sentences, the prepositions are missing. The child has to choose the preposition that completes the sentence correctly. If the child chooses a correct preposition, an image that represents what is said in the sentence is showed as a reward. If the child completes different phrases correctly, the images that appear as a reward are different, so even if there is just one story the child can play the activity several times by completing different sentences in order to see all the different images of the story.

Virtual and physical elements: the virtual elements are the sentences that the child has to complete and the images that are unlocked when the sentences are correctly completed. The physical elements are tokens with the name of the prepositions.

Fig. 4.17 *Oz* storytelling activity. **Left**: Virtual scene. **Right**: Tangible preposition cards.

Therapeutic goals: the activity was aimed to be used complementarily to speech therapy sessions. Its main purpose is to help the child understand how to use the most common prepositions. It was discarded that children could create their own stories from scratch since the activity gets very complex and its therapeutic goal was not clearly defined.

When the new activity was implemented, an initial evaluation was carried out to detect problems and to suggest improvements. The methodology of the evaluation of this new activity was the same as the one applied in the assessment of the six previous activities, though with less clients. Two sessions of 20 minutes each were carried out in the "Centro Base I" with two children aged 4 and 6, respectively. This time, only two speech therapists were present.

In the initial evaluation, children did not understand the game well, however once the speech therapists explained the use of the prepositions to them (with the help of the drawings in the cards) and after reading the sentences aloud, the children began to understand the mechanics of the activity and could complete the sentences.

When we asked the speech therapists for their opinion after this evaluation, they argued that the activity was very useful as a complement for their therapy sessions and they also suggested two improvements:

- In the audio that plays when a child completes a sentence, the tone of voice when spelling the preposition should sound louder than the rest of the sentence to make the child focus his/her attention on it;
- The possibility of repeating several times the same sentence should be added.

To make the first improvement, we simply recorded the audio again with special emphasis in repeating the prepositions in a louder voice. Regarding the second change, the activity was modified by adding a "back" button that allows to go back to the previous taken decision to re-do the sentence or to choose a different one.

After modifying the storytelling activity, we carried out a new set of sessions with the speech therapists. This time, eight children of ages between 2 and 6 years participated, all them with speech disorders.

As in the initial evaluation, 4 of the 8 children that participated in the session needed the help of the card drawings to understand the prepositions. The other four children easily understood the prepositions when the speech therapists read them aloud. Once the activity began, the children understood rather quickly the mechanics of the game. In fact, some of the children repeated the audio that played after completing a sentence correctly even if the therapists did not give them any indication to do that.

The speech therapists made good use of the "back" button to go back to the previous decision, so that the child completed a different sentence or to complete the same sentence in case of making it wrong. In this new evaluation, no other additional problems were detected.

4.2.3 New KitVision functionalities

The IASS experience lead to some modifications and improvements in KitVision software, which were carried out in the context of a Final Degree Project [Bonillo, 2016]. They are described in the following sub-section.

4.2.3.1 Navigation between activities

Up to that point the activities developed with KitVision had two limited aspects:

1. **All the areas defined in the activity had to be completed:** otherwise, the task is not considered fulfilled, and the next task will not begin.
2. **The tasks composing an activity developed were sequential**: when a task has been completed by placing all the correct objects (and only the correct ones) on their corresponding areas, the next task automatically begins.

Consequently, these two limitations had to be modified in order to develop the new storytelling activity explained in the section 4.2.2.4. In the *Oz* activity, a task is composed of three different areas (corresponding to the preposition children have to use to complete the sentence), and the task is considered fulfilled when just one of the three sentences has been completed (1). Also the tasks were not sequential anymore, since the next task to be ran on the tabletop depends on the sentence that was completed (2). KitVision Player had to be modified to include this alternative way of creating non-sequential activities (see Fig. 4.18).

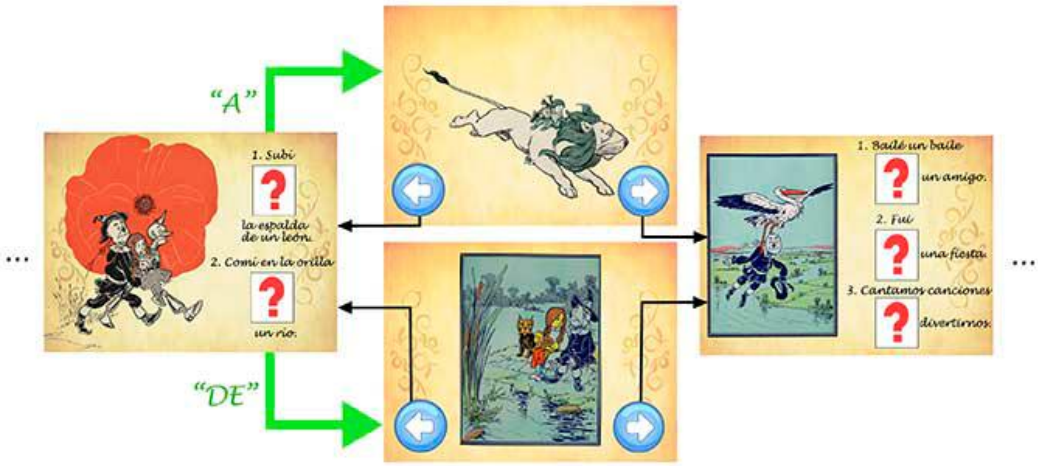


Fig. 4.18 Flow of the *Oz* storytelling activity.

4.2.3.2 Logs management system

A log file, with the information collected during the development of each activity, has to be stored by the system. Each log file will have the ".log" extension and must include the following data:

- Name of the activity;
- Date (“dd/mm/yyyy”);
- Time (“hh/mm/ss”);
- Time played (in seconds);
- Number of correct actions;
- Number of wrong actions;
- Whether the activity was completed or not.

To store the information of the child identity it was contemplated to create an application that would allow the user to introduce his/her personal data before beginning to use the activities or to create a menu similar to the activities menu but this time with users. However, after analyzing the options with the therapists it was decided that the simplest option was to include in the software the possibility of recording speech audio.

This way, the therapists would be able to record the child’s data that they consider more relevant but also to keep any other kind of information that cannot be stored in the text logs (for example, which activity the child likes most). We also decided to limit the fact that the recording of the audio could only be done through the menu, since recording during the execution of the activity could affect its playability.

Another consideration to bear in mind is how to make the logs (text and audio) available to the therapists. It was decided to save both reports in a file folder corresponding to the current session. We call “session” the time during which a child is performing the activities until the tabletop is shut down. Also, it was decided that the folders stored should be compressed to save memory space in the computer. Table 4.5 shows the requirements that the logs management system should fulfill.

Table 4.5 Logs management system requirements

Requirement	Description
R1	The system will automatically create a folder to store the logs of the session
R2	The logs of the session will be automatically stored in their corresponding folder
R3	The logs folder will be compressed at the end of the session to save space in the computer
R4	The logs folder of the current session (only the one corresponding to the current session) will be copied in the destination place
R5	The logs folder will be decompressed in the destination place
R6	It will be possible to record speech audio through the player menu
R7	The audio recording will be controlled by the therapist
R8	Audio files will be stored in the same folder as the logs

To be able to implement the requirements mentioned in the above table it was necessary to perform several modifications in KitVision software.

The first question to decide was the way to access the logs of the session (**R1**). As mentioned in requirements **R2** and **R3**, the logs are stored in a folder that is eventually compressed, however we had to determine how the therapists could access that information easily. After discussing the possibilities, it was decided that the simplest way to extract the information was by using a USB device, since the therapists were familiarized with it. Besides, the tabletop has a USB port on one of its sides, allowing to introduce the device to automatically copy the logs folder (**R4** and **R5**).

Secondly, to allow the possibility to record audio (**R6**), a microphone was set up in the NIKVision tabletop installed in the “Centro Base I”. That microphone was connected to the computer placed inside the tabletop. Regarding requirement **R7**, that established that the audio recording had to be controlled by the therapist, we decided to include a new tangible selector for that purpose (see Fig 4.19). The use of the selector is as follows: when it is placed on the tabletop surface (while being in the activities menu) audio speech begins to be recorded, and when the selector is removed (from the menu) the recording stops. At that moment, the recorded audio is stored in the corresponding logs folder (**R8**).

Fig. 4.19 New tangible selector to record audio in NIKVision tabletop.

These two improvements, specially the first one consisting of removing the limitation of sequential activities, allowed us to create more complete activities, as it will be shown in the following sections. After these two improvements, KitVision software and a NIKVision tabletop were permanently installed in the IASS center to support therapists daily work.

4.3 Tangible Tabletop Activities for ADHD Children

Attention deficit hyperactivity disorder (ADHD) is a mental disorder whose symptoms include attention and concentration difficulties, lack of emotional self-regulation, and a high level of impulsivity [Barkley, 2006][Bauermeister et al., 2005]. It is one of the most frequent neurodevelopmental disorders among children, having a prevalence of around 5% in Spain [Graham et al., 2011] and around 10% in the USA [Akinbami et al, 2011]. There are usually three kinds of interventions for ADHD children: psycho-pedagogical intervention, pharmacological intervention, and a combination of both [Sibley, 2014].

One of the main characteristic of ADHD children is having poor attention skills, meaning that, in general, they respond to a greater number of impulses, whether they are relevant or not to perform the tasks, and do not seem able to concentrate during the time necessary to perform them [Tripathi and Hasan, 2014]. This can lead to an increase in the level of activity, which translates into disruptive attitudes that hinder learning and also their acceptance by teachers and peers. Another feature that is attributed to children with attention problems is their disorganization and impulsiveness, which leads them to have problems in making decisions and solving problems [Bauermeister at al., 2012]. The problems of these children with attention, disorganization and impulsivity raise the consideration of the planning process as fundamental [Naglieri and Das, 2006]. This is why during the intervention children should be guided to be able to improve planning, to regulate themselves to develop strategies to succeed, to improve their decisions and to pay attention to how they carry out their tasks.

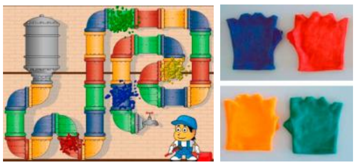
Thanks to the collaboration with Atenciona, an association of ADHD families and professionals also involved in the JUGUEMOS project, we used KitVision to develop activities specifically designed for the ADHD children that attended the center [Gil, 2016][Labarta, 2017].

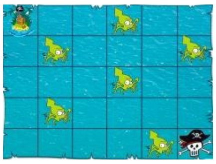
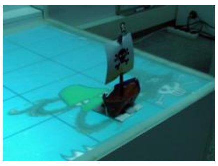
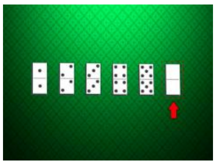
4.3.1 Preliminary study

It was decided to make a preliminary study to assess the usability and potential of our tangible tabletop activities with ADHD children. In the study, Atenciona children took part as well as their educators, as their opinions about the potential of the tangible tabletop and its activities for psycho-pedagogical intervention were one of the aims of the study.

The activities that were tested with these children were the ones created during the collaboration with the IASS (Section 4.2.2) and during the PhD student's Final Project [Bonillo, 2014]. In a first meeting at the Atenciona center the activities were shown to the educators. Although they had been developed for users whose characteristics and age range did not directly correspond to the Atenciona ADHD children, the educators thought they could be used and they selected ten of them. In Table 4.6 the selected activities are shown indicating the name, a brief description of the activity, the image projected on the tabletop surface and the physical toys necessary to play. They are grouped according to the skill they were designed to work: visual attention, memory and planning.

Table 4.6 Tabletop activities used in the evaluations

	Description of the activity	**Tabletop Image and Physical Toys**
ATTENTION	**Bees**: the tabletop surface shows an animation of a tree full of hives with several bees flying around. Among the bees, there is only one that carries honey. The activity is completed when the child places a honey pot toy under the hive where the bee with honey disappeared.	
	Fishing: the tabletop surface shows an animation of a pond with a cat and with shapes of the fishes that the cat likes. To complete the activity, the child has to use one of the rods to catch the fish that have the same shape and color as the ones next to the cat and place them on the pier.	
	Plumber: the tabletop surface shows an animation of a pipe that has water leaks of different colors. To complete the activity, the children have to place their gloved hands over the segments of the pipe that have water leaks of the same color as the gloves they are wearing.	
	Twister: this activity is a tabletop version of the original Twister game. The surface of the tabletop shows a twister roulette and four rectangular areas of different colors where the child has to place his hands.	

MEMORY	**Kraken**: the tabletop surface shows the image of a sea with krakens in some of the squares. After five seconds the image disappears and only the sea is shown. To complete the activity the child has to move the boat to reach the treasure, avoiding the squares on which there was a kraken.	 
	Shopping List: the surface shows an image with a list of several foodstuffs for five seconds. The image of the list is then replaced by an image of a shopping bag. The child has to remember the content of the list and select the correct foodstuffs to place them in the bag.	 
REASONING	**Analogies**: the child has a set of pieces. Each piece is composed of two pictograms and each pictogram can be paired with another pictogram from a different piece. The goal of the activity is to compose a chain by pairing the physical objects with the correct pictograms.	 
	Complete the sequence: the tabletop surface shows a sequence formed with domino pieces in which some of the pieces are missing. The child has to select the correct missing piece (or pieces) to complete the sequence.	 
	Silhouettes: the tabletop surface shows the image of a farm with several animal silhouettes. To complete the activity the child has to place the different animal toys over their corresponding silhouettes.	 
	Tangram: this activity is a tabletop version of the original Tangram game. The children manipulate seven figures to create the shape shown on the tabletop surface.	 

In order to carry out this preliminary session, a NIKVision tabletop was installed in the Atenciona center, in one of the rooms that the educators used for their therapies and exercises. The children who tested the activities were receiving psycho-pedagogical intervention in the center. A total of 26 children participated in the sessions (24 boys and 2 girls), the youngest being 6 years old and the oldest 14 years old. Most of them were diagnosed with either ADHD or ADD (Attention Deficit Disorder), all had learning difficulties (which is why they attended the center) and many had behavior problems (see their characteristics in Table 4.7). The evaluations were carried out during three days and each session lasted around 20 minutes. Every child tested a minimum of three activities chosen by the educator according to the child's capacities and the skills that they wanted to work with (memory, attention or planning).

Table 4.7 Characteristics of the children taking part in the evaluations

Number of children	Characteristics
9	Mild ADHD
9	Moderate ADHD, impulsive, behavior problems
3	Mild ADD
3	Moderate ADD
1	Moderate Asperger
1	Mild intellectual disability

The educators, a NIKVision expert and a psychologist were present in all the sessions. The method of evaluation was participant observation [Cohen et al., 2007], consisting of taking notes during the sessions about the children's behavior and reactions [Kawulich, 2005] since video recording was not allowed. The educators were responsible for observing the children's behavior while playing so that the activities could be stopped or changed if the educator considered that a child was getting tired or too distracted. The NIKVision expert controlled the tabletop and provided the children with the toys for the activities. Finally, the psychologist took notes about the children's particular behavior: if the game was unable to hold their attention, if they did not understand how to continue playing at some point of the game, or if they did not recognize some of the objects.

The activities were tested individually and in groups. First, the children played alone with the activities that could not be adapted to more than one person (Bees, Kraken, and Shopping List), and then they played in groups with the rest of the activities. The Twister and Plumber activities had been specifically designed for groups. However, some of the activities tested in groups, such as Analogies and Sequences, had been designed to be played individually. In these cases, the activities were played in groups by naming one of the children as the group representative, by dividing the children in subgroups, or by taking turns when giving the answer to the activity.

4.3.2 Problems and recommendations

Based on the observations carried out by the evaluators, the following conclusions could be extracted.

The activities and interactions seem to be quite usable for ADHD children: they played with the NIKVision tabletop without any difficulties, individually and in groups. The children showed their satisfaction when playing with it and all of them could complete the activities. Their educators expressed the potentialities of the tabletop: "*it awakens interest and increases motivation and that means that the attention is maintained for more time focused on solving problems*", "*it gets more interaction between children*", "*children enjoyed the joint resolution, learning from each other*".

However, when analyzing the observations, it was realized that some aspects of the activities had to be improved in order to create new activities specifically aimed at children with ADHD: there were several common mistakes made by children regardless of their age and the level of difficulty of the activity. These problems had not been detected in the previous evaluations of the activities with children with developmental delays. The problems detected and the recommendations to avoidthem are presented in Annex 2.

Problems to initially understand the activities.

On several occasions, the children did not pay attention to the audio instructions given by the tabletop and consequently they did not understand what they had to do. As a result, the educators had to go back to the main menu and restart the activity, telling the children to pay attention to the audio instructions. On other occasions, they heard the instructions but these were not sufficiently clear.

R1. Instructions have to be clear and offer the possibility of being replayed.

Problems to identify some toys.

The children sometimes had problems to identify the toys they had to use, either because the shape of the toy was not clear (for example, in *Shopping List* the onion toy was mistaken several times) or because the children did not know the object (in *Analogies* the children did not recognize some of the pictures, for example the ball of yarn).

R2. Objects have to be easily identifiable by the children.

Problems to be aware of the time.

When there was a set time to do a specific task (for example, to memorize something), the activity did not have any kind of countdown and consequently several children let the time pass without doing what they had to do.

R3. When there is a limited time to complete a task, this has to be clearly indicated.

Problems to complete the activities.

Sometimes the children understood what they had to do and what the objective of the game was, but they did not know how to act to achieve this. In such cases, the children often played through trial and error, simply putting the nearest object on the tabletop to obtain some kind of response or hint. When this happened, the educator wanted to begin again and repeat the task, but this was not possible as the whole game would have to have been restarted. Besides, when the children failed a specific task because they had not understood the activity correctly, they also wanted to repeat just that task, and not the whole game.

R4. The educator should be able to control the whole game, including the possibility of repeating every task.

Problems to memorize some elements.

The time to memorize the different elements in some of the games (food in *Shopping List*, position of the monsters in *Kraken*) was too short. In general, it was difficult for the children to memorize more than three elements.

R5. Consider carefully the number of elements to memorize and the time to assimilate them. The time should be established by the educator.

Problems playing in-group

It was observed that children usually became more distracted when playing in groups than individually. While the *Twister* and *Plumber* activities worked well when playing in groups, those adapted to be played by more than one child did not work so well, since they had not been designed for that purpose. In most cases, the children did not collaborate but just competed against each other to see who was the fastest to solve the exercise. Competiveness does not favor the control of the impulsivity, a problem for these children, whereas collaborative play may help them to learn self-regulation and respect for others' rhythms.

R6. The game should be designed to encourage children to interact, fostering joint resolution of problems and not competition.

Finally, despite the limitations revealed in the evaluation of these activities (which were not specifically aimed at children with ADHD), the positive comments from the educators encouraged us to go ahead. However, we realized that in order to develop activities for children with ADHD, a careful design of the activities must be followed. For that purpose, we thought it was essential to analyze in depth the characteristics of ADHD children, considering their shortcomings and potentials, the way they process information and the mediation role that technology and digital games (in this case, the tangible tabletop) should adopt.

These recommendations (R1-R6) were complemented by other coming from the study (made in the context of the JUGUEMOS Project) of information processing in ADHD children and its impact in their learning abilities (R7-R10), and from the analysis of how effective educative mediation should be carried out (R11-R13):

- **R7**. Focus specifically on selective attention and planning.
- **R8**. Design activities that bring cognitive challenges to the children, stimulating their attention and their development potential.
- **R9**. Develop activities that favor reflection on the consequences of their actions, considering alternatives and sharing their points of view with others.
- **R10**. Make the most of the manipulative possibilities of the tabletop as a resource to favor learning, interest, involvement and motivation of the children.
- **R11**.The design of the technological interaction has to facilitate the maintenance of the attention and interest, favoring the regulation of the impulsivity.
- **R12**.The activity should stimulate interaction among peers and with the person that facilitates the mediation.
- **R13**.The technological design has to be flexible and allow positive intervention of the mediator if needed, adapting to the each specific situation of the learning process and of the child's attitude.

The detail of how these recommendations were extracted can be seen in Annex 2. In the next section, the guidelines extracted from these recommendations are presented.

4.3.3 Extracted guidelines

From the previous recommendations, ten guidelines to design tangible activities for ADHD children were obtained [Cerezo et al., 2019]. These guidelines have their origin in the previously identified recommendations.

G1. The level of difficulty of the game should be adaptable.

It is necessary to allow the time and effort needed to fulfill a task to be adaptable to the specific characteristics of the child playing. In particular, the number and type of elements to memorize and the time given to the child to assimilate them has to adaptable and modulated by the educator.

Origin: this guideline is based on the problems identified during the evaluation sessions regarding the elements and the time needed to memorize them. As a result, it was recommended to give children enough time to assimilate the information, allowing the educator to set the time (**R5**).

G2. The objective of the game and how to achieve it have to be clear.

The instructions have to be clear and re-playable and should precisely express intermediate states during the game and final results. The game must allow the child to have all the information relating to the game at any moment to be able to decide and plan.

Origin: this guideline is based on the problems that children had in the evaluation when trying to understand and complete the activities. This could be because they were not paying attention to the instructions (for example, missing audio instructions) or because they did not know how to play because the instructions were not clear. This guideline covers the recommendation of giving initial clear instructions (**R1**), but applies to all the phases of the game.

G3. The game should help the children be aware of the time.

When there is limited time to complete a task, this has to be clearly indicated. Moreover, the time left to complete it should also be indicated.

Origin: this guideline is based on the problem detected in the evaluation regarding the lack of reaction to a limited time: the children, not knowing the time limitation, let the time pass by without doing anything. This resulted in the recommendation of clearly indicating the time assigned to a task, or the time remaining to complete it (**R3**).

G4. The manipulative possibilities of the tabletop should be potentiated.

Interaction with physical objects should be promoted, but it is necessary to adapt these objects to the experience and age of the children. Changes in the object attributes (size, shape, direction, number) should be avoided during the game.

Origin: this guideline is based on the study of children with ADHD (**R10**), and on the problems detected during the evaluation sessions in the identification of certain objects which resulted in the recommendation of paying special attention in designing objects that can be easily identified (**R2**).

G5. The game should be totally controllable by the educator

The educator must be able to freeze the game until certain data is provided, a consensus is achieved, or the child calms down or rests. Moreover, it should be possible to redo an activity either because the child has failed or the educator considers it is appropriate.

Origin: this guideline is based on the study of mediation (**R13**) and on the problems detected during the evaluation when, after completing activities, it was necessary or desirable to play again. The detection of this problem resulted in the recommendation of giving the educator total control over the game (**R4**) to facilitate the adaptation to each child and situation.

G6. The game should promote the search for information and the identification of alternatives.

The search for information should be promoted by the game when players are asked to make a decision. This can be done by asking them to look for information that is relevant for the decision. Even if the answer is correct, the game should ask the children about other ways of performing the task and about the reasons for their action.

Origin: this guideline arises from the analysis of the specific needs of children with ADHD (**R9**) in relation with the improvement of their planning skills, and from the recommendation that the technological interaction should stimulate learning and all the processes involved (**R11**).

G7. Positive and encouraging feedback must always be given.

Positive feedback to correct answers must always be given. In the case of negative answers, visual or verbal feedback should also be given to encourage the child and give him/her the opportunity of repeating the task.

Origin: this guideline arises from certain needs of the children with ADHD (**R13**) related to the need to enhance their feeling of competence, but it is also related to some of the recommendations extracted from the evaluation of the activities, such as allowing tasks to be repeated when needed (**R4**).

G8. Interest and motivation should be maintained through several stimuli.

The stimuli must be chosen taking into account the children's interests and needs, as well as the activities and games.

Origin: this guideline arises from the analysis of the needs of children with ADHD (**R10**), in terms of attracting and holding their attention (**R8**), learning to select the correct stimuli at any moment, and also from the recommendations about orientating technological interactions (**R11**), the interaction with people (**R12**) and the flexibility of the process (**R13**).

G9. Games should enhance selective attention.

Stimuli should be used to focus attention. The game should lead children to focus their attention on a particular characteristic that differentiates one element from all the others.

Origin: this guideline arises from the analysis of the needs of children with ADHD (**R7**), since one of the children's main problems is their lack of selective attention.

G10. The game should promote collaboration to solve the problems.

Children have to be encouraged to interact with others. The game should foster joint resolution of problems.

Origin: this guideline arises from the problems detected during group play in the preliminary study (**R6**) as well as from the analysis of the needs of children with ADHD (**R9** and **R12**) relating to the considerable benefits of social interaction, as well as the need to focus attention and suggest new possibilities.

Having come up with the guidelines, it was decided to apply them to the design of activities for tangible tabletops with the children from Atenciona in mind.

4.3.4 Designing new tangible tabletop activities

As stated in the preceding section, it is essential to allow the educator to have entire control of the activities (G5) and of the time to perform each of them (G3). Therefore, it was decided to add a menu bar (see Fig. 4.20 Left) to facilitate navigation between the activities and the different activity levels. Educators may also use this button to pause the activity if a child requires more time or if it is necessary for him/her to mediate. For example, before beginning to play, the educator may ask the children about the objective of the activity (G2) and motivate the child to explain how he/she will do the activity (G6). It also allows returning to the beginning of the activity (home button) and repeating the instructions. This menu bar was incorporated into both games and is located in the lower part of the screen. The educator can control the menu by means of a couple of new tangible objects (see Fig. 4.20 Right).

All the activities give a positive audio feedback when children perform the task correctly (G7). However, if the children fail, the audio feedback is conceived as a positive reinforcement, encouraging them to repeat the activity and continue playing.

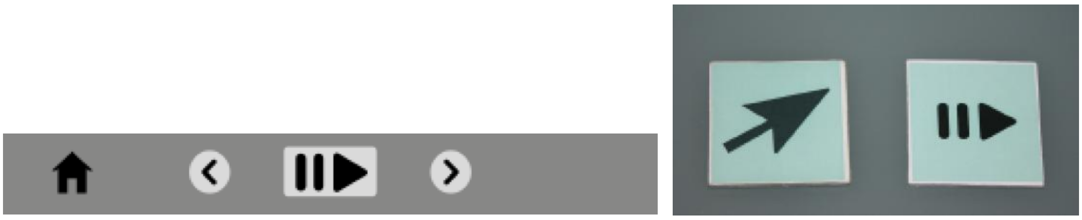


Fig. 4.20 Navigation through activities. **Left**: Menu bar. **Right**: Physical objects for controlling the activities.

The activities developed for ADHD children, called *Shapes and colors*, *Once upon a time* and *Walking around the city*, are presented below. For each one, there is a brief description of the activity, focusing on the guidelines applied, and an explanation of its intervention goals.

4.3.4.1 Shapes and colors

Activity description: *Shapes and colors* is a memory game designed to be played by 2, 3 or 4 children (G10). The educator can choose to let the children read the instructions or to listen to them. At the beginning of the activity, the tabletop surface shows a green grid with several figures placed on different grid positions (see Fig. 4.21 Left). After several seconds (established by the educator - G3), the figures disappear and the child has to remember which figure (and color) was in each square. The physical objects (G4) are bracelets with a picture of a figure or a color (see Fig. 4.21 Right) that have to be worn by the children. The children have to place their hands on the square on which appears the figure with the same shape and color as that shown on the bracelet they are wearing.

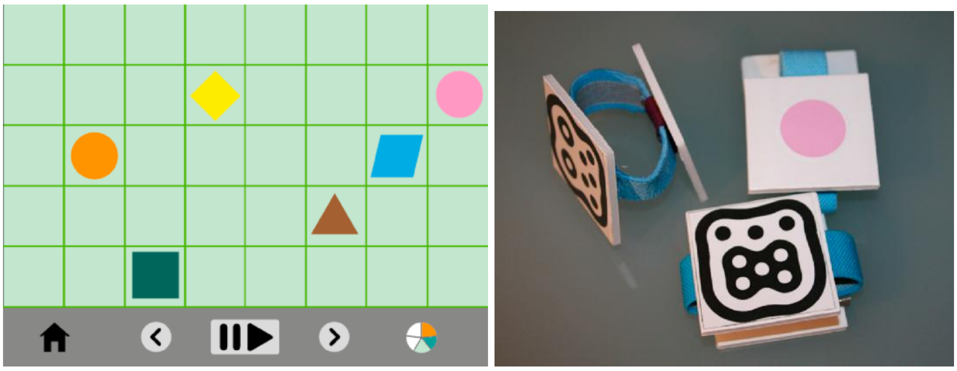


Fig. 4.21 *Shapes and colors* activity. **Left**: Tabletop surface. **Right**: Bracelets used in the activity.

The activity begins with a set of figures with the same shape but different colors. The difficulty of the task gradually increases (G1) by showing different geometrical shapes with different colors (there are 10 levels of difficulty). In all the tasks, there is at least one figure that does not appear on the bracelets and that acts as a "distractor" to foster selective attention (G9). The educator can stop the game at any time (G5) to discuss progress with the children, trying to promote reflection about the achievement of the activity's goal (G6).

Intervention goals: The possibility of using objects attached to the hands instead of a finger to interact with the table allows working abilities such as bilateral coordination (use of the two hands) and the coordination of the upper body. These abilities are essential for daily life, since most of the activities that we do involve the use of both hands. The game helps children to work with their laterality, making them differentiate their left hand from their right hand, since when two children play together each child wears two different bracelets: one on his/her right hand and the other on his/her left hand. The child has to pay attention not just to the figure but also to the hand where the picture is, in order to correctly place the hand on the square.

This game also involves the use of memory, but in a complex manner, since not only a color or a shape but also its location must be remembered. In this way, spatial reasoning is favored, which it is important to potentiate at an early age.

4.3.4.2 Once upon a time

Activity description: *Once upon a time* is a game for improving reading and listening comprehension. As in the previous activity, just before beginning to play the educator can choose between making the children listen to the instructions or read them and they can be replayed as many times as wanted (G2).

At the beginning, two tales are presented on the surface of the tabletop: *The sleepyhead dragon* and *Uga, the turtle* (see Fig. 4.22 Left). The educator will usually choose between the two different stories that the children have to listen to or to read. This game can be played individually or by several children using different toys related to the stories (see Fig. 4.22 Right). In the latter case, the game is performed collaboratively (G10). In contrast to the previous activity in which children have a limited amount of time to finish, in this case children can take all the time they need to read the story and, when they finish, the educator can continue with the activity (G1).

Fig. 4.22 *Once upon a time* activity. **Left**: Tabletop surface. **Right**: Tangible objects used in the activity.

Once the story has been listened to or read (see Fig. 4.23 Left), a set of questions is displayed to see if the children have paid attention to the story (G9) (see Fig. 4.23 Right). In this case, the level of difficulty of the game lies in the questions that are asked about the story (G1). For all the questions there are at least two different answers and the child has to choose the correct one (G9). In order to answer the questions, the tangible playing pieces (G4) are used to indicate the correct answer. When the children respond correctly, a "correct" sound is reproduced. Otherwise, they hear a "wrong" sound followed by a phrase that encourages the children to try again (G7). The game may be stopped by the educator at any time to promote discussion and reflection about the answers given by the children (G6).

Fig. 4.23 Left: Story *Uga, the turtle*. **Right**: Question "Which character gave the turtle good advice?"

Intervention goals: This activity includes written texts that the children can read or listen to, working on reading or listening comprehension, respectively. They must select the correct answers about these texts, so that they must work semantic processing. This semantic processing requires the use of the planning system, the use of previous knowledge, and simultaneous processing. As in other tasks, their attention, and especially selective attention, is essential.

4.3.4.3 Walking around the city

Activity description: the proposed activity consists of a game with different mini-games, each of them aiming to work certain skills and composed, at the same time, of different tasks. As in the two previous games, the educator always has the control of the game thanks to the menu bar, that allows to decide to come back to the menu, to re-play an activity or to pass the next one (G5). This also allows to control the time devoted to each activity (G3). Also, the game was designed to promote the search of information together with the work of selective attention (G6, G9), since those are characteristics that ADHD children usually need to work on.

The game is composed in four different parts:

- Instructions: the background of the tabletop presents the map of a city with different buildings. The children are given hints, through a story, to visit certain places to advance in the game (see Fig. 4.24). This first part of the game can be played individually or in pairs (G10). Each child controls a different character to move along the map (G4). They can choose among four characters the one they are going to control (G8) (see Fig. 4.34 Top-Left). The instructions that appear on the map can be replayed any time by placing an especial object designed to control the menus of the game (G2) (see Fig. 4.28 Top-Right B).

Fig. 4.24 Instructions part. **Left**: "*Since you don't have enough space at home, where is player2 going to sleep? You two go there to leave the suitcase*". **Right**: Player1 (green path) and Player2 (blue path) go to the hotel.

- Riddles: when children pass the first part of the game, a menu with 10 riddles is shown on the tabletop (see Fig. 4.25). The difficulty of the riddles increases with each level (G1). Children have to choose between three options the correct one by using an object designed to select the different answers of the game (see Fig. 4.28 Top-Right A). When children select the correct answer, a green tick appears next to the correct solution and a sound indicating it is correct is reproduced (G7).

Fig. 4.25 Riddles part. **Left**: Menu to select the riddles. **Right**: Example of riddle.

- Order the sentence: in this mini-game, composed also of 10 different tasks, a key is given to the children about certain element related to the first map (see Fig. 4.26). The mentioned element appears on the task but the letters that compose it are disorganized. By using physical letters (see Fig. 4.28 Bottom), children have to order the element. Each time that the children place a correct letter, this one is written on the corresponding place on the tabletop as feedback (G7).

Fig. 4.26 Order the sentence activity. **Left**: Menu to select the task. **Right**: Example of ordering a sentence: "*Place where a great number of travelers come and go*". Key: SOCTIANE; Solution: ESTACIÓN (Station).

- Memory: in this game, two different images are presented to the children (see Fig. 4.27). One of them appeared in the first map of the Instructions part, while the other has been made up. Children have to remember the image that belonged to the map and selected it with the "Selection" object. If the choice is correct, the same as in the Riddle activities a green tick and a correct sound are displayed (G7).

Fig. 4.27 Memory activity. **Left**: Menu to select the task. **Right**: Example of choosing the drawing that appeared on the initial map.

Fig. 4.28 *Walking around the city* toys. **Top-Left:** Instructions part. **Top-Right: a)** Select the answer; **b)** Control the menus. **Bottom:** Order the sentence.

It was decided to add an avatar as a gamification element to encourage children to progress in the activity. When children complete the different games, the avatar appearing on the bottom-right corner level ups, obtaining more accessories (see Fig. 4.29) to indicate that children are completing the game.

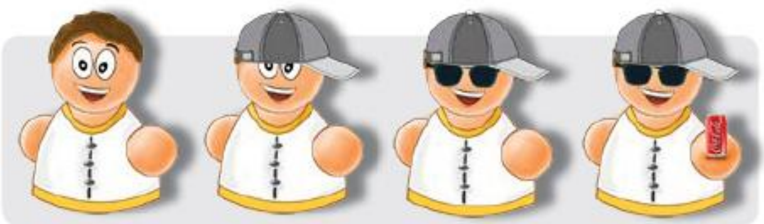


Fig. 4.29 Avatar according to the minigame. **From Left to Right**: Instructions, Riddles, Order the sentence, and Memory.

Intervention goals: the activities were designed in the context of a Master Thesis in Education [Ginés, 2017] to carefully fulfill different psychopedagogical aspects:

- Instructions: planning, correct execution of instructions, the process of waiting for their turn (when two children are playing and one of them has to wait for the other to complete certain instructions), collaborative work.
- Riddles: logical and associative reasoning.
- Order the sentence: selective attention and reasoning.
- Memory: visual memory and perception.

4.3.5 Testing the new activities in Atenciona

Once the activities were developed following the previously explained guidelines, we proceeded to test them at the Atenciona association. The objective of this evaluation was to analyze the usefulness of the applied guidelines and also to detect usability problems in order to refine or adapt the guidelines where necessary.

As in the previous evaluations (Section 4.3.1) the method followed in the evaluation was observational. This time 20 children aged from 7 to 12 participated in this evaluation. The games were played individually, in pairs and in groups, depending on the groups of children that were in Atenciona in the moment of the sessions. The first two games were tested in one session of around 30 minutes. However, since the third game was longer, it was tested in another session. As in the previous session the educators, a NIKVision expert and a psychologist were present. During the observation, notes were taken by the psychologist and the expert on the actions and reactions of the children while playing, focusing on the impact of the proposed guidelines. After the evaluation, the educators were interviewed about their perception of the experience with the new activities and with the new mediation support.

Some conclusions have been extracted from the interviews with the educators and the notes taken during the sessions about the design considerations taken into account when developing the two activities. The conclusions are presented below, including some representative comments extracted from the interviews:

- The game experience was very well received by the educators: "*At first it was difficult for some children to get used to the tabletop, but after some screens they were able to interact with it with ease*" (notes); "*Despite being with a child that didn't stop jumping, apparently not paying much attention, she was able to solve the activities successfully*" (notes).
- The educators made extensive use of the facility to adapt the level of difficulty of *Shapes and colors* (G1): when they saw that children performed the first tasks too quickly, they selected the last ones which were the most difficult.
- The possibility of "traveling" between tasks and of being able to return to the beginning of the activity without having to interrupt and restart the game (G5) saved a lot of time. "*It is good to be able to stop the game and restart it to read the instructions again in case the child has doubts. It is well designed to deal with planning*" (interview). Besides, it also prevents the child from feeling frustrated, since before adding this possibility the child had to repeat the tasks that he/she had already done until reaching the task that he/she wanted to revise.
- The possibility of controlling the game (G5), giving more time when needed, was also appreciated: "*If he is provided with enough time to think, he performs all the activities correctly. He just needs time to think*" (note).
- The opportunity for the children to be autonomous and to be able to decide to read or listen to the instructions again was well received (G2): "*When there are two or three instructions, the child forgets the order and reads the indication autonomously*" (notes).
- The games motivated the children to collaborate: the *Shapes and colors* game cannot be completed until each one of the four children has his/her hand placed on the corresponding square, in the *Once upon a time* game the answer to the question cannot be given until both children discuss the correct answer (G10), and in *Walking around the city* the multi-player option makes children wait for their respective turn and perform some actions together to advance. This last aspect reduced trial and error, since the educator stopped the game (G5) and did not allow an answer to be given until the children had reasoned together (G6). Some positive behaviors were documented: "*The toys are distributed by turns*" (notes), "*Children talk to each other and take a common decision*" (notes). However, some negative behaviors were also noted: "*He is unable to give his partner enough time to think about the solution before answering himself, or in*

case of waiting he does it without stopping shouting: 'Please, I know it, I know it!' and jumping" (notes); "*Children argue about who should control the manipulative toy*" (notes).

- The manipulative characteristics of the tabletop were recognized as a motivating element (G4): "*Working with the tabletop is very interesting since it is something innovative, visual and manipulative*" (interview).

The evaluation has also been useful for detecting some usability problems in the design of the activities:

- Some colors in the *Shape and Colors* activity were too similar and children mistook them when playing. This has to be considered when using color as the stimulus to focus attention (G9).
- The vocabulary used in the *Walking around the city* instructions was sometimes too difficult and the instructions too long, so children stopped listening and/or reading them. This has to be considered when stating the objective of the game (G2).
- The educators (and the children) were sometimes "lost" in the game structure, not remembering the order of the tasks in the games. This has to be considered to make the game more easily controllable by the educator (G5).
- In the *Once upon a time* game legibility problems on the table arose and strong differences in reading comprehension levels among children of similar ages were detected, making the game difficult for some of the children. These problems have to be taken into account when establishing the goal of the game (G2) and its level of difficulty (G1).
- Despite the positive feedback (G7), some children asked the educator for verbal or gestural indications to confirm that he/she had given the correct answer.

These problems have allowed us to extract some additional recommendations to apply the guidelines successfully (in italics):

- **G1. The level of difficulty of the game should be adaptable.**
  It is necessary to be able to adapt the time and effort needed to fulfill a task to the specific characteristics of the child playing. In particular, the number and type of elements to memorize and the time given to the child to assimilate them has to adaptable and adjusted by the educator. Besides, if reading comprehension is involved in an activity it is necessary to introduce an adaptable level of difficulty in the activity. This adaptation can be used for working on the different levels of text comprehension (literal, inferential and critical).
- **G2. The objective of the game and how to achieve it have to be clear.**
  The instructions have to be clear and re-playable and should precisely express intermediate states during the game and the final results. The game must allow the child to have all the information of the game at any moment to be able to decide and plan. *The instructions must be short and the steps clear*. *It is necessary to pay attention to the vocabulary that is used so that children of diverse ages and reading comprehension levels can understand it. Legibility has to be assured.*
- **G5. The game should be totally controllable by the educator.**
  The educator must be capable of freezing the game until certain data is provided, a consensus is achieved, or the child calms down or rests. Moreover, it must be possible to redo an activity because either the child has failed or the educator considers it

appropriate. *To help control the game, it is necessary to indicate which task is being performed at any moment, and its position within the general structure of the game.*

- **G7. Positive and encouraging feedback must always be given.**
  It is necessary to reinforce positive feedback in the case of correct answers.
- **G9. Games should enhance selective attention.**
  Stimuli should be used to focus attention. The game should lead children to focus their attention on a particular characteristic that differentiates one element from all the others. *The use of color as a distinguishing characteristic should be avoided or else colors must be clearly distinguishable.*

The evaluation enabled the detection of strengths and weaknesses of the design and usability of the activities. Additionally, it helped to show the relevant role of the educator to facilitate the development process in the learning and to go further: "*He needs the educator's help to associate concepts*" (notes); "*He associates concepts correctly with the mediator's help*" (notes). This strengthens our idea that technology should complement the educator's role, whose task remains essential.

4.4 Participatory Design Experience with ADHD Children

In order to carry out the Participatory Design (PD) experience we collaborated with Atenciona once again. The objective was to use KitVision so that children could carry out, in group, the whole process of designing and implementing a tabletop game.

4.4.1 Adapting the D4D framework

We found very interesting the proposal of Benton et al. [2014] of the D4D (Diversity for Design) framework and decided to adapt it to the case of ADHD children. Benton et al. give three general recommendations to adapt the D4D framework to neurodiverse children.

4.4.1.1 Understand the culture of ADHD

During our design work for ADHD children we have made use of the PASS Model [Naglieri and Das, 1988] as the theoretical framework to understand their behavior and learning difficulties. The PASS model explains how attention problems have consequences in all the processes involved in learning. In particular, attention can interfere in the planning process. Therefore, not only selective attention but strategic behavior must be worked focusing on the planning process and promoting interaction.

The role of the educator during the interventions is crucial: children should be guided to be able to improve planning and to regulate themselves [Feuerstein et al., 1980]. Combining this theoretical framework with our direct experience designing activities for ADHD children we had come to a set of recommendations when designing activities for them. We realized that a subset of those recommendations (Section 4.3.2 R7-R12) could be translated and applied to the design of the PD experience:

- **R7**. Focus specifically on selective attention and planning.
  <u>PD adaptation</u>: *The necessity of planning the work and concentrate on the successive objectives has to be highlighted to the children.*
- **R8**. Design activities that bring cognitive challenges to the children, stimulating their attention and their development potential.
  <u>PD adaptation</u>: *The session activities should be tailored to the abilities and potential of every child. The mediator should help them to finish their duties to promote their feeling*

of competence. Their hobbies and interests should be taken into account when distributing the activities or defining the elements of the game.

- **R9**. Develop activities that favor reflection on the consequences of their actions, considering alternatives and sharing their points of view with others.
  PD adaptation: *All children proposals have to be considered and analyzed. Alternatives of the initial proposals have to be explored and discussed.*
- **R10**. Make the most of the manipulative possibilities of the tabletop as a resource to favor learning, interest, involvement and motivation of the children.
  PD adaptation: *The game to be designed should make the best of the tangible possibilities offered by the tabletop. The fabrication of physical toys should be one of the activities to be performed by the children.*
- **R11**. The design of the technological interaction has to facilitate the maintenance of the attention and interest, contributing to the regulation of the impulsivity.
  PD adaptation: *The session should contain short activities, each of them with a clear objective to help children focus on it and maintain their interest.*
- **R12**. The activity should stimulate interaction among peers and with the person that facilitates the mediation.
  PD adaptation: *The concept of design team formed by members with different but complementary roles that share a common and discuss their design decisions with the rest. Some of the activities should be performed in group.*

4.4.1.2 Structure the environment and provide support

Additionally to the general recommendations already presented it was decided:

- To include their therapist in the design team to give them appropriate support and make them feel more comfortable.
- To use a visual schedule to present children the sessions structure; at the beginning and at the end of each session a recapitulation of what has been done and what is left to be done will be carried out.
- To incorporate to the initial sessions structured activities focused on building team rapport and skills.
- To incorporate visual design templates to guide the process of generating and documenting individual ideas, and combining these with other design team members.

4.4.1.3 Understand the individual children

Before the PD experience we decided to have a meeting with children families and their therapist to know their specific characteristics, motivation and preferences.

The first step was to install a NIKVision tabletop in the Atenciona association, in one of the rooms that the educators used for their therapies and exercises. After that, we prepared a document in which the participatory design experience was explained, together with an authorization to ask for the families' permission to take pictures, record the sessions, and use the materials in scientific publications, in case some of them preferred that their children were not recorded or the materials published. When that document was ready, the association sent both documents to the families and arranged a meeting with the ones that showed interest in their children participating in the experience.

In that meeting, we showed the NIKVision tabletop together with the activities that had been created up till that date. Also, we explained the different sessions that were going to compose the experience. The parents signed the authorizations after the meeting. All of them gave us permission to record the sessions and to use the material.

A week after the meeting, the therapist of Atenciona sent us the data of the 5 children that were going to participate (see Table 4.8).

Table 4.8 Characteristics of the children taking part in the experience

Gender	Name	Age	Characteristics
M	(R)	9	ADHD, Asperger
M	(A)	11	ADHD, Asperger
M	(D)	11	Impulsivity, Gifted
F	(I)	12	ADHD, dyslexia
M	(F)	14	Hyperactivity, Gifted

After that, the Participatory Design experience began.

4.4.2 Experience

The experience was divided into 5 sessions of 2 hours each, carried out once a week on Fridays from 6 p.m. to 8 p.m. after the children finished their previous activities in Atenciona. Following, each session is described in detail.

4.4.2.1 Session 1: Presentations

Knowing the children that were going to participate, previously to the first session we prepared personalized letters for each child inviting them to the first session, so that Atenciona sent them to the children's parents (see Fig. 4.30).

Also, we prepared five A4 posters to visually represent the different sessions, because one characteristic of ADHD children is that they usually lack concentration and it is necessary to clearly show them the tasks they need to perform in a visual way, so that they know better in which point of the experience they are, what tasks they have already carried out and which ones still remained to be completed (see Fig. 4.31).

Fig. 4.30 Personalized letters. **Left**: girls. **Right**: boys.

Fig. 4.31 Sessions of the experience.

Some children had already played with the tabletop while performing the initial evaluations (Section 4.3.1), but we let them play with it for 30 minutes so that they got used to it and also so that they played together, since among the children just (R) and (A) (who were brothers) knew each other.

After that, we asked them to help us complete a game called *Greetings* (prepared beforehand) by using the KitVision Graphic Assistant, so that they had an initial idea of how it worked. In *Greetings*, the background shows a total of five empty pictures, each one with the name of one of the children written on it (see Fig. 4.32). Also, each child has a personalized object with his/her name on it.

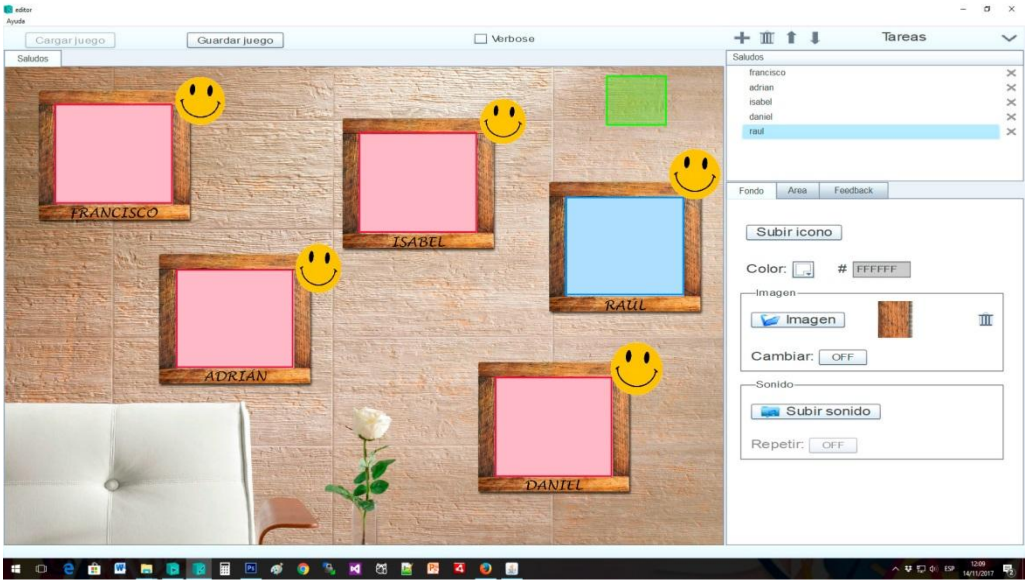


Fig. 4.32 KitVision graphic assistant with *Greetings* game loaded

The objective of the game was that, when children placed their objects on their corresponding picture, an image of them appeared on it and an audio reproduced saying "hello" to the child. The audio had already been prerecorded, but the images had to be taken during the sessions, and the children had to use the Graphic Assistant to add these images and the objects.

Again, with the aim of making the children feel comfortable with each other since they were going to be working together, they were the ones who took the pictures by using the mobile phone of one of the experts present in the session. Four of the five children agreed to take pictures of themselves to include them in the game. The older child, (F), preferred to make a drawing and take a picture of it (see Fig. 4.33).

Fig. 4.33 Background with children pictures

4.4.2.2 Session 2: Brainstorming

In this session the children had to think of ideas about the game. In order to do this, they sat together with their therapist and two experts in order to suggest ideas about possible games to make. Before beginning to draw ideas, the experts showed some games to the children once again so that they could talk about what they liked and did not about them, and also to identify their main elements (areas, toys involved, characters…).

After that, each child was given a template to draw or write two ideas (see Fig. 4.34).

Fig. 4.34 Background with children pictures

(R) and (A), the two brothers, were the only ones who did not manage to come up with any idea in the brainstorming, since they just drew in the templates characters and situations of the last game they had played (*Cuphead*), often getting distracted to talk about things of the game instead of thinking about the one they had to design together. The other three children however managed to come up with different ideas:

- (D) came up with a game in which a spaceship was controlled.

- (I) had two ideas: a rhythm based game and a game where the children had to find a treasure following a map, by completing different mini-games.

- (F) also thought of two game concepts: the same as (I), an idea consisted of following the rhythm of a song, while the other was about helping a character cross the road while avoiding the cars that were racing on it.

The final game concept was completed by choosing ideas from each child: the game would be situated in the space and children would use spaceships to interact with the game ((D)). Since rhythm based games ((I) and (F)) went beyond KitVision's limitation of placing objects in areas, they were discarded. However, we kept (I)'s idea of advancing through the game by completing different mini-games, and adapted (F)'s idea of avoiding cars by having to avoid meteorites using the spaceships. Also, since (R) and (A) had not came up with any ideas, we decided to adapt some characteristics of the game they liked: since the protagonists of *Cuphead* used different weapons to kill the bosses, it was decided that, as children completed mini-games, they would acquire different weapons that would be used to fight the Final Boss.

4.4.2.3 Session 3: Designing the game

Up till this point we had the general idea of the game but we still had to come up with the mini-games that the children had to overcome. It was decided that there would be a total of four mini-games that the children would access by visiting different planets, and the prize for completing each min-game would be a different weapon.

- **Meteorites**: as (F) had suggested in the previous session, the children would have to avoid them while moving the spaceship toy on the tabletop. Since he liked to program animations and he had made some games on his own, he was assigned the task of creating an animation of meteorites. ***Prize***: *Power Blade.* ***Toys involved***: *Spaceships.*

- **Riddles**: we were the ones who prepared this mini-game beforehand and proposed it in order to make the most of the toys we already had, since we just had two hours and making new toys for four mini-games was unfeasible. Therefore, previous to the session we gathered related-space riddles and once in the session children selected the two they liked the most. ***Prize***: *"The Reaper" Axe.* ***Toys involved***: *Letters.*

- **Quiz questions**: this riddle was suggested by (R), (A) and (D). We decided to search questions related to space and the children selected two of them to use in the game. ***Prize***: *Galactic Shotgun*. ***Toys involved***: *Spaceships.*

- **Maze**: this one was suggested by (I), and complemented by (F) who proposed to increase the difficulty making the character memorize the sequence of directions to follow to escape the maze; i.e.: the sequence "right-up-right-down-left" appears for 5 seconds before disappearing, and children have to remember it to escape. ***Prize***: *rocket launcher*. ***Toys involved***: *Spaceships.*

- **Final Boss**: when the four mini-games are completed and the corresponding weapons gathered, they can travel to the final planet to defeat the evil Mr. Meeseeks (a character the children took from the "Rick and Morty" animated science fiction series). ***Toys involved***: *The four weapons.*

After deciding the mini-games, the group was divided into two: (R) and (F) were in charge of drawing the Final Boss and the weapons to be used (see Fig. 4.35 Left) while (I), (D) and (A) created the spaceships using Lego (see Fig. 4.35 Right).

Fig. 4.35 Moments of the third sessions. **Left**: drawing the Final Boss and some of the weapons. **Right**: building space ships with Lego

When the spaceships were finished, (D) asked us to write the script of the game (the initial narration explaining the story and the ones explaining each mini-game). Meanwhile, as (F) and (R) finished the drawings, (I) and (A) adapted the weapons that had been already made so that they were recognized by the tabletop. To do so, we gave them some foam bases that we had prepared before the session to glue the corresponding fiducials and the weapons/spaceships to them (see Fig. 4.36).

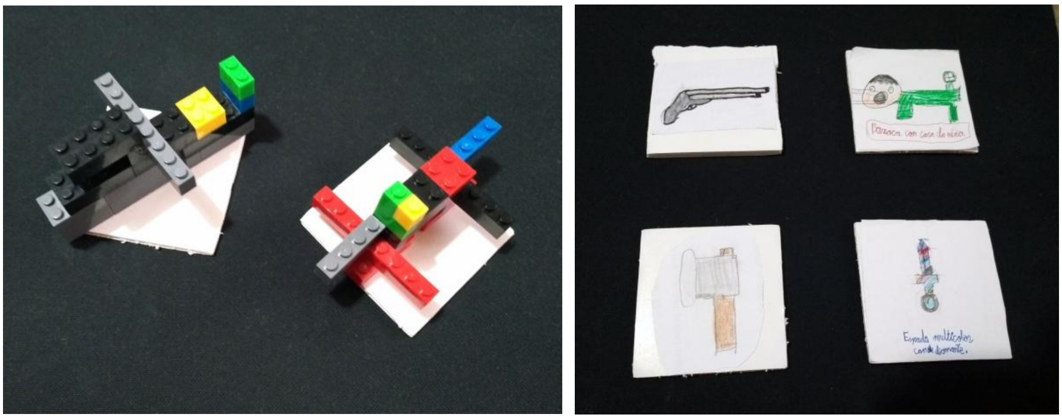


Fig. 4.36 Toys created during the session. **Left**: spaceships. **Right**: weapons for the minigames.

4.4.2.4 Session 4: Implementing the game

Previous to this session, we prepared the graphical resources that the children would be using on the game because in a single session it was unreal that they selected the resources as well as implementing the game.

(I) was the only one who could not assist to this session, so the four boys were divided into two groups (see Fig. 4.37). Since the two brothers would easily be more distracted if they were together, we decided to put (R) with (F) together, also because (R) was the youngest and (F) the oldest and therefore he could control (R) better.

Fig. 4.37 Using KitVision graphic assistant to complete the game

- **Meteorites**: since this game consisted of an animation, children just had to select it and set is as a background (see Fig. 4.38 Top-Left). They created then an area surrounding the whole surface and, finally, assigned the fiducials corresponding to the spaceships (1 and 2) to the defined area.

- **Riddles**: the background showed a riddle with the answer missing some letters. The children had to create the areas corresponding to the missing letters and assign them the fiducial associated to that letter (A=0, B=1, C=2, … , Z=26) (see Fig. 4.38 Top-Right).

- **Quiz questions**: in this mini-game a question with four possible options appeared. In this case the children could choose to create four areas, being one of them correct and the other three incorrect, or just to create the area corresponding to the correct answer. The groups composed of

(R) and (F) chose the first option while (D) and (A) chose the second (see Fig. 4.38 Bottom-Left). The fiducials that needed to be assigned were, again, the ones of the spaceships.

- **Maze**: in this one, the areas to be created had to be the squares that the ship had to visit in order to escape from the maze, and to assign them again the fiducials glued to the spaceships (see Fig. 4.38 Bottom-Right).

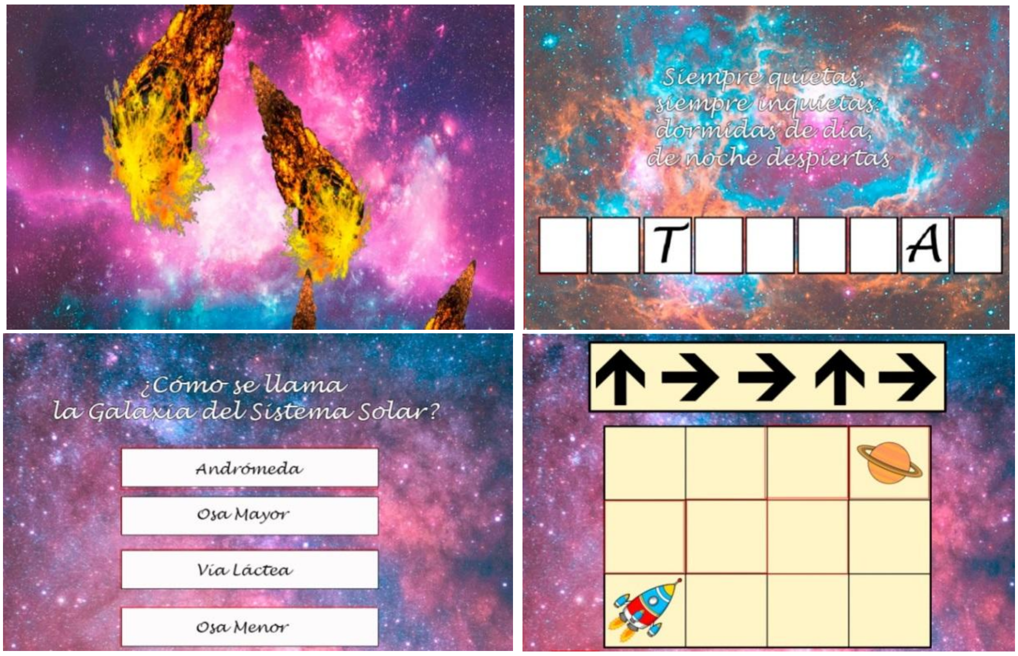


Fig. 4.38 Mini-games. **Top-Left**: Meteorites. **Top-Right**: Riddles. **Bottom-Left**: Quiz. **Bottom-Right**: Maze.

The final mini-game, which consisted of defeating the Final Boss, could not be made yet because (F) was in charge of designing it and he could not finish in time for this session, so we completed this final stage when he later sent us the drawings (see Fig. 4.39).

Fig. 4.39 Final Boss. **Left**: Mr. Meeseek about to fight. **Right**: Mr. Meeseek defeated

4.4.2.5 Session 5: Testing the game

In this last session, we gathered the children and their families so that the children explained themselves the game that they had made. (see Fig. 4.40).

Fig. 4.40 Testing the game.

After they tested it, we asked the children and the parents to fill different questionnaires based on a 5-points Likert scale regarding the Participatory Design experience. The questionnaires were anonymous.

- The children were asked 15 questions regarding the experience: for example, if they had felt nervous during the sessions, if their ideas had been taken into account for the game, if they have got along well with the rest of the children and if they would recommend the experience and would be willing to participate in a similar one (see Table 4.9).

- The parents were asked 5 questions. The score for each question can be seen in Figure 4.41:

1. If their children had talked about the experience with them at home.
2. If their children felt motivated when they came to the sessions.
3. If their children felt happy when they left the sessions.
4. If they had noticed any positive changes in their children's attitude
5. If they thought the experience had been positive for the children.

Also, they were asked if they would change/add something to the sessions. Two families answered that they would have liked longer sessions: "*children were left wanting more*". Also, another family said that they would have liked sessions with more complexity.

Table 4.9 Children's questionnaire results

CHILDREN Global evaluation (max 100)					**MEAN**
63.33	75	86.66	88.33	96.66	*80.22*

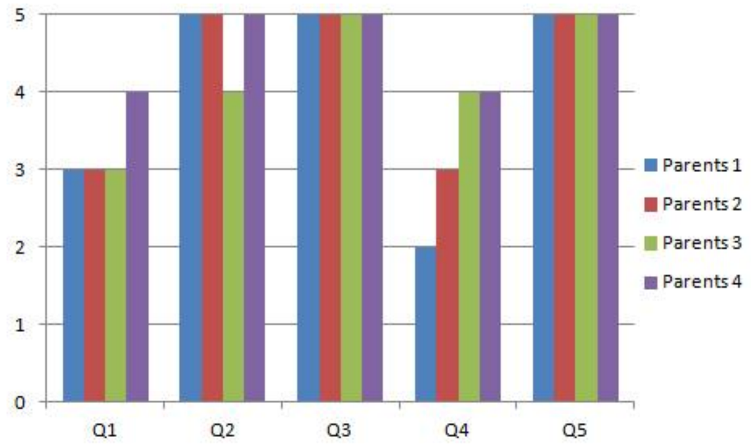


Fig. 4.41 Parents' questionnaire results.

Finally, we also gathered relevant information in our talk with the therapist. After each session we held a small meeting with the therapist to assess the session. She also shared what the families had told her during the week about their kids. Here are some of those comments.

Just after the first session the therapist commented that she saw the kids very motivated and participative but still quite expectant and worried about failing (especially (D)). In the second session (I), who was usually inhibited, became quite active trying to integrate all her mates' ideas. (D) remained shy but began to work. In fact, after the first session their parents observed a change of attitude: he accepted to do a school project he had refused to do during several days and that week he obtained a good mark in an exam (he was quite unmotivated and usually got bad marks). In the third session they were all quite talkative, and they helped each other and collaborated to accomplish the different tasks. After that session the parents of (F) commented he had accepted to join the football team and that they were quite surprised. All the families commented they saw their kids quite happy and wanting to participate in the next session.

The therapist was also asked if she thought that the experience had been positive for the children, if it had managed to keep the children's attention, if their behaviors had been good, if it had helped to stimulate the children's imagination, and if the children had felt motivated with the experience. The therapist also filled the question "What aspects of the children do you think the experience had helped to work?", giving the following answer: "*Creating a videogame was the main motivation, being able to make it day by day has made possible that they were involved actively in all the steps. The changes of activity had allowed them not to get bored and distracted. All the proposals were accepted and included in the game, there wasn't any direct criticism to them, neither between the group members, which made them have a sense of belonging to the group. Seeing the advances in each session made them aware of what they were creating, which enhanced their imagination, attitude and effort.*" Also, she commented that she would have liked a couple of more sessions to be able to better select the resources and record the audios involved in the game, since these ones were added later because of lack of time.

The results showed that everyone was satisfied with the experience and willing to participate in another one in case it was performed.

4.5 Contributions Related to Chapter 4

Bonillo, C., Baldassarri, S., Marco, J., & Cerezo, E. (2017). Tackling developmental delays with therapeutic activities based on tangible tabletops. *Universal Access in the Information Society*, 1-17.

Bonillo, C., Cerezo, E., Baldassarri, S., & Marco, J. (2016a, September). Tangible activities for children with developmental disorders. In *Proceedings of the XVII International Conference on Human Computer Interaction* (p. 9). ACM.

Bonillo, C., Cerezo, E., Marco, J., & Baldassarri, S. (2016b). Designing Therapeutic Activities Based on Tangible Interaction for Children with Developmental Delay. In *International Conference on Universal Access in Human-Computer Interaction* (pp. 183-192). Springer, Cham.

Cerezo, E., Coma, T., Blasco, A. C., Bonillo, C., Garrido, M. Á., & Baldassarri, S. (2019). Guidelines to Design Tangible Tabletop Activities for Children with Attention Deficit Hyperactivity Disorder. *International Journal of Human-Computer Studies*.

CHAPTER 5:

THE JUGUEMOS TOOLKIT FOR INTERACTIVE SPACE HYBRID GAMES

5.0 Chapter Introduction

One of the main objectives of this Thesis was to develop a toolkit that facilitated the creation of hybrid games for an Interactive Space [Bonillo et al., 2016c][Bonillo et al., 2019b] built in the context of the JUGUEMOS Project (TIN2015-67149-C3-1R). The toolkit should support different interaction styles including the tangible. Therefore, the ToyVision toolkit [Marco et al., 2012], aimed at the development of tangible tabletop games, was the starting point. The author of this Thesis was familiar with ToyVision as she had used it to develop tangible music activities in the context of another research project [Baldassarri et al., 2016].

The structure of the chapter is as follows:

Section 5.1 describes the JUGUEMOS Interactive Space that served as the base to develop the toolkit.

Section 5.2 outlines the design decisions that were taken to develop the toolkit.

Section 5.3 explains the TUIML model used to design the games for the JUGUEMOS Interactive Space.

Section 5.4 presents the general architecture of the toolkit.

Section 5.5 thoroughly explains the implementation of the toolkit by describing the way to address the three challenges when developing hybrid games, and which were extracted in the Chapter 2 of this work.

Finally, section 5.6 presents two game prototypes developed with the JUGUEMOS toolkit in the two research stays performed by the author.

5.1 JUGUEMOS Interactive Space

The JUGUEMOS IS is an indoor area of 70 square meters. It has been designed with no specific applications in mind, but as a hybrid-game laboratory to support the exploration and prototyping of innovative interactive games that blends both physical and virtual game elements. Figure 5.1 shows a schema of the IS:

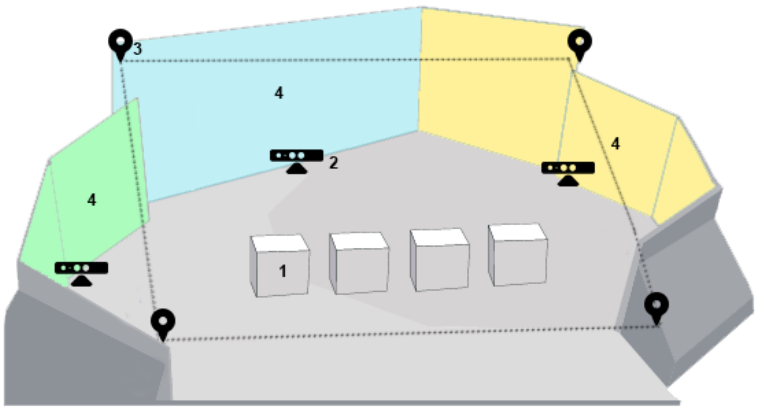


Fig. 5.1 Interactive Space configuration. **1**) Tabletop devices. **2**) Kinect sensors. **3**) Real Time Localization System. **4**) Video projection on walls.

We can distinguish two types of elements that compose the IS: ubiquitous technologies and multiple displays. Regarding the ubiquitous technologies, the IS integrates a set of sensor devices that allow different ways of interactions:

- **Four tabletops**: Tangible tabletops are digitally-augmented active tables capable of displaying images on their surface, and capable of sensing both finger and objects placed on them. The four tabletops can be spatially composed depending on the specific IS application requirements, and also more tabletops can be added at any moment. The recognition of objects on the table surface is provided by the use of ReacTIVision fiducials.
- **Three Kinect sensors**: They are used to make active the walls surrounding the IS area. Kinect sensors allow to track the movements of users situated in front of the walls. Also, thanks to the integrated microphone sensor, the users' voices can be detected.
- **A Real-Time Localization System (RTLS)**: this sensor tracks the users' position on the IS area. It is based on the use of small active RF beacons whose position is triangulated by four sensor receptors placed on the IS corners.

This is our initial technical configuration of the IS; however, other kind of sensors devices can be integrated in case a specific application requires to detect other users manipulations (e.g. tactile surfaces, cameras, biometric sensors, etc).

Regarding the display devices that can be found in the system, the IS has three video projector screens that cover the surrounding walls. Also, tabletop devices display images on their surface. Furthermore, other display devices can be integrated as requirement of specific applications; e.g., mobile, tablet or other portable screens, LED matrix, etc. The IS also provides audio feedback on all the IS area, and on each tabletop device.

We have just described the different elements of the current configuration of our IS. However, we want to stress the importance of having a flexible IS configuration in which new ubiquitous and display technologies can be integrated at any moment as required by the specific hybrid game, since this has been one of the main objectives that has driven us in the design of the toolkit.

5.2 Toolkit Requirements and Design Decisions

The JUGUEMOS toolkit architecture has been designed with the following requirements in mind, related to the challenges extracted from the state of the art:

1. To allow the easy integration of multiple devices.
2. To facilitate the coding of the game application.
3. To support the management of multiple displays.

Regarding the first requirement, the solution lies on the use of a standard communication protocol between devices of very different hardware characteristics. In the first part of the state of the art, when analyzing how the hybrid games had been created we realized that, among the works that gave details about the communication protocol that they used, there were some that used the OSC Protocol and the TUIO Protocol (also based on OSC). As we have commented briefly before, OSC is a protocol for networking multimedia devices that has been adopted and incorporated in several development environments aiming physical computing, such as Processing [2001], a flexible software aimed to code within the context of the visual arts, Pure Data [1996], an open source programming language specialized in visual and sound based applications, or vvvv [2014], a programming environment designed to facilitate the handling of large media environments with physical interfaces. Also, the TUIO protocol was built on OSC in order to allow the transmission of messages between tangible multitouch surfaces. Besides these programming environments, there are many other tools that make use of OSC (and TUIO) to isolate the hardware details of the system from the development of the interactive application, such as ReacTIVision, a toolkit focused on vision based sensors that simplifies the tracking of conventional objects by only requiring attaching a printed marker on the object, and KinectOSC [2015], an utility to transmit data from official Microsoft Kinect SDK via OSC, facilitating the way to deal with the diverse Kinect messages by adopting a simpler format. After seeing that existing toolkits made use of OSC for interconnecting very different applications, we decided to adopt it in our toolkit and to use Processing to implement the whole toolkit due to its facility to implement OSC connections.

Regarding the second requirement, the development of tools that allow an easy and rapid prototyping of applications is not a trivial matter, due to the low-abstraction level of the data received from the ubiquitous technologies, and the impact in the code when changing the interaction methods. For this reason, the solution to facilitate the prototyping of applications is to allow the development of prototypes in a high-abstraction level, reducing this way the gap between the definition and the development of the application. Several works that focus on the definition of ubiquitous technologies in a high-abstraction level can be found in the literature: Shaer et al. [2004] present in their work the Token and Constraint (TAC) paradigm for describing and specifying tangible user interfaces, and Hornecker and Buur [2006] created a model with four different categories that allow to better understand, define and analyze Tangible interactive applications. However, these last works are focused on helping designers by providing them with means to define the physical interactions that are carried out in a Tangible system, but they do not address the development process. Yet, in order to allow a rapid prototyping of applications, it is necessary a model that facilitates the work of developers. As we have commented before, TUIML addresses this necessity, not only allowing designers to define the system by using the TAC paradigm, but also proposing a way to translate the application concept into a language understandable by a computer. For that reason, some toolkits have make use of TUIML and the TAC paradigm, such as ToyVision [Marco et al., 2012] and Anyboard [Mora et al., 2015], which have been already analyzed in the state of the art section. Until now, TUIML had only been used in the field of Tangible Interaction, so it could seem at first glance that TUIML would fail short when trying to define hybrid games for interactive spaces. However, after analyzing it we realized that, despite certain limitations that will be commented later, TUIML could also be extended to other kind of interactions apart from the Tangible one, so we adopted it as a model for the JUGUEMOS toolkit.

Finally, regarding the third requirement, hybrid games that are played in interactive spaces where multiple interaction paradigms converge require to show information in very different displays, such as projection screens, mobiles, tabletop surfaces, or even the floor itself. For that reason, in order to be able to distribute the game’s visual information in multiple displays easily, we decided to ground our work on the Virtual Space topology paradigm [Nacenta et al., 2005]. In this paradigm, the interactions between the different displays are limited and determined by a virtual space that covers all the physical displays involved in the system. Also, whenever it is necessary to show information related to a specific device, each one of them provides a viewport into this virtual space that corresponds to the actual physical display where the information must appear. In a later section we will explain in more detail how this Virtual Space paradigm was adapted in our toolkit.

5.3 Abstraction Model: TUIML

It has been already commented that in order to allow a rapid prototyping of applications, a model that facilitates the work of both designers and developers is necessary.

TUIML [Shaer and Jacob, 2009] addresses this necessity, allowing designers to define the system by using the TAC paradigm, but also proposing a way to translate the application concept into a language understandable by a computer. TUIML syntax is composed of three different elements:

- **Token**: any physical element that appears in a TUI.

- **Constraint**: a physical restriction that a token imposes to the manipulation of another token, called **Subtoken**, of the first one.

- **TAC** (**T**oken **A**nd **C**onstraint): a conceptual structure used to describe the status of a subtoken in a specific instant of time. This status is defined as the relation of that subtoken inside the constraint of a bigger token. The TAC structure can be easily used to describe the current status of a board game.

TUIML hierarchy can have multiple levels, so subtokens can also have associated constraints: i.e., the playing pieces (subtokens) can have associated constraints on which other playing pieces (subsubtokens) can be manipulated (see Fig. 5.2).

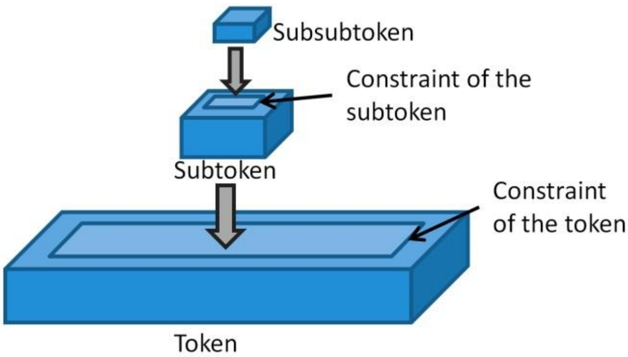


Fig. 5.2 Representation of TUIML hierarchy between Tokens and Constraints

This hierarchy can be easily used to describe the current status of a board game. For example, in the Chess game the board itself is a **Token** divided in **64 different Constraints** that imposes that each constraint may or may not content a Chess playing piece, the **Subtoken** (see Fig. 5.3); or, in other words, placing a playing piece outside the squares has no meaning in the game. The status of a Chess game at a specific moment can be described as a list of TACs; each TAC describing which playing piece (Subtoken) is placed on which cell (Constraint) of the Board (Token).

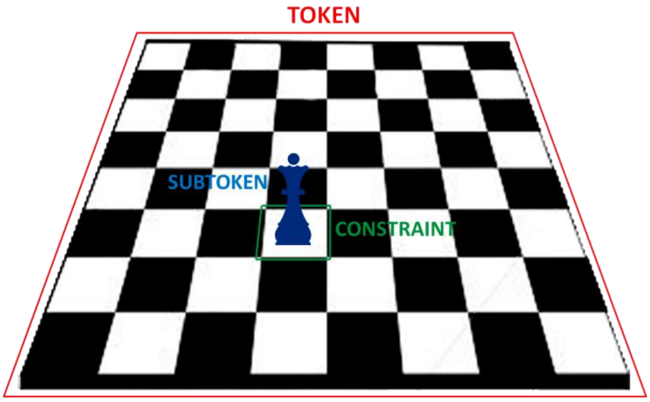


Fig. 5.3 Chess game defined with TUIML

In order to describe the states of the different elements in a TUI in a specific time instant, a **TAC palette** is used: each TAC of the TAC palette describes a different relationship between two tokens through a constraint. Digital variables bounded to a TAC are used to represent physical properties of the subtoken inside the constraint. The TAC paradigm defines constraints as mechanical restrictions to the manipulation of tokens: physical manipulations take place in the 3D space, so constraints are defined as regions in the space. They can be classified according to the number of dimensions they enable the subtokens to be manipulated, as 0D (Dimensions), 1D, 2D, and 3D. Depending on the number of dimensions of a constraint, this one enables a different set of physical manipulations. In the tabletop particular case, the manipulations stop in the 2D, since the playing pieces are manipulated when being in direct contact with the tabletop surface (see Fig. 5.4).

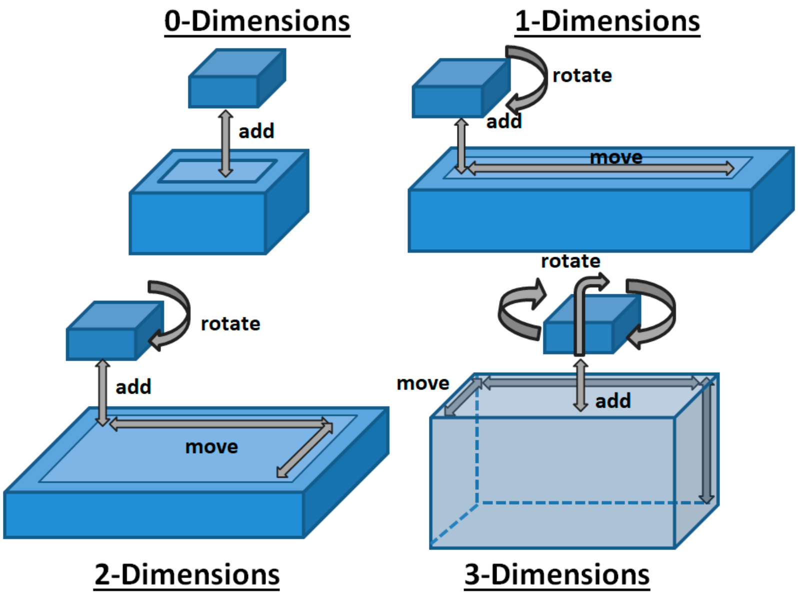


Fig. 5.4 Manipulations according to the dimension of the Constraint

- **0-Dimension**: Subtokens can only be manipulated inside a 0D constraint by inserting or removing the subtoken into/out of the constraint. Therefore the digital variable associated to a TAC describing the status of a subtoken inside a 0D constraint is binary: “true” if the subtoken is in the Contraint (add manipulation) and “false” if the subtoken is not in the Constraint (remove manipulation).

- **1-Dimension**: Subtokens can also be added/removed into/out of a 1D Constraint, but also, subtokens can move and rotate along the constraint. Therefore the digital variables associated to the TAC constraint are a binary value (add "true/false"), a numerical value defining the relative position of the subtoken inside the constraint (move), and a numerical value with the orientation of the subtoken (rotate).

- **2-Dimension**: Subtokens can also be added/removed into/out of a 2D Constraint. Moreover, subtokens can move in two space coordinates, as well as rotate. Therefore the digital variables associated to the TAC constraint are a binary value (add "true/false"), a 2D vector value defining the relative position of the subtoken inside the constraint (move), and a numerical value with the orientation of the subtoken (rotate).

- **3-Dimension**: Finally, subtokens can also be added/removed into/out of a 3D Constraint. This time, subtokens can move in three space coordinates, as well as rotate. Therefore the digital variables associated to the TAC constraint are a binary value (add "true/false"), a 3D vector value defining the relative position of the subtoken inside the constraint (move), and a 3D value with the orientation of the subtoken (rotate).

5.4 Architecture Description

Figure 5.5 sketches the toolkit architecture.

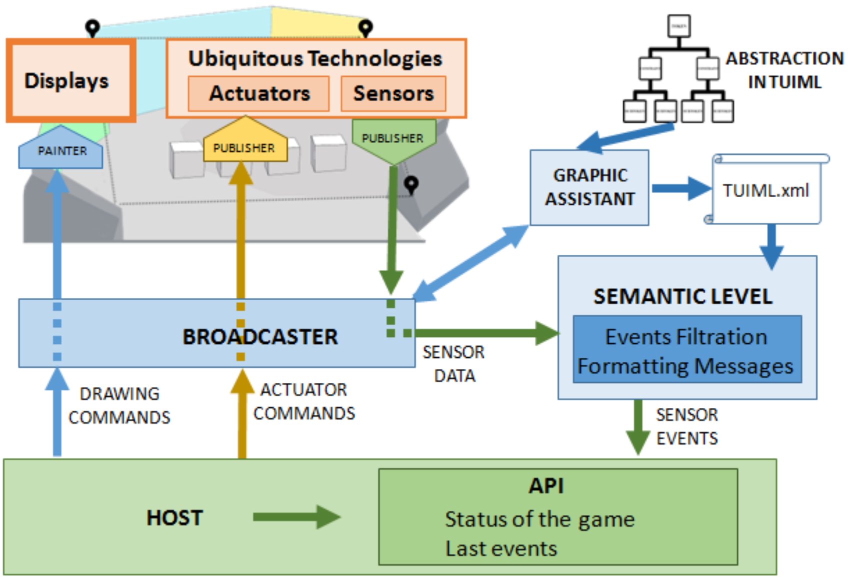


Fig. 5.5 Toolkit architecture.

The JUGUEMOS toolkit is based on a centralized network architecture in which a software **Broadcaster** is individually connected to the **Host** application and to each of the hardware devices integrated in the IS (display, sensor or actuator). Each device has a software process associated in charge of dealing with the specific hardware issues:

- Each **display** device has a "Painter" software process associated in charge of painting visual information or playing audio streams in the specific display device.
- Each **actuator** device has a "Publisher" software process associated in charge of sending commands to the corresponding hardware actuator. Actuator devices are

capable of performing physical actions perceptible by the users (e.g., object movements, turning on/off lights, etc)

- Each **sensor** device has also a "Publisher" software process associated in charge of processing and interpreting the raw data captured by the hardware sensor.

Communication between the devices and the Broadcaster is based on the OSC Protocol. Therefore, all devices of the IS are connected to a local network by Ethernet or Wi-Fi. The Broadcaster keeps an UDP network socket with each device and with the **Host** (the application in charge of managing the game logic). The Broadcaster is used as a central network distribution node in the IS network: on the one hand, it redirects the commands that are sent by the Host to the displays and actuators; on the other hand, it redirects the data of the sensors to the **Semantic Level**. This latter process is in charge of interpreting the data sent by the sensors in a high abstraction level. As previously noted, the JUGUEMOS toolkit uses the TUIML modeling language to **abstract the data** received from the sensors as meaningful physical manipulations of players in the context of a specific hybrid game. In order to do this, the Semantic Level needs to previously "know" the context of the game that is running on the IS. Once the game is being defined in TUIML terms, the **Graphic Assistant** allows to translate this model into an XML file (**TUIML.xml**). The Graphic Assistant is also directly connected to the Broadcaster in order to visually show all the Publishers and Painters connected to it, and also the elements detected by the different ubiquitous technologies in real time, so that it is easier for the developer to define the TUIML.xml file. The data written on this file allows the Semantic Level to filter and process the sensor data in the context of the game, keeping an updated status of all the physical elements involved in the IS during the game.

Game developers will be in charge of implementing the Host application; therefore, they need to access this updated status in order to make evolve the game logic (as response of players' physical actions). For that purpose, the developers use an **API** that provides several functions to consult the status kept by the Semantic Level. That way, the development of the game is completely isolated from the hardware details of the IS. Also, it was decided to separate the Semantic Level from the coding of the game so that developers can code the game in any computer language, as far as an OSC socket could be implemented. At this moment, we have an API implemented in the Processing Programming Environment, but the API can be easily translated into other programming environments.

The creation of the JUGUEMOS toolkit was an iterative process in which we incrementally developed and added new tools according to the requirements that have been commented at the beginning of this section. Next we will explain this process in detail.

5.5 Implementation

The creation of the JUGUEMOS toolkit was carried out iteratively in three different stages that correspond to the three requirements explained in the Chapter 2 of this Thesis. In each stage, an example of use to show the fulfillment of the requirement was carried out in the JUGUEMOS IS, an IS built in the ETOPIA Arts and Technology Center in the city of Zaragoza (Spain) thanks to a national research project.

5.5.1 Stage 1: Integrating heterogeneous devices

This first stage is related to the first requirement, consisting of carrying out the integration of very different and diverse displays by making use of the OSC Protocol (see Fig. 5.6).

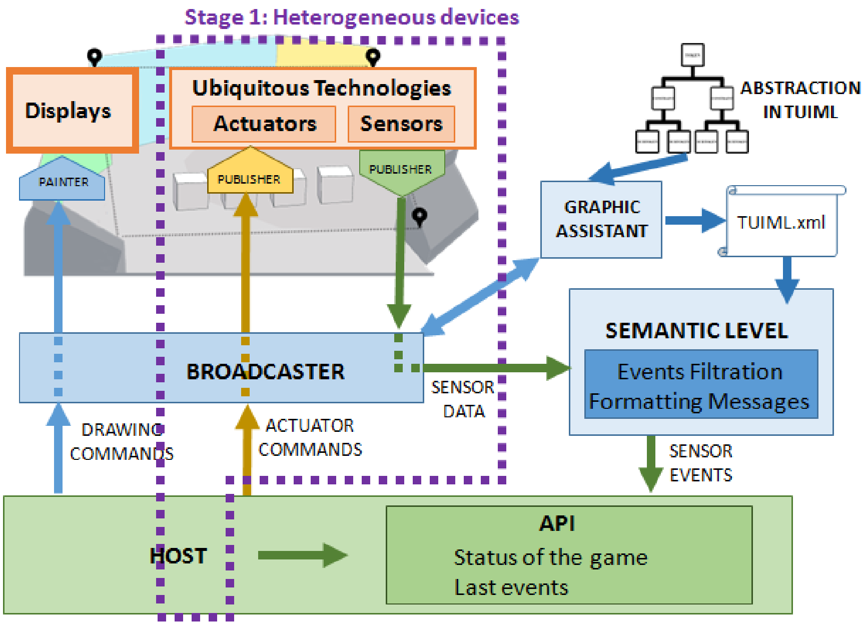


Fig. 5.6 Stage 1: Integration of heterogeneous devices

Each electronic device (sensor, actuators and displays) needs a software process (painters and publishers) implementing a standardized communication protocol with the Broadcaster process, using a common format of OSC messages. The Broadcaster is a software process that runs on a computer with a unique IP address. The Broadcaster opens a network port (i.g: 32000) to listen to the “Publisher” managers. In order to communicate with the Broadcaster, each painter and publisher process has to send the Broadcaster an OSC message indicating the kind of device that is connecting (actuator, sensor or display) in the OSC address, and the port number in which the device will listen to the OSC messages coming from the Broadcaster (see Table 5.1).

Table 5.1 OSC Message format to connect to the Broadcaster

Address (string)	Port (int)
actuator/connect	value
sensor/connect	value
display/connect	value

That way, the Broadcaster can keep a list of all the devices connected, and it is able to receive and send OSC messages to any particular device, to a group or to all the connected devices (see Fig. 5.7).

Once the connection is established, sensor publishers can send OSC messages to the Broadcaster with the data captured by the sensor hardware; actuator publishers can receive OSC messages from the Broadcaster with commands to be performed by the actuator hardware; and painters can receive OSC messages with paint commands to be drawn (image displays) or played (sound devices) in the display hardware. All the devices carry out the connection in the same way as showed in Figure 5.8. The only difference is the value of the variable **type** that is “sensor”, “actuator”, “display” or “host” depending on the device that is connecting.

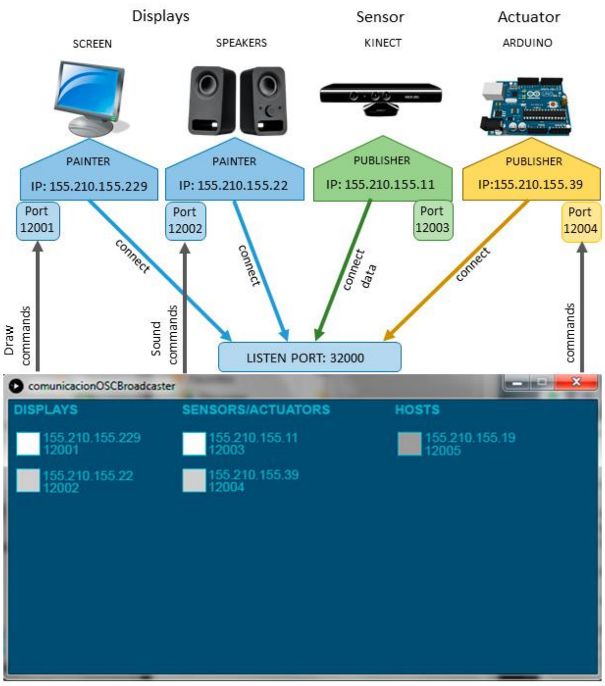


Fig. 5.7 List of devices connected in the Broadcaster

```
OscP5 oscP5;
NetAddress myBroadcastLocation;
String remoteIP="155.210.155.1"; // IP address of the Broadcaster
int listenPort=12000;  // Port in which the "Publisher" manager listens
   // to the Broadcaster messages
oscP5 = new OscP5(this,listenPort);
myBroadcastLocation = new NetAddress(remoteIP,32000);
OscMessage m;
String address="/" + type + "/connect";
m = new OscMessage(address,new Object[0]);
m.add(listenPort);
oscP5.send(myMessage, myBroadcastLocation);
```

Fig. 5.8 Processing code to connect to the Broadcaster

The "Publisher" managers associated to sensor devices store one or several variables that correspond to the physical magnitudes that the sensor tracks. These physical magnitudes are characterized by the number of dimensions that they need in order to represent the numerical value that has been tracked:

- **0D**: the tracked value is binary (1=true/0=false); e.g.: a sensor button has two states: "on" and "off".
- **1D**: the sensor tracks a numerical value; e.g.: a micro sensor that captures the audio volume.
- **2D**: the sensor tracks a bi-dimensional vector; e.g.: a sensor that track 2D position of objects on a surface

At this moment, our toolkit is limited to 2D sensors for simplicity, but it can be upgraded to support 3D sensors. Also, each dimension has a certain set of associated manipulations:

- **Add**: a new object has been tracked in the IS (value1 argument is 1), or has stopped being identified (value1 argument is 0).
- **Move**: an object that has been previously identified has moved inside the IS. The value1 argument is the new value of the object if the dimension is 1D, and (value1, value2) is the bi-dimensional vector if the dimension is 2D.
- **Rotate**: an object that has been previously identified has rotated. value1 is the new angle of the object

Sensors categorized as 0D have just the "add" manipulation, since they just allow two different status (button that is "on" or "off", object that is "placed" or "removed"), while 1D-sensors and 2D-sensors have the three of them.

The format of the OSC messages to send messages between the different "Publishers" and the Broadcaster is shown in Table 5.2. The **address** of the OSC message indicates the name of the device and the dimension of the data that it is going to be sent. The **manipulation** is also indicated as an argument. All numerical values are normalized between 0 and 1 with the exception of the rotate **values**, which are ranged between 0 and 2π radians. Finally, the rest of the arguments are the **ID**, which corresponds to the name of the object that has been manipulated, and **SessionID**, which is the copy number of the object that has been manipulated, enabling this way to track identical objects (same ID) individualized by the "session ID". Also, the structure of the messages that the Broadcaster sends to the "Publisher" managers of the actuators is the same as the one explained in Table 5.2 changing the first parameter of the address with "actuator" instead of "sensor".

Table 5.2 OSC Message format of the sensors

Address	Manipulation	ID	SessionID	Value1	Value2
/sensor/0D/device_name	add	-	-	0/1	
/sensor/1D/device _name	move rotate	- -	- -	0 to 1 0 to 2π	
/sense/2D/device _name	move	-	-	0 to 1	0 to 1

Integration example

In order to prove that our Broadcaster network worked, the *Butterflies* game was developed. In this game, the sensors involved were:

- A Real-Time Localization System (RTLS) to track the children's position on the IS area thanks to small active RF beacons that they wear hanging around their necks, and whose position is triangulated by four sensor receptors placed on the IS corners.
- A microphone, in order to detect when children are shouting.

Regarding the displays involved, a projection screen was in charge of showing an animation with several butterflies flying. While children are quiet, the butterflies fly around until they eventually land on the flowers. However, if children shout, the butterflies that are closer to the children get scared and fly away from the children (see Fig. 5.9).

Fig. 5.9 Child scaring butterflies in one projection screen

In *Butterflies*, the child's meaningful manipulations are to walk in front of the projection screen next to the butterflies, and to shout in order to scare them. Table 5.3 shows the OSC messages that must be generated by the sensors "Publishers" to carry out this game logic.

Table 5.3 OSC messages that the sensors send for *Butterflies* game

RTLS					
Address	Manipulation	ID	SessionID	Value1	Value2
/sensor/2D/RTLS	move	RF beacon	0	x	y
MICROPHONE					
Address	Manipulation	ID	SessionID	Value1	Value2
/sensor/1D/micro	move	0	0	[volume]	--

The ID corresponds to the id of the RF beacon that the child is wearing in order to be detected by the RTLS system. Since in our case we do not have more than an RF beacon with the same ID, it is not necessary to differentiate copies of the same ID, so the SessionID field is 0. T Likewise, the microphone just detects noise but is unable to differentiate voices, so its IDs and SessionIDs will be always 0, which may difficult the creation of certain games where it is necessary to know when a specific child is speaking or shouting.

Also, to test whether the format of the OSC messages was flexible enough to deal with heterogeneous devices, we developed another version of the *Butterflies* game that used a sensor different from the microphone. In this new version, we used a *Muse* band [2018], an EEG sensor that measures the concentration and relaxation of the user. In this case, while the user remains calm or is not concentrating, the butterflies stay on the flowers. However, when the user gets nervous or concentrates, the butterflies run away from him/her (see Fig. 5.10).

Fig. 5.10 Butterflies run away when the player concentrates

In Table 5.4 we can see that the only difference when changing the sensor that is being used is the name of the different elements, but the way to send the data with the EEG sensor would be the same as with the microphone sensor.

Table 5.4 OSC messages that the sensors send for *Butterflies* (EEG) game

RTLS					
Address	Manipulation	ID	SessionID	Value1	Value2
/sensor/2D/RTLS	move	RF beacon	0	x	y
MUSE					
Address	Manipulation	ID	SessionID	Value1	Value2
/sensor/1D/Muse	move	muse_id	0	[concentration]	--

5.5.2 Stage 2: Multi-display management

This second stage is related to the second requirement, consisting of dealing with multiple displays (monitors, projectors, and Android smartphones and tablets) by making use of the Virtual Space paradigm (see Fig. 5.11).

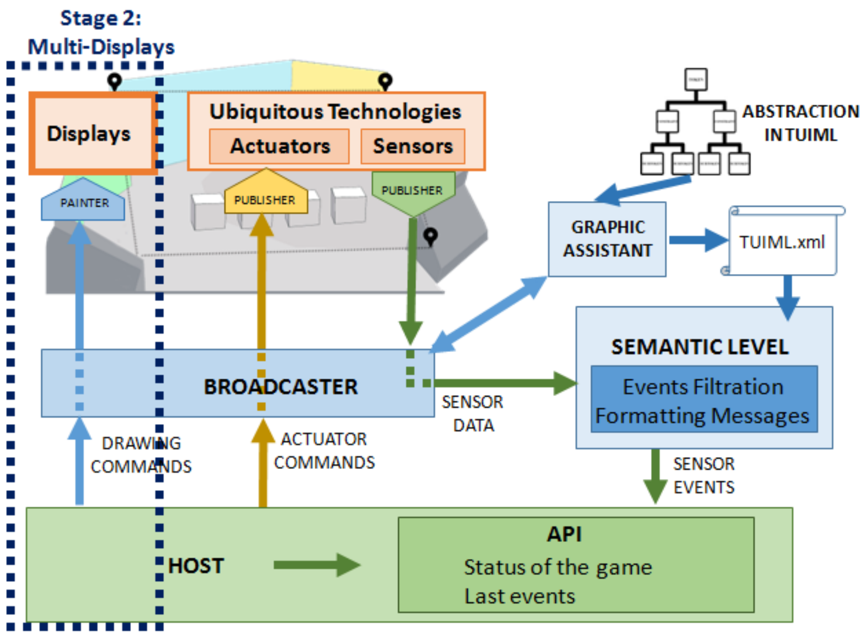


Fig. 5.11 Stage 2: Multi-displays management

In order to do this, a multiplatform painter software was implemented in order to deal with different display platforms: monitors, projectors, and Android smartphones and tablets. "Painter" processes wait for OSC messages coming from the Broadcaster containing commands for drawing graphic elements (lines, shapes, bitmaps, etc), or for playing sounds. The way to integrate different displays is to consider each display device as a part of a Virtual Space (VS) that covers them all. Figure 5.12 shows an example of how to arrange different displays inside the Virtual Space.

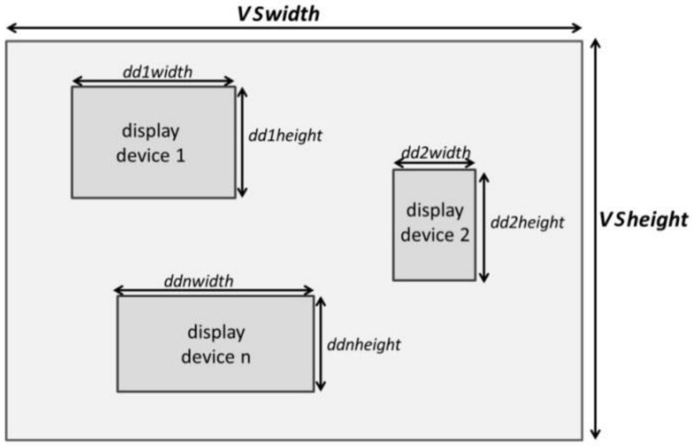


Fig. 5.12 Example of integration of displays.

By using this technique, it is possible to adapt different displays configurations as far as the virtual space area covers all device displays involved in the IS. The arrangement of the displays is defined in an XML file (displays.xml). The content of the “displays.xml” is composed of an **ID** that allows to identify the device, the **position** of the display (the (0, 0) coordinate corresponds to the bottom-left corner), and the **dimension** of the display.

Each paint command received by the Broadcaster is in Virtual Space coordinates. Using the information stored in “displays.XML”, the Broadcaster can locate which display devices must paint the command, convert its coordinates to local display device coordinates, and send the OSC command to each display device in particular. Table 5.5 shows the structure of the OSC messages that the Broadcaster sends in order to draw commands or reproduce sounds.

Table 5.5 OSC Message format of the displays

Address	Argument1	Argument2	…
/display/*command*	Value1	Value2	…

The address of the OSC message indicates the **command**, while the arguments of the message are the values that are needed to carry out the command. For example, if we want to write text in the display, the address would be “**display/writeText**” and the arguments would be the **text** itself, the (x, y) values that indicate the **position** of the text, the **size** of the font, and the three RGB values to indicate the **color** of the text. This list of commands can be easily extended by creating a new OSC message with the format previously presented. The use of some of these commands will be showed later in a following subsection, when the coding of the game with the API is explained.

Multi-display example

We proceeded to use this technique of integration of displays by re-designing the *Butterflies* game using the three projections walls instead of just one of them. This way children would be able to walk around the entire IS instead of being forced to just move in front of one single projection screen, clearly improving the game experience.

This time, three entries will appear in the “displays.xml” file, each one of them corresponding to the size of the projection walls (see Fig. 5.13).

```
<xml >
<virtualDisplay width="3840" height="1248">
        <display id="1" x="0" y="0" width="1280" height="768" />
        <display id="2" x="1280" y="0" width="1280" height="768" />
        <display id="3" x="2560" y="0" width="1280" height="768" />
</virtualDisplay>
</xml>
```

Fig. 5.13 “displays.xml” file of the *Butterflies* game

In order to show the different elements on the screen, the Host will use a “draw” function in charge of formatting an OSC message and send it to the “Painter” process. Figure 5.14 shows the code necessary to draw the background in the different screens.

```
displays.draw("background_screen1.jpg", 0, 0, 1280, 768, 0, "corner");
displays.draw("background_screen2.jpg", 1280, 0, 1280, 768, 0, "corner");
displays.draw("background_screen3.jpg", 2560, 0, 1280, 768, 0, "corner");

public void draw(String name, float x, float y, int width, int height, float angle, String pivot) {
 idDisplay = "";
 for(int j = 1; j < displayList.length; j++) {
        // calculation of the display on which the element will be drawn by using the x, y, width, and
        // height arguments (idDisplay)
 }
 myMessage = new OscMessage("/display/draw");
 myMessage.add(idDisplay);        // 1, 2 or 3
 myMessage.add(name);   // name of the element that is going to be drawn
 myMessage.add(x);                // x position of the element
 myMessage.add(y);                // y position of the element
 myMessage.add(width);  // width of the element
 myMessage.add(height); // height of the element
 myMessage.add(angle);            // rotation angle of the element
 if (pivot.equals("center")) myMessage.add("center"); // coordinates relatives to center or corner
 else myMessage.add("corner");                          // of the element
 sendOSCMessage(myMessage);
```

Fig. 5.14 Processing code to draw elements in multiple displays

Finally, Figure 5.15 shows the result of the *Butterflies* game being extended to multiple displays, where children can scare butterflies by getting close to the different screens.

Fig. 5.15 Multi-display version of *Butterflies* game

5.5.3 Stage 3: Easing the code of the game

This third stage is related to the third requirement, consisting of easing the coding of the application. This stage has a total of four different iterations: we first adapted the TUIML model to define the hybrid games, afterwards the Semantic Level was added to the toolkit to filter the different messages, a Graphic Assistant was also created to make the definition of the game easier, and finally an API to facilitate the creation of the game logic was developed (see Fig. 5.16). As a case of use, and Interactive Space game found in the literature, selected for the variety of the interaction supported, was developed.

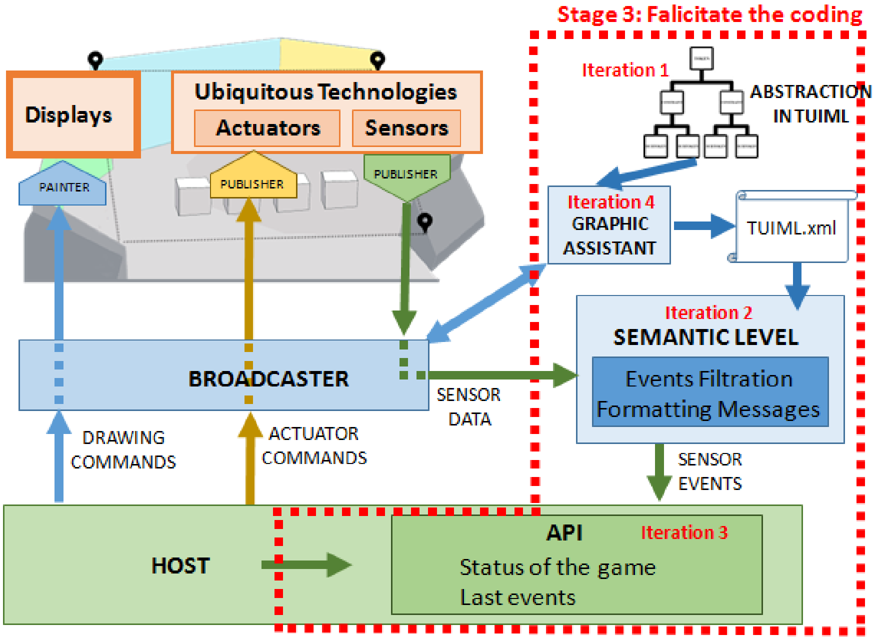


Fig. 5.16 Stage 3: Easing the code of the game (four iterations)

The game that is going to be used to explain the different iterations is the *The Indian World*. This game was devised by two students of the Industrial Design Engineering degree at the University of Zaragoza as part of their final degree project [Marzo and Meléndez, 2016]. The students designed the game concept and all the graphical resources (images, animations, and sounds). Figure 5.17 shows the design of the game's world.

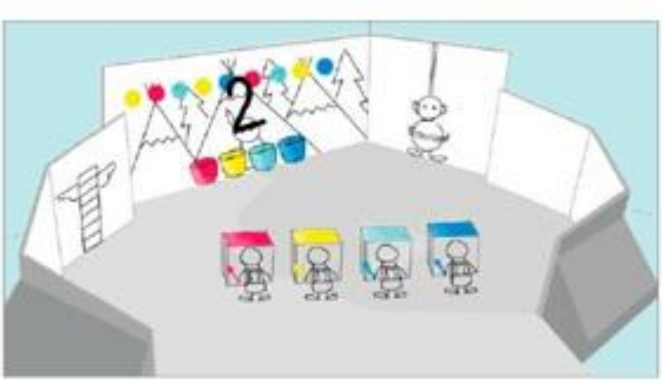


Fig. 5.17 Design of *The Indian World*.

In this game, the protagonist, Drippy, meets an Indian Chief who has a key that Drippy needs to travel to other worlds. In order to recover the key, children have to play drums of different colors with drumsticks by following the sequence that the Indian Chief performs. After doing so, the Indian throws the key to the top of a totem that is also composed of different colors. Children have to play drums to destroy the corresponding colors of the totem: for example, if the first totem piece is yellow, the child with the yellow drum must play it. After the totem is destroyed the key falls to the ground, a light appears over it and then children can grab it to approach it to the keyhole that has just appeared to end the game.

The correspondences of the different elements that compose the game concept and the technologies involved in the IS are presented next:

- The different animations are displayed on the three projection walls and on the four tabletop surfaces. This makes a total of seven displays organized in a unique Virtual Space. Also, the sound effects, such as the voices of Drippy and the Indian Chief and the sound of the drumsticks connecting with the drum, are reproduced through the different speakers of the room and the ones inside the tabletops.

- The drums are the tabletop devices. Each tabletop displays a different color on its surface (red, green, yellow and blue) and each child “controls” one tabletop. In order to interact with it, children use drumsticks with small white foam balls attached to their tip, so that reacTIVision can detect when they hit the tabletop surface as if they were actually playing a drum (see Fig. 5.18a).

- The light that appears over the key when children finish breaking the totem is a LED spotlight placed in the corner of the projection screen, which illuminates the physical key that has been on the floor during the game. The LED turns on thanks to its connection to an actuator that has its own Publisher process connected to the Broadcaster.

- The key is a 3D printed object (see Fig. 5.18b) which contains a RTLS tag inside (see Fig. 5.18c), to be tracked when children approach it to the keyhole.

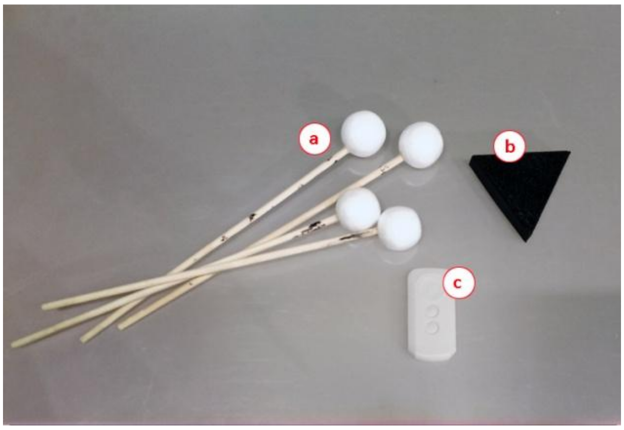


Fig. 5.18 Indian World’s toys. **a)** Drumsticks. **b)** Key. **c)** RF beacon that children wear and which is also placed inside the key object.

Once the game that will serve as the example of this section 5.5 has been explained, the different iterations to address the facilitation of the coding will be explained.

5.5.3.1 *Iteration 1: Abstraction of the game in TUIML*

Our hypothesis was that a broader interpretation of TUIML would also allow to define the interactions produced in a hybrid game in an interactive space. In TUIML, the relations established between two tokens (Token and Subtoken) limited by Constraints are described using TACs: conceptual structures used to describe the status of a subtoken in a specific instant of time. In hybrid games for IS, this hierarchy of Token-Constraint-Subtoken remains with the difference that the elements involved on it are not just playing pieces that are manipulated on a tabletop device. As the tangible interaction design space expands, also the tangible interaction perspective extends. In an IS, users can interact with the game by simply walking on the floor, by manipulating a variety of digital augmented objects, by making certain gestures, or by physical interacting with another player.

From the TUIML point of view, the different elements involved in an IS, such as different furniture, interactive walls, and the floor itself, become **Tokens**; the physical restrictions imposed by these Tokens, such as the surface of a piece of furniture, the surface of a wall and the floor itself, are **Constraints**; and the elements that are manipulated on these Constraints, such as toys and the user who is moving in front of the wall and on the floor, are the **Subtokens**.

This re-interpretation of TUIML also allows to describe hybrid games, since it is just necessary to classify the different elements involved in the game by following the TUIML hierarchy. Nevertheless, we are aware that TUIML has also certain limitations. For example, TUIML does not allow to represent the state of the elements, just relations between them, so this model falls short when trying to define games in which the status of objects is meaningful, limiting that way the range of games to be developed with the toolkit. However, we believe that its capacity to define relations between elements in a rather simple way facilitates the iterations during the development process, as we will show in the last subsection of this section.

To better explain how TUIML can be used to describe hybrid games in IS we are going to describe *The Indian World* in terms of Tokens, Constraints and TACs. The TAC palette of *The Indian World* (see Table 5.6) is composed of five different **Tokens**: the four tabletops Tokens that the children have to play in any place of the tabletop surface (**Constraints**) by using the drumsticks (**Subtokens**), and the RTLS **Token**, that detects the children carrying out RF beacons (Subtokens) in the IS in order to determine when they approach the area next to the key (Cosntraint). Figure 5.19 shows the TUIML hierarchy of the game.

Table 5.6 TAC palette for *The Indian World*

Manipulation	Token	Constraint	Subtoken	Values
add	Tabletop1	surface (2D)	drumstick	0/1
add	Tabletop2	surface (2D)	drumstick	0/1
add	Tabletop3	surface (2D)	drumstick	0/1
add	Tabletop4	surface (2D)	drumstick	0/1
move	RTLS	Key-area(2D)	RF beacon	0 to 1 0 to 1

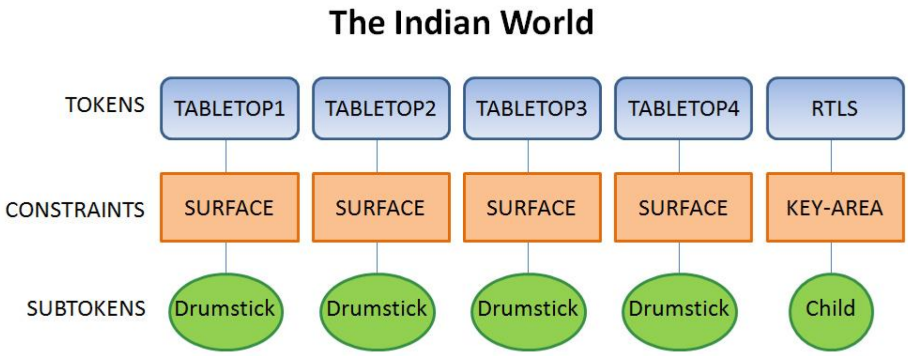


Fig. 5.19 TUIML hierarchy of *The Indian World* game.

5.5.3.2 Iteration 2: Semantic Level

Up till this point, the toolkit was dealing with the raw data that the sensors sent, which meant that the Host application received all the messages of all the sensors that were connected to the Broadcaster, even if some of them were not meaningful for the game: for example, in the *Butterflies* game if a tabletop was connected, the Host received its messages even if that device was not used in the game. As the complexity of the game prototypes grew, we decided that it was necessary to filter the messages that the Host received, and also to define them in the context of the game to facilitate the development of the game logic.

The function of the Semantic Level is to create and keep updated the TAC palette which, as its name points out, contains a set of TACs describing relations that take place in the IS between two tokens through a constraint.

In order to do so, OSC messages arriving to the Broadcaster from the sensor publishers are processed by the Semantic Level thanks to the "TUIML.xml" that has been created, where the different elements of the game have been defined in TUIML terms. The Semantic Level uses the **ID** of the message that has been sent by the sensors to identify the element that has been manipulated. If the **ID** of the message that has arrived is defined in the "TUIML.xml" file, the next step is to consult the **type** of the Subtoken (0D, 1D or 2D), and in case of being 1D or 2D, the Semantic Level will extract the position of the Subtoken to know if it has been manipulated inside a Constraint. This way, raw messages from sensor are:

- **Filtered**: OSC messages from tokens not related to the game (not defined in the "TUIML.xml" file) are discarded. OSC messages from Tokens related to the game but that fall out of all the Constraints defined in the "TUIML.xml" are also discarded.
- **Abstracted**: by defining Constraints, game events are identified by constraint names. Also, relations between Tokens, Subtokens and Subsubtokens are identified as manipulation inside Constraints.

Filtering example

Table 5.7 shows the events related to *The Indian World* that the Semantic Level will receive from the different sensors.

Table 5.7 *The Indian World* events to be filtered

tokenName	type	manip	ID	SessionID	Value1	Value2
Tabletop1	0D	add	drumstick	num	0/1	--

Tabletop1	1D	rotate	drumstick	num	0 to 1	--
Tabletop1	2D	move	drumstick	num	0 to 1	0 to 1
Tabletop2	0D	add	drumstick	num	0/1	--
Tabletop2	1D	rotate	drumstick	num	0 to 1	--
Tabletop2	2D	move	drumstick	num	0 to 1	0 to 1
Tabletop3	0D	add	drumstick	num	0/1	--
Tabletop3	1D	rotate	drumstick	num	0 to 1	--
Tabletop3	2D	move	drumstick	num	0 to 1	0 to 1
Tabletop4	0D	add	drumstick	num	0/1	--
Tabletop4	1D	rotate	drumstick	num	0 to 1	--
Tabletop4	2D	move	drumstick	num	0 to 1	0 to 1
RTLS	0D	add	RF Beacon	0	0/1	--
RTLS	2D	move	RF Beacon	0	0 to 1	0 to 1

The Semantic Level receives all the manipulations related to the sensors involved in the game, so it is necessary to filter the ones that have meaning in the context of the game. The constraints do not appear in the messages received because, at this point, the Semantic Level only has the data sent by the sensors.

The next step is to take this data, that in this case belongs to the interactions carried out in *The Indian World* game, and check if those interactions are taking place in the constraints that have been defined in the context of the game. For example, the Semantic Level will receive messages every time that a child with an RF beacon moves, but when consulting the XML it will just take into consideration the message when a child moves inside the area next to the key.

In order to carry out the filtering, the Semantic Level reads the XML, where the constraints are defined with their vertex, and calculates if the RF beacon position (2D move manipulation) is inside that constraint. The same way, the Semantic Level filters the values sent by the different tabletops just to take into account the "add" manipulations.

5.5.3.3 Iteration 3: API

Although the definition of the "TUIML.xml" file was a simple task for developers, it was still necessary to provide them with functions that easily allowed to consult the status of the TAC palette at any moment, which was the objective of this last iteration.

The Semantic Level keeps updated the whole physical status of the elements involved in the IS as a list of instantiated TACs, which represents all the manipulations taking place at any moment. Each token involved in the hybrid game has its own TAC list, expressing that way its relation with other subtokens through manipulations inside constraints. A TAC list is a table in which each row is an instantiated TAC, while the columns contain the information related with the TACs (see Table 5.8).

Table 5.8 TAC list

TOKEN					
Constraint	Constraint_values	Manipulation	ID	SessionID	Values

The **first** field is the name of the constraint in which the Manipulation, the **second** field, has taken place. These manipulations are the ones described in Section 5.3. The **third** and **fourth** fields are the ID and SessionID of the subtoken that has been manipulated inside the Constraint of the Token. Finally, the **fifth** field is the values of the manipulation. Depending on the type of the manipulation there will be one value (0D and 1D) or two values (2D).

The coding of the Host application consists of listening to OSC messages from the Broadcaster, parsing them, evolving the game according a game rules, responding to players composing OSC messages, and sending them to displays and actuators. In order to simplify the parsing and composing of OSC messages with the adequate format the toolkit provides developers with an API. This API is at the moment for the Processing programming environment, but it could be easily translated to other programming environments as far it enables OSC implementation.

The Functions of the API are classified in three groups:

1. Functions to **consult the TAC list of each Token**: the API offers different functions that allow to:
   - **Consult the status of the game**: the developer can always know the status of the elements that are involved in the hybrid game at any moment.
   - **Event of the last TAC that has been instantiated in the system**: A callback function can be implemented to be triggered each time a TAC has changed; it informs of the last manipulation that has taken place in the IS.
     The API also provides functions so as to consult the specific attributes of the TAC that have been explained in the Table 5.2.
2. Functions to **send commands to actuators**: these commands will cause the actuator to react physically. For example, the functions can lit a LED in a specific color.
3. Functions to **send graphic and sound commands to displays**: these commands are the ones explained in the Table 5.5.

Implementation of The Indian World with the API

In *The Indian World*, the list of TACs that need to be consulted are shown in Table 5.9, since we need to know when the children hit the four tabletops with the drumsticks (TAC1-TAC4) and when the children step inside the area next to the key (TAC5).

Table 5.9 TAC list of TAWB

TABLETOP1						
Num	Constraint	Constraint_values	Manipulation	ID	SessionID	Values
1	surface	[surface-vertex]	add	drumstick	num	0/1
TABLETOP2						
Num	Constraint	Constraint_values	Manipulation	ID	SessionID	Values
2	surface	[surface-vertex]	add	drumstick	num	0/1
TABLETOP3						
Num	Constraint	Constraint_values	Manipulation	ID	SessionID	Values
3	surface	[surface-vertex]	add	drumstick	num	0/1
TABLETOP4						
Num	Constraint	Constraint_values	Manipulation	ID	SessionID	Values
4	surface	[surface-vertex]	add	drumstick	num	0/1
RTLS						
Num	Constraint	Constraint_values	Manipulation	ID	SessionID	Values

5	Key-area	[key-area-vertex]	move	RF beacon	0	0 to 1 0 to 1

Next, in Figure 5.20 we show part of the code in Processing language for *The Indian World* Host application. We make use of the API functions (1) that allow the developer to know the last TAC that has been instantiated, and the API functions (3) in order to draw the background and reproduce sounds.

```
void eventoTAC(TAC lastTAC) {
 // tabletop1 has been touched
 if (lastTAC.getTokenName().equals("tabletop1") &&
     lastTAC.getConstraintName().equals("surface") &&
   lastTAC.getSubtokenName().equals("drumstick ") &&
   lastTAC.getManipulation().equals("add")) {
     if (lastTAC.values.get(0) ==1){
            // stage one of the game: follow sequence
             if (gameStatus==1) {
              if ((sequence[current]==”red”) {
                     current++;
              }
             }
             else if (gameStatus==2) {
              if ((totem[current]==”red”) {
              // the child hasto hit the table four times to break the totem section
                golpes++;
                if (golpes==4) {
                  current++;
                  golpes=0;
                }
               } // totem=red
             }// gameStatus=2
    } // add =1
 } // lastTac
  …
  //The code for the rest of the Tabletops is the same, but consulting if sequence[current] is
 //“green”, “blue” or “yellow”

 // key is next to the keyhole
 else if (lastTAC.getTokenName().equals("RTLS") &&
    lastTAC.getConstraintName().equals("keyhole") &&
    lastTAC.getSubtokenName().equals("[RF-beacon-ID]") &&
    lastTAC.getManipulation().equals("add")) {
     if (lastTAC.values.get(0) ==1){
            endgame= true;
     }
    } //lastTAC
} // END
```

Fig. 5.20 Processing code to treat the events for *The Indian World*

Figure 5.21 shows *The Indian World* running in the IS, with children interacting with the tabletops.

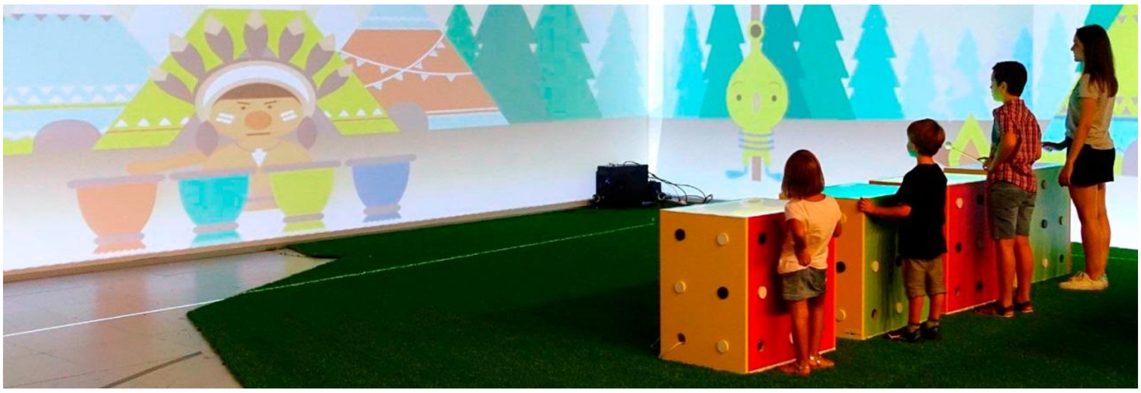


Fig. 5.21 *The Indian World* running the Interactive Space

5.5.3.4 Iteration 4: Graphic assistant

TUIML allowed us to model the different interactions of the games, but it was necessary to translate them into a language understandable by the computer system. For this reason, a Graphic Assistant was created in the context of a Final Degree Project [Navarro, 2018] that allowed (1) to define these interactions by following the hierarchy of Token-Constraint-Subtoken, and (2) to create an XML file containing the game's descriptions in terms of that hierarchy.

As we have commented before, the Graphic Assistant connects directly with the Broadcaster to show in runtime all the Publishers and Painters connected to it together with the name of the device (sensor, display or host) associated to them (see Fig. 5.22a). Display, host and actuator devices just show the IP where they are connected. However, when clicking on the name of one of the sensors (Tokens) connected to the Broadcaster, the Graphic Assistant shows the objects (Subtokens) that are currently being detected by the sensor.

The Graphic Assistant translates all these devices into a list of Tokens, the elements detected by those devices into Subtokens, and the areas where manipulating those elements have meaning in the game into Constraints. This hierarchy is then translated into an XML-file. The Graphic Assistant also allows working with a previously created XML file, in case it is necessary to carry out some modifications (see Fig. 5.22b).

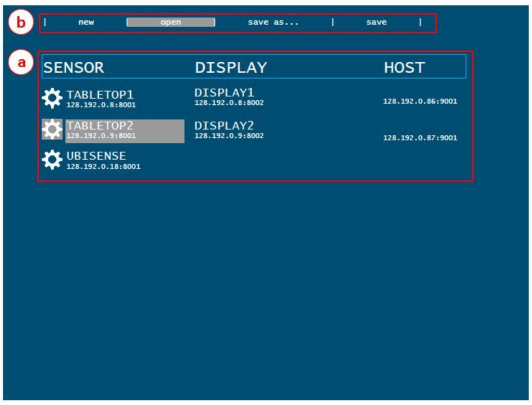


Fig. 5.22 Devices connected appearin the Graphic Assistant main screen. **a)** Different sensors. **b**) Option to create/modify XMLs.

Example of use

In *The Indian World* five sensors are involved: the RTLS to detect where the children wearing RF beacons are, and the four tabletops to detect when someone hits the tabletop with the drumsticks. Therefore, to define this game with the Graphic Assistant, we need to create the constraint and subtokens associated to those sensors.

The RTLS sensor has one constrait associated, related to the area that children have to approach with the key to finish the game. The process to create this constraint is as follows: after running the Broadcaster, we initiate the Graphic Assistant and click on the RTLS sensor name. When doing so, the Graphic Assistant will show where the RF beacons are in the space. To define the constraint correctly, we situate the RF beacon of the key in the place of the IS where we want to situate the key-area. That RF beacon will appear on the Graphic Assistant, so we just need to draw a constraint associated to the RTLS sensor around that RF beacon (see Fig. 5.23). The constraint is created by clicking directly on the screen in order to compose the vertex of the constraint. Once the constraint is created, it is necessary to assign a name to it (KEY-AREA) and to select the tokens to be manipulated inside that constraint. The RF beacon that appear on the image (147) is the ones that has been placed inside the key, so it is added as subtokens of the constraint.

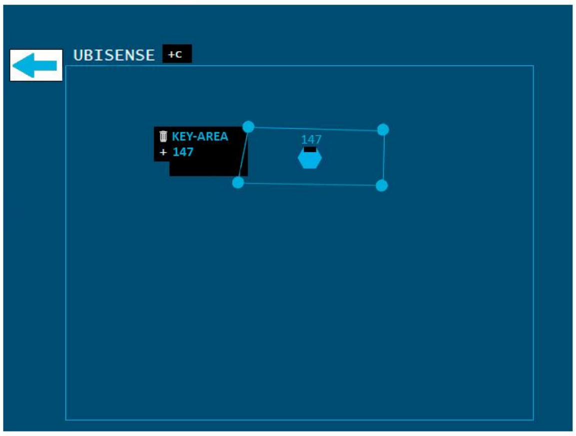


Fig. 5.23 Definition of "key-area" interaction.

The way to define the constraint of the four abletops would be the same than the example showed in Figure 5.27, with the difference that the constraint defined will cover all the surface.

5.6 Prototypes

The author had the opportunity to carry out two research stays during the realization of her PhD: the first one was carried out at the Eindhoven University of Technology (TU/e), in the User Centered Engineering (UCE) group, while the second took place at the Faculty of Sciences and Technology in the New University of Lisbon, with the NOVA LINCS group. Next, two game prototypes developed thanks to the JUGUEMOS toolkit during those stays are shown.

5.6.1 *The Magic Spell* game prototype

The objective of this first stay was to test the facility of integrating diverse devices in the JUGUEMOS Interactive Space. To do so, a PICOO device was integrated to create a prototype of hybrid game [Bonillo et al., 2018].

5.6.1.1 Head Up Games

Head Up Games (HUGs) [Soute et al., 2010] are a specific type of hybrid games that combine traditional outdoor play with hybrid technologies. The main characteristics of these games are that the toys used during games are easy to bring along, the symbolic play prevails over virtual visualization to enhance children's imagination, and, like in traditional games, children interact with each other through spoken language or body language.

The RaPIDO platform (Rapid prototyping of Physical Interaction Design for Outdoor games) was created to facilitate the development of HUGs [Soute et al., 2017]. In the HUGs developed with RaPIDO, children make use of special devices to interact with other children while playing (see Fig. 5.24). RaPIDO devices comprise several components to support different ways of interaction between children (see Table 5.10). The platform provides designers and developers with a set of libraries and an API that abstracts from the hardware of the devices, allowing their configuration and the creation of the game logic by just connecting the device to a computer via USB and using the functionality that the API offers.

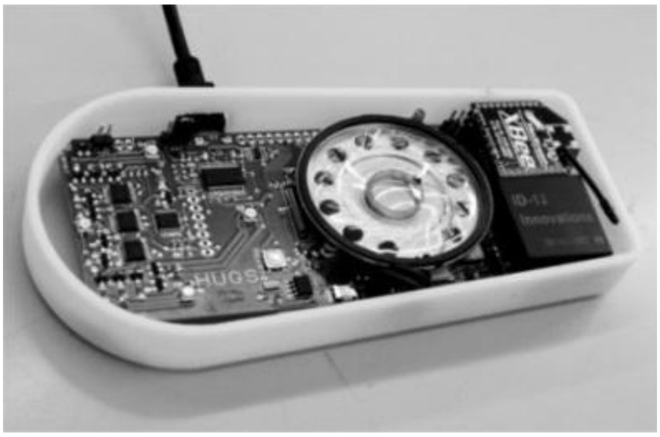


Fig. 5.24 RaPIDO device hardware (Soute et al., 2017)

Table 5.10 Main components of RaPIDO devices (Soute et al., 2017)

Technology	Interaction
4 RGB LEDs	Visual feedback
Sound chip+speaker	Auditory feedback
RFID Module	Detect RFID tagged objects
XBee Module	Inter-device communication Distance measurement
Vibration motor	Tactile Feedback
Accelerometer	Movement measurement

Several outdoor games have already been developed with RaPIDO [Soute et al., 2013]. In the fame prototype developed, the RaPIDO platform was used to configure their devices, and then the JUGUEMOS toolkit was used to integrate them in the JUGUEMOS IS.

5.6.1.2 Integration of the devices

In order to integrate the RaPIDO device (RD) in the IS, it was necessary to develop a publisher to communicate with the device, to establish the format of the messages that were going to be sent to the RD, and to configure the device so that it could receive messages from the Publisher, and also send messages back to it.

As we have commented when explaining the architecture of JUGUEMOS toolkit (Section 5.4), each device that is integrated in the IS has a Publisher to deal with the hardware of the device. In this case, the objective was to enable the RaPIDO Publisher to communicate with the RD and send commands to it to make it turn into a certain color, play a sound or vibrate. Similarly, the RD should be able to send messages to the Publisher when carrying out any of the previously said actions, thus requiring a bidirectional communication.

Up till now, the RaPIDO devices were programmed to communicate exclusively between each other through a microcontroller and an integrated XBee module. To allow an external software program such as the Publisher to communicate with the RaPIDO devices, we used an XBee explorer connected to the computer (see Fig. 5.25).

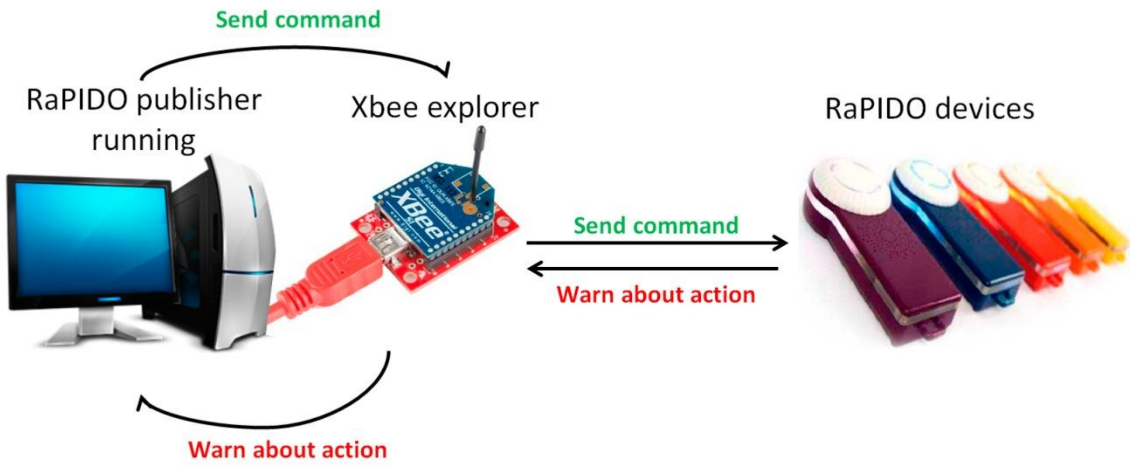


Fig. 5.25 Communication between Publisher and RaPIDO devices

On the one hand, the messages that the RaPIDO publisher sends to the RD through the XBee Explorer consist of two bytes to define the message and two optional arguments. In our case, we established a set of commands to turn one of the four LEDs of the RD on a given color, to playback an audio file, and to (de)activate the vibration motor (see Table 5.11).

Table 5.11 Format of the messages from Publisher to RD

Message	Arg1	Arg2	Meaning
L1	*color*	1/0	LED1 turned on/off <*color*>
L2	*color*	1/0	LED2 turned on/off <*color*>
L3	*color*	1/0	LED3 turned on/off <*color*>
L4	*color*	1/0	LED4 turned on/off <*color*>
AU	*num*	--	Reproduce audio file <*num*>
MT	1/0	--	Turn on/off the vibration motor

The first four rows of the table are messages to show the LED that is going to illuminate/light. The first argument of these rows corresponds to the color the LED is going to display. It has 8 different values that correspond to the colors that have been already defined in the RaPIDO platform: ‘R’ (red), ‘B’ (blue), ‘G’ (green), ‘Y’ (Yellow), ‘P’ (purple), ‘W’ (white), ‘M’ (mint), and ‘O’ (orange). Finally, the second argument indicates if the LED is going to turn on a color (arg2 = 1), or off (arg2 = 0).

The fifth row is the message to playback an audio file. In this case we just need the first argument to tell the RD the audio that must be played.

Finally, the sixth row is the message to control the vibration motor. The first argument is needed to state if the motor has to be turned on (arg1 = 1) or off (arg1 = 0).

The messages that the RD sends to the Publisher follow the same format as those in Table 5.11, with the sole difference that the RD also sends the address of its XBee, so that the Publisher can identify the device from which it is receiving the information.

The RaPIDO platform provides the developer with several functions to configure the RD. We used the "*radio::receive()*" to check when new messages had been sent to the XBee, and executed the corresponding function to carry out the interaction. For example, if the message received corresponded to the first four rows defined in Table 5.11, the RD turned on/off the LED in the indicated color using the function "*rgb::{on/off}(led, theColor)*".

5.6.1.3 Design and implementation of the game prototype

In order to test the integration of the RD in the IS, we created a prototype of a game that combines the use of one of the tabletops of the IS with the RD. In the demo, the RD becomes a magic wand that can be charged with different spells. Placing an object on the tabletop allows first to select between different types of magic (fire, ice, wind, lightning and darkness) and by placing more objects on the tabletop the magic wand gradually turns brighter. Depending on the magic selected, the RD shows different colors: red (fire), blue (ice), green (wind), yellow (lightning), and purple (darkness).

Figure 5.26 Top shows one of the tabletops of the IS with three objects placed on it. The object that appears in the top-right corner is the one in charge of selecting the magic (see Fig. 5.26 Left a), while the other two objects have caused two LEDs of the RD to turn on red (see Fig. 5.26 Left b). The more objects are placed over the tabletop, the more LEDs of the RD turn on the corresponding color. In addition, to tell the child that the spell is charging, one of the projection screens shows a number of flames that correspond to the LEDs that are currently on, and also to the number of objects that are on the tabletop (see Fig. 5.26 Right). Finally, when a fourth object is placed on the tabletop, the last LED is turned on and the spell is cast.

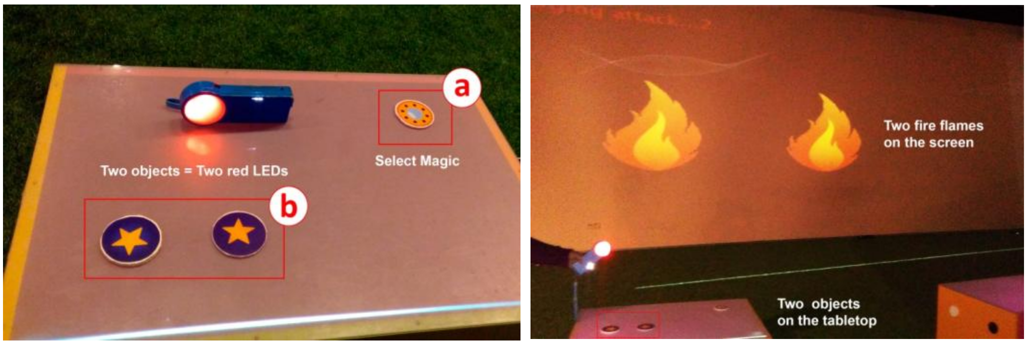


Fig. 5.26 *The Magic Spell*. **Left**: Two objects placed on the tabletop correspond to two LEDs turned on red in the RD. **Right**: Two fire flames indicate that the spell is charging.

The criteria followed to choose the mechanics of the game was to try to use as many functionalities of the RaPIDO device as possible. Unfortunately, due to time limitations, we could not implement a game prototype that made use of all the functionalities, but we believe that our case of use proves that the device's integration has been carried out correctly.

Table 5.12 shows the TACs of the game. In this case, the tabletop has two constraints defined: one of them is the place where the five objects corresponding to the different magics are placed to select the magic (ID=[1..5]). The second constraints covers the whole surface and has associated the objects that allow to charge the spell (ID=8).

Table 5.12 TAC list of *The Magic Spell*

TABLETOP1						
Num	Constraint	Constraint_values	Manipulation	ID	SessionID	Values
1	selection	[selection-vertex]	add	1	num	0/1
2	selection	[selection-vertex]	add	2	num	0/1
3	selection	[selection-vertex]	add	3	num	0/1
4	selection	[selection-vertex]	add	4	num	0/1
5	selection	[selection-vertex]	add	5	num	0/1
6	surface	[surface-vertex]	add	8	num	0/1

Next, in Figure 5.27 part of the code in Processing language for *The Magic Spell* Host application is presented.

```
void eventoTAC(TAC lastTAC) {
 if (lastTAC.getTokenName().equals("tabletop1") &&
  lastTAC.getConstraintName().equals("selection") &&
  lastTAC.getManipulacion().equals("add")) {
    if(lastTAC.getValores().get(0) == 1) {
     // If magic has not been chosen, we proceed
     if (!chosenMagic) {
      if (lastTAC.getSubtokenName().equals("1")) {
       colour='R'; r = 255; g=0; b=0; //red
       lastMagic="1";
       texto="I choose Fire Magic!";
       magiaElegida=true;
      }
      ...
      // repeat with the five magics
     }
   }
   else {
    // if the magic object is removed, another magic can be chosen
    if (ultimaMagia.equals(lastTAC.getSubtokenName())) {
     chosenMagic=false; mana=0;
     r=255; g=255; b=255;
     texto="You can choose your magic again!";
    }
   }
 }
  else if (lastTAC.getTokenName().equals("tabletop1") &&
    lastTAC.getSubtokenName().equals("8") && lastTAC.getConstraintName().equals("surface")
     && lastTAC.getManipulacion().equals("add")) {
   //objects to charge the spell are placed
   if (lastTAC.getValores().get(0) == 1) {
    if (chosenMagic) {
```

```
    mana++;
    if (mana<=4) {
    //sending commands to the picoo to turn on the indicated colour
    //myAPI.actuator1D(device_name, device_ID, LED_number, colour, status [on/off]);
    if (mana==1) myAPI.actuator1D("picoo", "4", "L1", str(colour), 1);
    else if (mana==2) myAPI.actuator1D("picoo", "4", "L2", str(colour), 1);
    else if (mana==3) myAPI.actuator1D("picoo", "4", "L3", str(colour), 1);
    else if (mana==4) myAPI.actuator1D("picoo", "4", "L4", str(colour), 1);
    if (mana<4) texto="Charging attack..." + mana;
    else {
     texto="Spell charged!"; audio=true;
    }
   } //chosen Magic
  } //add
  else texto="First choose the magic!";
 }
}
```

Fig. 5.27 Processing code to treat the events for *The Magic Spell*.

5.6.2 *The Hidden Treasure* Game Prototype

The objective of this second stay was the creation of a persuasive game by using the technologies involved in the JUGUEMOS IS and the JUGUEMOS toolkit [Bonillo et al., 2019c].

5.6.2.1 Persuasive games

Persuasive systems aim to enhance a positive change in the attitude and behavior of the users through the entertainment. Fogg [2002] was the first one in settle the bases for persuasive systems, and from then on the range of application in this field has not stopped growing. The healthcare field is the one in which persuasive technologies tend to focus on. In fact, Orji and Moffat [2018] carried out a recent review of 16 years (corresponding to a total of 85 papers) of literature on persuasive technology for health and wellness, which included topics such as physical activity, healthy eating, smoking cessation, avoiding risky sexual behavior and unwanted pregnancy, and dental health. For example, more than ten years ago Toscos et al. [2006] developed *Click Chick*, a cell phone application aimed at motivating teenage girls to exercise, by making the most of their social desire to stay connected with friends. Nowadays, we can easily find products based on this same idea, in which users are informed about the physical exercise they do each day so that they can keep track and also configure their personal goals to fulfill.

Also, besides the healthcare field, works focused on taking care of the environment and sustainability are also frequent: *LEY* (Less energy Empowers You) [Madeira et al., 2011] is a mobile serious game approach whose goal is persuading people to change negative energy consumption habits, by making them understand household energy usage. The objective of the game is to bring your virtual house to the best consumption level, obtaining that way the best score, which is calculated by taking into account real energy consumption values, responses to quizzes and competitions with other users. Also, *GAEA* [Centeiro et al., 2014] is a persuasive multiplayer mobile game to encourage people to recycle virtual object. Players use their mobile to find and recycle virtual rubbish by collecting them and throwing in their corresponding bin.

The game also promotes physical activity and social interaction by using a score system and a competitive mode with other players.

After analyzing several the works of the literature, we noticed two things:

First, most part of the persuasive applications make use of a single interaction paradigm, with a clear preference of mobile applications. Therefore, one of the objectives of our work was to create an hybrid persuasive game that combined traditional game techniques with the new possibilities that IS offer, consisting of the use of multiple interaction paradigms.

Second, even if the social component is usually addressed in persuasive games as a way to encourage people to keep using the applications, there were not many works whose exclusive aim was to foster good behaviors.

For that reason, the aim of this research stay was to develop a persuasive hybrid game for an IS aimed to foster adequate social interactions in children (one of the aims of the JUGUEMOS Project).

5.6.2.2 Design and implementation of the game prototype

The Hidden Treasure was designed by following some of the principles presented by Oinas-Kukkonen and Harjumaa [2018] which, at the same time, transformmed Fogg's initial principles into system requirements so that developers could implement them directly as system features. In Annex 3 a more detailed explanations of the application of this framework is presented.

In the main projection screen of the IS a story is showed. The protagonists of the game are two fairies that live in a forest, Green and Red, and the children playing the game, since both fairies talk to them too, involving them in the game. The fairies begin to explain that they need the children's help to find a treasure they buried when they were little (see Fig. 5.28 Top). In order to do so, they have a map but it is encrypted, so they need to solve the riddle written on it to find the treasure. At some point of the conversation, Green and Red begin to fight for the map (see Fig. 5.28 Bottom-Left). After that, a set of questions related to the fight that had just taken place appear on one of the tabletops of the IS (see Fig. 5.28 Bottom-Right).

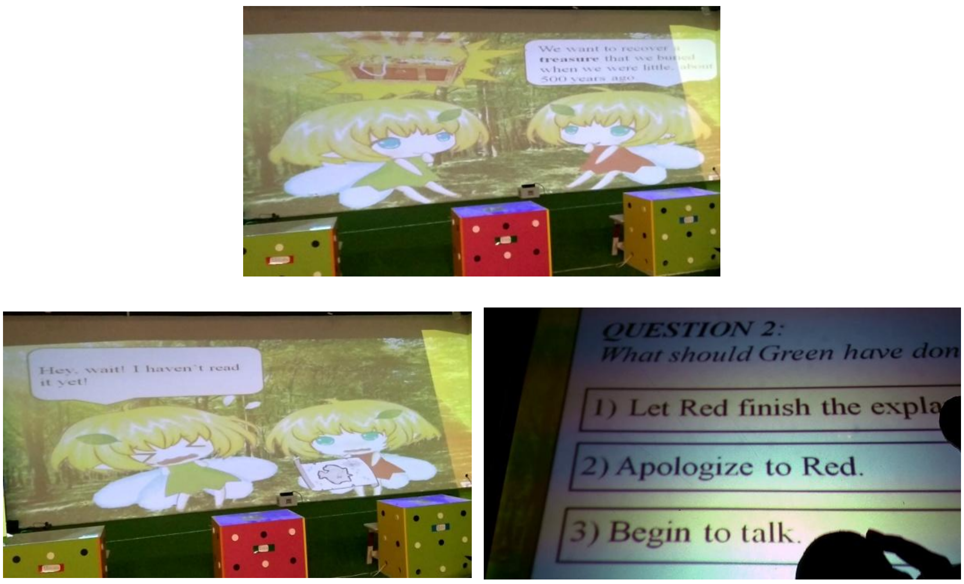


Fig. 5.28 *The Hidden Treasure*. **Top:** Fairies explaining the game. **Bottom-Left:** Fairies fighting. **Borrom-Right**: Answering questions on the tabletop.

To select the answers, each child has an object that they have to place on their choice. All the children have to agree on the answer so that the game continues, encouraging them that way to communicate and reach an agreement.

What happens in the second part of the game depends of the children’s answers:

- If the children have been paying attention to the story and answer correctly at least 5 of the 7 questions formulated, Green and Red stop fighting, apologize to each other and the game continues.

- If children fail three questions however, the map is torn up, so the treasure cannot be found and the game finishes with a “Game Over”.

In case children passed the questions, the main screen shows seven different roads (see Fig. 5.29 Left) while the tabletop shows information about them: two of them are dead ends, three are dangerous and two lead to the treasure. Also, the tabletop informs that the children have to find four different keys to solve the riddle (see Fig. 5.29 Right).

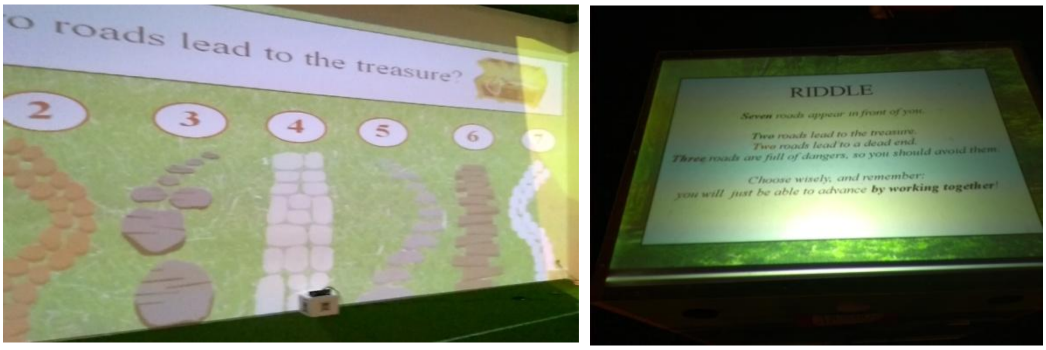


Fig. 5.29 Riddle game. **Left**: Screen with roads. **Right**: Tabletop information.

In this part of the game, each child is wearing a RF beacon, that allows the RTLS to pinpoint his/her location, and the children are also given a single mobile that initially does not show anything. In order to discover the correct roads, children have to move along the interactive space to search for keys. When children approach certain areas of the space, different keys appear on the mobile (see Fig. 5.30). There are keys assigned to each child, meaning that certain keys just appear when a particular child approaches the defined areas. That way, it is assured that all the children have to move around the space, and collaborate to gather all the keys of the game.

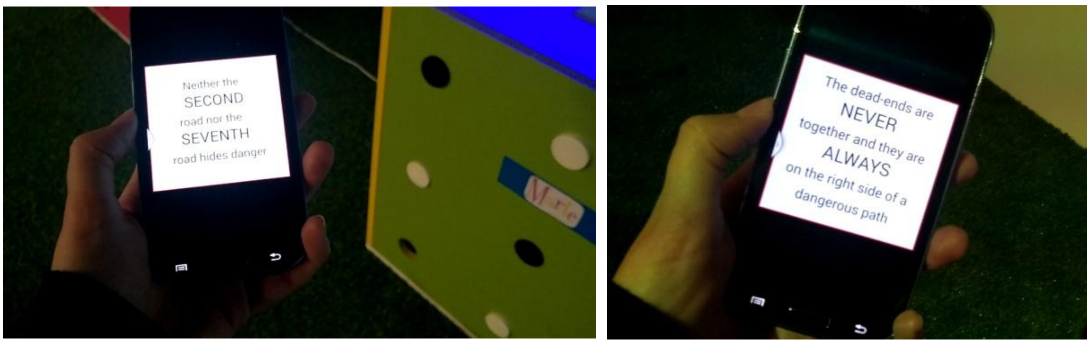


Fig. 5.30 Different keys to solve the final riddle.

Finally, when the children solve the riddle, they have to select among seven objects representing the roads the ones they thought they are correct and place them on the tabletop (see Fig. 5.31 Left). If the roads are correct, the image of the screen changes and victory music plays, announcing the end of the game (see Fig. 5.31 Right).

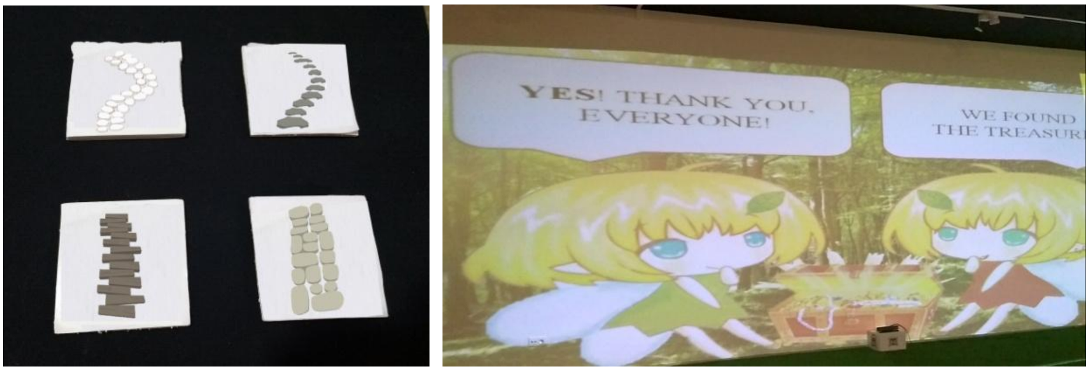


Fig. 5.31 Game ending. **Left**: some objects representing the roads. **Right**: Finding the treasure.

Table 5.13 shows the TACs of the game. In this case, the tabletop has three areas defined that correspond to the three different answers that the child can choose with each question. In its current state, the game allows two group of children to play, each group carrying an object (ID=1 and ID=2), so there is a total of 6 TACs corresponding to the questions part of the game. Also, there are two more TACs to have into consideration when the children place on the tabletop the two objects representing the correct paths (ID=3 and ID=5 in this case). Regarding the RTLS sensor, there are a total of four areas defined on the IS: two areas are activated when child wearing "RF beacon1" enters them, while the remaining two are associated with the child wearing "RF beacon2".

Table 5.13 TAC list of *The Hidden Treasure*

TABLETOP1						
Num	Constraint	Constraint_values	Manipulation	ID	SessionID	Values
1	option1	[option1-vertex]	add	1	num	0/1
2	option2	[option2-vertex]	add	1	num	0/1
3	option3	[option3-vertex]	add	1	num	0/1
4	option1	[option1-vertex]	add	2	num	0/1
5	option2	[option2-vertex]	add	2	num	0/1
6	option3	[option3-vertex]	add	2	num	0/1
7	surface	[surface-vertex]	add	3	Num	0/1
8	surface	[surface-vertex]	add	5	Num	0/1
RTLS						
Num	Constraint	Constraint_values	Manipulation	ID	SessionID	Values
9	key1-area	[key1-area-vertex]	move	RF beacon1	0	0 to 1 0 to 1
10	key2-area	[key2-area-vertex]	move	RF beacon2	0	0 to 1 0 to 1
11	key3-area	[key3-area-vertex]	move	RF beacon1	0	0 to 1 0 to 1
12	key4-area	[key4-area-vertex]	move	RF beacon2	0	0 to 1 0 to 1

Next, in Figure 5.32 part of the code in Processing language for *The Hidden Treasure* Host application is presented.

```
void eventoTAC(TAC lastTAC) {
 if (lastTAC.getTokenName().equals("tabletop1") && ta.getManipulacion().equals("add")) {
 //object added in tabletop1
 If (lastTAC.getValores().get(0) == 1) {
  // Player 1
  else if (lastTAC.getSubtokenName().equals("1")) {
  if (lastTAC.getConstraintName().equals("option1") && !youSure) player1=1;
  else if (lastTAC.getConstraintName().equals("option2") && !youSure) player1=2;
  else if (lastTAC.getConstraintName().equals("option3") && !youSure) player1=3;
 }
 // Player 2
 else if (lastTAC.getSubtokenName().equals("2")) {
  if (lastTAC.getConstraintName().equals("option1") && !youSure) player2=1;
  else if (lastTAC.getConstraintName().equals("option2") && !youSure) player2=2;
  else if (lastTAC.getConstraintName().equals("option3") && !youSure) player2=3;
 }
 // Final part of selecting the answers
  else if (lastTAC.getSubtokenName().equals("3") &&
       lastTAC.getConstraintName().equals("surface")) camino3=true;
  else if (lastTAC.getSubtokenName().equals("5") &&
       lastTAC.getConstraintName().equals("surface")) camino5=true;
 }
 }
  If (lastTAC.getTokenName().equals("RTLS") && lastTAC.getManipulacion().equals("add")){
   // children entering on the different areas
  if (lastTAC.getValores().get(0) == 1 && status==10) {
    if (lastTAC.getConstraintName().equals("key1-area") &&
          lastTAC.getSubtokenName().equals("RF-beacon1")) key=1;
    else if (lastTAC.getConstraintName().equals("key2-area") &&
          lastTAC.getSubtokenName().equals("RF-beacon2")) key=2;
    else if (lastTAC.getConstraintName().equals("key3-area") &&
          lastTAC.getSubtokenName().equals("RF-beacon1")) key=3;
     else if (lastTAC.getConstraintName().equals("key4-area") &&
          lastTAC.getSubtokenName().equals("RF-beacon2")) key=4;
   }
 }
}
```

Fig. 5.32 Processing code to treat the events for *The Hidden Treasure*

Once that the JUGUEMOS toolkit has been explained in detail together with the first prototypes that came from it, in the next chapter three use cases related to the toolkit will be explained.

5.7 Contributions Related to Chapter 5

Bonillo, C., Cerezo, E., Marco, J., & Baldasarri, S. (2016c, September). Toolkit for the development of Interactive Collaborative Environments: architecture and proof of concept. In *Proceedings of the XVII International Conference on Human Computer Interaction* (p. 32). ACM.

Bonillo, C., Marco, J., & Cerezo, E. (2019b) Developing Pervasive Games in Interactive Spaces: The JUGUEMOS Toolkit. In *Multimedia Tools and Applications* (***Minor revisions***).

Bonillo, C., Tetteroo, D., & Cerezo, E. (2018, September). Merging outdoor and indoor technologies for the creation of pervasive games. In *Proceedings of the XIX International Conference on Human Computer Interaction* (p. 1). ACM.

Bonillo, C., Romão, T., & Cerezo, E. (2019c). Persuasive games in Interactive Spaces: The Hidden Treasure Game. In *XX International Conference on Human Computer Interaction* (***Accepted***).

CHAPTER 6:

JUGUEMOS USE CASES

6.0 Chapter Introduction

During the last two years, the JUGUEMOS toolkit has been employed in several projects with students, which has helped us to obtain valuable feedback about its usability.

Section 6.1 explains the implementation of a game that makes use of diverse interaction styles and that allowed to carry out an assessment of the toolkit usability.

Section 6.2 presents the complete implementation of a game developed for an IS.

Finally, section 6.3 shows how the toolkit can support multi-disciplinary experiences in which the objective is to reduce the gap between designers and developers.

6.1 Implementing *The Augmented Bedroom World*

In order to gather information about JUGUEMOS toolkit usability, a group of students of the Master's Degree in Computer Sciences at the School of Engineering and Architecture (EINA) used the JUGUEMOS toolkit to create an hybrid game for the IS as part of their practical lessons.

The hybrid game the students had to adapt to the IS was the *The Bedroom World* from Bobick et al. [1999]. This game was previously published as an exploration of children story-telling in IS and it was chosen due to the variety of interactions supported. In *The Bedroom World* a child enters an interactive bedroom where different pieces of furniture talk when the child approaches them. The child has to go asking around until discovering a magic word that will allow him/her to travel to another world (see Fig. 6.1). At the end of the game, the voice of the child's mother tells the child to go to bed. When the child enters the bed a monster appears asking the child to say the magic word. When the child does so, the game ends and the next world begins.

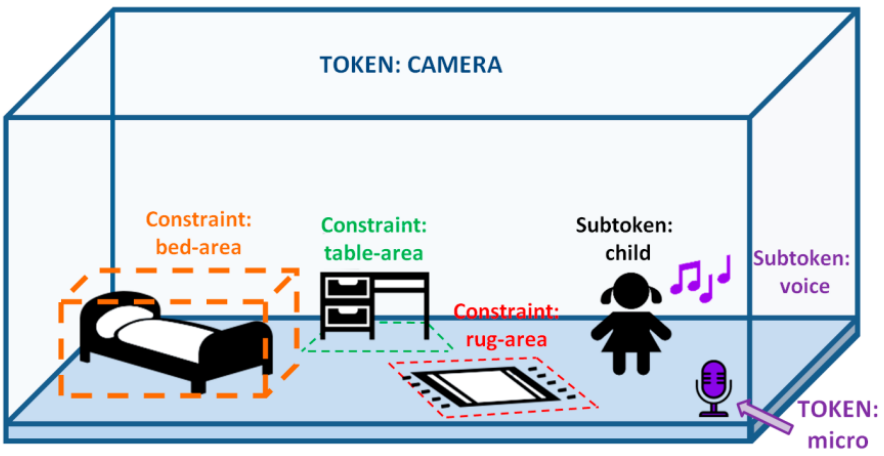


Fig. 6.1 *The Bedroom World* game.

Now we are going to explain the different tasks the students needed to carry out in order to implement the game.

6.1.1 TUIML adaptation

The original game did not use any tabletops, but in order to make the most of the devices currently installed in the JUGUEMOS IS it was decided to change the table that the child has to approach for a tabletop device on which the child has to place his/her hand to "make it talk". For this reason, the adapted game will be called *The Augmented Bedroom World* (TABW) from now on.

In TABW, the pieces of furniture were simplified to three items: a rug, a table, and a chair that works as a bed. When the game begins, a voice tells the child to ask the rug what the magic word is. When the child steps on the rug, it “speaks” and tells the child to wake up the table to ask her. The child then has to place a hand on the table to wake her up. The table tells the child the magic word and at that moment the mother asks the child to go to bed. When the child sits on the bed and shouts the magic word, the game finishes.

In order to detect the child’s manipulations, the following **sensors** of our IS are used:

- The RTLS to locate where the child is in the IS.

- A tabletop to detect when the child place a hand on the table.

- A microphone to detect when the child is shouting the magic word.

Therefore, the TAC palette of TABW is composed of three different **Tokens**: (1) the RTLS Token, that will detect when the RF beacon that the child carries (**Subtoken**) is close to the rug and the bed (**Constraints**); (2) the Tabletop Token, that will detect when a child places a finger (**Subtoken**) on the tabletop; (3) and the Microphone Token, that will detect when someone shouts with a volume inside a certain range (**Constraint**). Since the microphone could not differentiate the children’s voices, a default value=0 was assigned to the volume detected by it (**Subtoken**) (see Table 6.1).

The manipulations that we are going to take into account are “add” instead of “move” because we just need to know when the child enters the rug and the bed areas, and when the finger is placed on the tabletop, but nor their exact position. For the Microphone though we use the “move” manipulation because we need to know the exact value of the voice in order to know if the child is shouting or not. Figure 6.2 shows the TUIML hierarchy of TABW.

Table 6.1 TAC palette for TABW game.

Manipulation	Token	Constraint	Subtoken	Values
add	RTLS	rug-area (2D)	RF beacon (child)	0/1
add	RTLS	bed-area (2D)	RF beacon (child)	0/1
add	tabletop	surface (2D)	finger	0/1
move	micro	shout (1D)	0	0 to 1

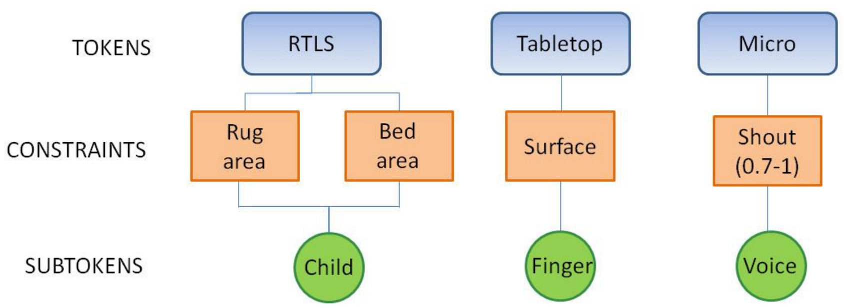


Fig. 6.2 TUIML hierarchy of the TABW game.

With those manipulations in mind, the resulting “**TUIML.xml**” is as follows:

TUIML

```
<token name="RTLS">
 <constraint id="rug" type= "2D" list_vertex="[vertex_of_the_rug_constraint]">
 <tac subtoken="child"/>
 </constraint>
 <constraint id="bed" type= "2D" list_vertex="[vertex_of_the_bed_constraint]">
 <tac subtoken="child"/>
 </constraint>
</token>
<token id="tabletop">
 <constraint id="all" type= "2D" list_vertex="[vertex_of_the_tabletop_constraint]">
 <tac subtoken="finger"/>
 </constraint>
</token>
<token id="micro">
 <constraint id="range" type= "1D" list_vertex="0.7, 1.0">
 <tac subtoken="voice"/>
 </constraint>
</token>
```

Regarding the feedback provided to the child, the following **displays** are used:

- Visual projection on the screens of the IS to simulate the child's bedroom.

- Visual projection on the tabletop surface, where a smiling face will appear to indicate that the table has woken up.

- Sound to simulate the voices of the rug, the table, and of the child's mother, through the speakers connected in the space and also inside the tabletop,

Therefore, when defining the "displays.xml" file, two displays have to be indicated: **display1** is the projection on the wall while and **display2** is the projection on the tabletop.

displays.xml

```
<xml>
 <VirtualSpace width="2080" height="768">
	<display id="1" x="0" y="0" width="1280" height="768" />
	<display id="2" x="1280" y="0" width="800" height="600" />
 </ VirtualSpace>
</xml>
```

6.1.2 Implementation

Table 6.2 shows the events related to TABW that the Semantic Level will receive from the different sensors.

Table 6.2 TABW events to be filtered

tokenName	type	manip	ID	SessionID	Value1	Value2
RTLS	0D	add	RF Beacon	0	0/1	--
RTLS	2D	move	RF Beacon	0	0 to 1	0 to 1
Tabletop	0D	add	finger	num	0/1	--
Tabletop	1D	rotate	finger	num	0 to 1	--
Tabletop	2D	move	finger	num	0 to 1	0 to 1
Micro	0D	add	0	0	0/1	--
Micro	1D	move	0	0	0 to 1	--

The Semantic Level receives all the manipulations related to the sensors involved in the game, and filters the ones that have meaning in the context of the game. The constraints do not appear in the messages received because, at this point, the Semantic Level has only the data sent by the sensors.

The next step is to take this data, that in this case belongs to the interactions carried out in TABW game, and check if those interactions are taking place in the constraints that have been defined in the context of the game. For example, the Semantic Level will receive messages every time that a child with an RF beacon moves, but when consulting the XML it will just take into considerations when a child moves inside the rug area and the bed area. In order to do this, the Semantic Level reads the XML, where the constraints are defined with their vertex, and calculates if the RF beacon position (2D move manipulation) is inside that constraint. Likewise, the Semantic Level filters the values sent by the micro sensor inside the "shout" constraint (0.7 - 1.0).

Therefore, in TABW, the list of TACs that need to be consulted are shown in Table 6.3, since we need to know: when the child steps on the rug (TAC1), when the child steps on the bed (TAC2), when the child places his/her hand on the tabletop (TAC3) and when the child is shouting the magic word (TAC4).

Table 6.3 TAC list of TAWB

RTLS						
Num	Constraint	Constraint_values	Manipulation	ID	SessionID	Values
1	rug-area	[rug-vertex]	add	RF beacon	0	0/1
2	bed-area	[bed-vertex]	add	RF beacon	0	0/1
TABLETOP						
Num	Constraint	Constraint_values	Manipulation	ID	SessionID	Values
3	surface	[surface-vertex]	add	finger	0	0/1
MICROPHONE						
Num	Constraint	Constraint_values	Manipulation	ID	SessionID	Values
4	shout	[0.7-1]	move	0	0	0 to 1

Next, part of the code in Processing language for the TABW Host application is presented. In TABW the students have to make use of the API functions (1), that allow the developer to know the last TAC that has been instantiated, and the API functions (3) in order to draw the background and reproduce sounds (see Fig. 6.3).

```
void eventoTAC(TAC lastTAC) {
// child is on the rug
 if (lastTAC.getTokenName().equals("RTLS") &&
        lastTAC.getConstraintName().equals("rug-area") &&
                lastTAC.getSubtokenName().equals("[RF beacon ID]") &&
                        lastTAC.getManipulation().equals("add")){
                                if (lastTAC.values.get(0) ==1){
                                        displaysClient.playAudio("rugVoice.mp3");
                                }
 }
// child places the hand on the tabletop
 else if (lastTAC.getTokenName().equals("tabletop") &&
        lastTAC.getConstraintName().equals("surface") &&
                lastTAC.getSubtokenName().equals("finger")) &&
                        lastTAC.getManipulation().equals("add") {
                                if (lastTAC.values.get(0) ==1){
                                        displaysClient.playAudio("tabletopVoice.mp3");
                                }
 }
 // child is on the bed
 else if (lastTAC.getTokenName().equals("RTLS") &&
        lastTAC.getConstraintName().equals("bed") &&
                lastTAC.getSubtokenName().equals("[RF beacon ID]") &&
                        lastTAC.getManipulation().equals("add")) {
                                if (lastTAC.values.get(0) ==1){
                                        childInBed = true;
                                }
 }
// child has shouted while being on the bed
 else if (lastTAC.getTokenName().equals("micro") &&
        lastTAC.getManipulation().equals("move") &&
                lastTAC.values.get(0) > 0.7) {
                        if (childInBed) {
                                displaysClient.playAudio("endGame.mp3");
                        }
 }
} //eventoTAC
```

Fig. 6.3 Processing code for TABW.

6.1.3 Evaluation

The group of students of the Master's Degree in Computer Sciences was composed of a total of 8 participants (6 males, 2 females) with ages ranged between 22 and 29 years old. They all had programming skills but they did not have previous experience on developing games for IS.

6.1.3.1 Methodology

As it had been commented while explaining the hybrid game to be implemented by the participants, the work was divided into two tasks:

- **Task 1**: to define the TUIML of the game.

- **Task 2**: to implement the game logic.

The Etopía lab was arranged to accommodate two computers with the necessary software to develop the hybrid game. The 8 participants were divided in groups of two people and a total of three sessions were carried out. Each session lasted three hours. During the first session the students were introduced to the developed toolkit and then they created, in pairs, the TUIML of the game. In the second session two of the four groups developed the hybrid game, and in the third session the remaining two groups did the same. The reason for dividing the groups this way was due to the available hardware. Every group also worked with different projection screens, Kinects and tabletops so that they could test the game while programming in parallel (see Fig. 6.4).

Fig. 6.4 Participants programming the hybrid game.

All the graphic and audio resources that had to be used in the game (bedroom image to be projected in the screen, furniture and mother's voices) were provided to the participants so that they just had to focus on their tasks.

It was decided to use standard usability measures [ISO, 2001] to assess the usefulness and easy of use of the toolkit. Therefore, effectiveness, efficiency and usability are measured.

6.1.3.2 Results

The four groups developed the proposed hybrid game successfully. Following, quantitative measurements about the toolkit usability are now presented:

Effectiveness: All participants were able to fully develop the hybrid game. Therefore, it can be concluded that the toolkit is an effective tool for developing hybrid games for interactive spaces.

Efficiency: Table 6.4 shows the resources (lines of code and time to complete the application) used in each task by each participant.

Table 6.4 Efficiency measures

Group	Lines of code		Time (minutes)	
	TUIML	Game	TUIML	Game
1	23	31	14	97
2	25	26	15	110
3	23	46	13	102
4	22	32	25	100
Average	23	32	17.5	102,25
Total Average	55		119,75	

Regarding the definition of the game, all the participants created a practically identical TUIML scheme. The only differences that were found consisted of the name of the ids that each group assigned to the different elements, and also to the range of volume (between 0 and 1) that they assigned to the “shout” action.

While programming the game logic, the participants had to invest around 20 minutes to re-adjust the range of volume. For example, G1 and G3 considered that a person shouts when the volume of his/her voice is between 0.8 and 1 (being 1 the maximum volume that the microphone detects), but after some tests they realized that a volume of 0.5 already meant to shout rather loudly. After making the corresponding changes in the TUIML all the groups were able to consult the right events and managed to create the hybrid game without major problems (see Fig. 6.5).

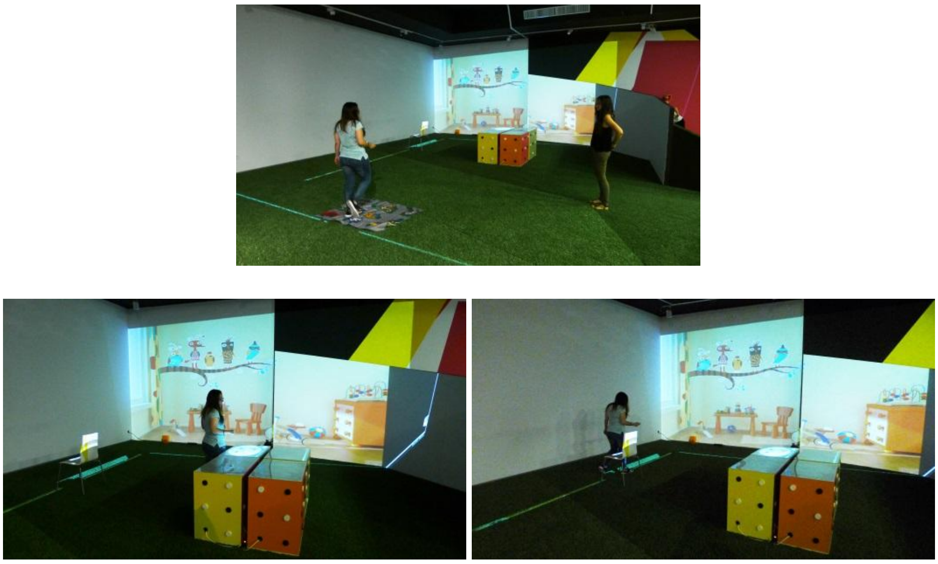


Fig. 6.5 Functional hybrid game. **Top:** The player steps in the rug. **Bottom-Left:** The player wakes-up the tabletop by touching it (a face appears in the surface). **Bottom-Right:** The player goes to sit on the chair.

Usability: At the end of the three tasks, the participants completed a survey comprising a System Usability Scale (SUS) [Brooke, 1996], that aimed to give a global view of the subjective assessment of the toolkit usability. This questionnaire is rated on a seven point Likert Scale rating from 1 (strongly disagree) to 7 (strongly agree), and it has a range of 0 to 100, 100 being the perfect score (see Table 6.5).

Table 6.5 Usability measures

GROUP	**1**	**2**	**3**	**4**
SUS	71	70	69.67	74.67
Avergage	71.34			

According to Brooke [2013] a SUS score above a 68% can be considered above average, although it would still be necessary to improve the evaluated software. In the same way, the IMI questionnaire obtained high scores for interest and usefulness subscales, and low values for tension subscales.

6.2 Implementing *StarLoop*

In order to have a first assessement of the potentiality of the JUGUEMOS toolkit to create hybrid games for IS, *StarLoop* game was created in the context of a Final Degree Project [Ruiz, 2017]. *StarLoop* aims to support middle-school children in the learning of programming and computational logic [Marco et al., 2017]. The game transmits advanced programming concepts such as loops and procedures. Children have to solve a set of challenges based on space missions by programming the movements of a space ship. The game is played in the JUGUEMOS IS by up to four children to solve different challenges by coding simple computer programs. *StarLoop* was the first complete game to be developed with the JUGUEMOS toolkit.

6.2.1 Game design

The game is set in the space: a one-eyed green alien character (Spowy) is in charge of instructing the new space-cadets (the children) through a set of challenges that progressively transmit the essential programming concepts they need to learn (see Fig. 6.6 Left). Each challenge consists of a grid board projected on the IS walls, with some cells containing colored stars (see Fig. 6.6 Right). At the bottom of the grid up to four spaceships (one for each player) appear. In order to complete a challenge, each spaceship has to collect all stars with its same color. Each child has a space ship assigned, and has to code a program with the sequence of movements that his/her spaceship need to do in order to collect all its stars.

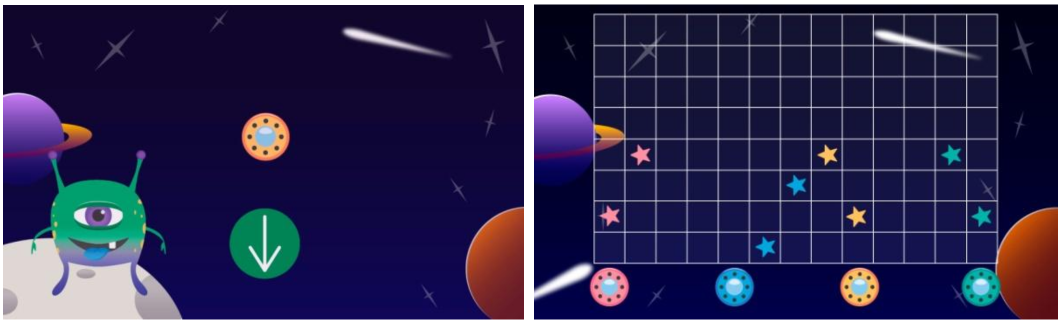


Fig. 6.6 *StarLoop* game. **Left**: Spowy explaining how to play the game. **Right**: A game scenario.

Each child makes his/her code using one of the tabletop devices. In each tabletop surface, a “Control panel” is projected (see Fig. 6.7). Children distribute playing pieces representing programming commands to compose a program. The tabletop control panel is divided in three rows:

- The lower row represents the Main program: commands placed in this row are executed in sequence (from left to right).
- The middle and upper rows represent the Pink and Blue procedures respectively: Procedures are used to store programs which can be called from the Main program. Children can optionally use procedures to solve the challenges; moreover some scenarios necessarily require procedures to be solved.

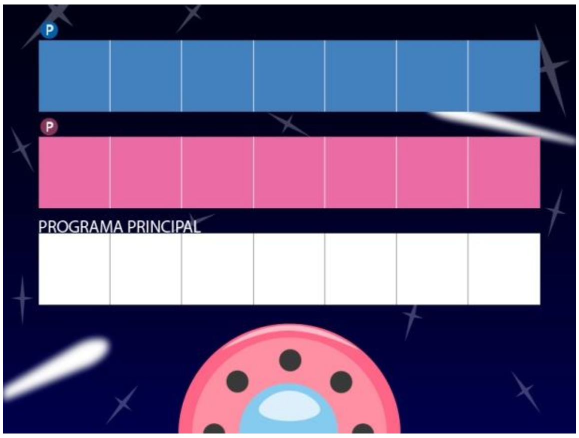


Fig. 6.7 Tabletop control panel.

Each Main program and Procedure rows are divided into seven cells each. Each cell has room for one command. Commands are physical tokens that children have to place on Main and Procedure rows in order to build the code. There are six different command tokens:

- **Movement** command (see Fig. 6.8a): This playing-piece orders the spaceship to move a cell on the grid. By rotating the playing piece, the direction of the movement (up, down, left or right), can be controlled.
- **Pick-a-star** command (see Fig. 6.8b): this playing-piece orders the space ship to recover a start in the cell where the spaceship is placed. If there is no star on that cell, the command has no effect.
- **Loop** command (see Fig. 6.8c): this playing piece is used to repeat all the commands placed to the left of this loop command. By rotating the playing-piece, the number of loops can be set. The commands that are covered by the loop command are those on the left which are connected with no discontinuity. That way, by having an empty cell, it is possible to have commands on the left of the loop, but unaffected by it. Figure 6.9 shows different examples of loops: six commands are covered by the loop, but the loop command is set to “1 loop” so the loop has no effect (up); three commands are affected by the loop command, which are going to be repeated four times (middle); only two commands are covered by the loop command, because an empty cell has been left after the two first commands (bottom).
- **Blue Procedure** command (see Fig. 6.8d): this playing piece is used to call the set of commands placed on the “Blue Procedure” row.
- **Pink Procedure** command (see Fig. 6.8e): this playing piece is used to call the set of commands placed on the “Pink Procedure” row.
- **Run** command (see Fig.6.8f): each child has a “run” playing piece with the color of his/her space ship. When this playing-piece is placed on the bottom area of the tabletop control panel, the program is executed. When this playing piece is removed from the tabletop, the program stops, and the child can rebuild his/her command, until all stars have been collected.

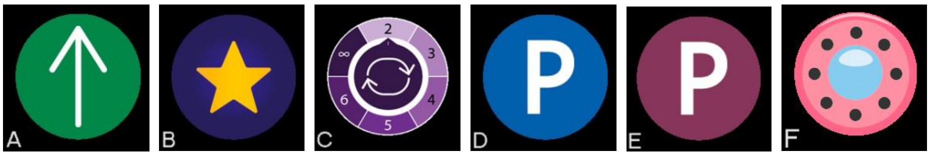


Fig. 6.8 The playing-pieces set. **a)** Movement command. **b)** Pick-a-star command. **c)** Loop command. **d)** Call blue procedure command. **e)** Call pink procedure command. **f)** The "run" command.

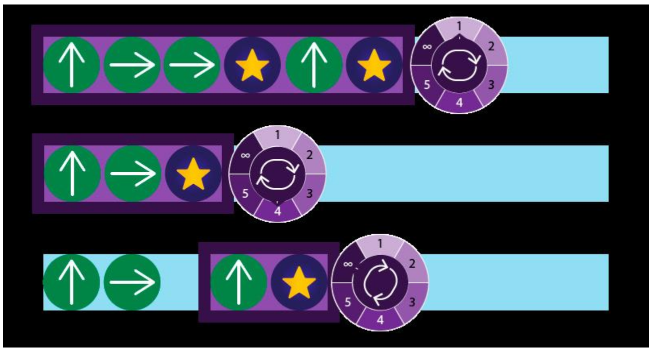


Fig. 6.9 Different loop examples.

StarLoop is composed of twelve challenges that progressively introduce programming concepts: the first five challenges can be solved using only the main program and no loops; the next three challenges require the use of loop commands; and the last four challenges have to be solved with loops and procedures. Prior to a challenge that requires the use of a new programming concept, Spowy appears on the wall projection and explains the new concept. Figure 6.10 show a sample challenge and its solution for the red starship, involving all the programming concepts supported by *StarLoop*. A challenge successfully ends when all color stars have been collected. When the twelve challenges have been completed, Spowy congratulates the children and promote them to "Space commanders".

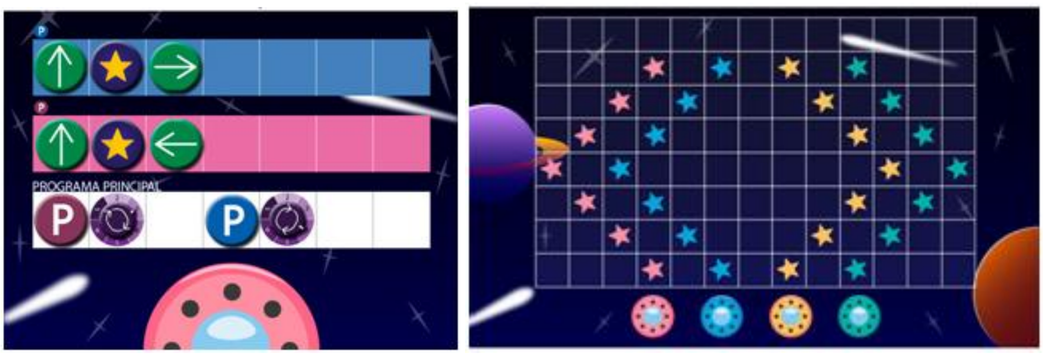


Fig. 6.10 Sample challenge solved by the red starship. **Left**: tabletop surface. **Right**: projection screen.

6.2.2 User tests

A test session has been carried out to retrieve the usability of *StarLoop* with children (see Fig. 6.11). Three children aged 8, 10 and 11 years were involved in the test. The 8 and 11 year-old children had some previous experience in coding using Scratch, and the other had no previous experience. Three adult supporters were also present during the session; they took observations notes, and also gave support to children when they got struck. Furthermore, the complete session was video-recorded to be later reviewed and analyzed to find usability problems.

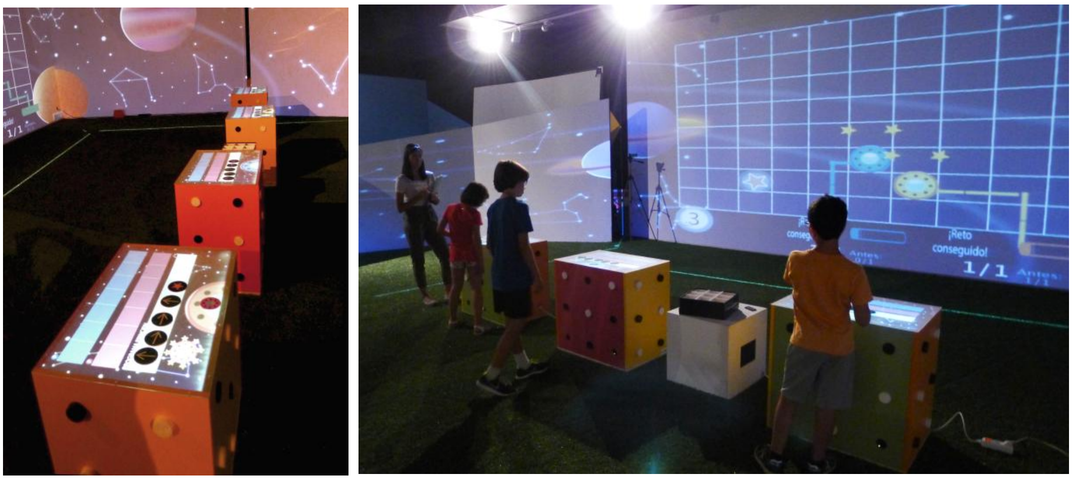


Fig. 6.11 Test session with children.

The three children played in order the twelve challenges. They needed 45 minutes approximately to complete the game. The three of them were able to complete all the challenges without nearly any support from adults: only in the few occasions the challenges were too difficult for children, they asked for help. The youngest child needed more support during the first challenge, as she did not completely understood what she had to do to complete the challenge, since some concepts were not previously explained by the Spowy character; for example, she did not know the order in which tokens are executed (from left to right). Therefore, an adult guided her to complete the first challenge, but after that she was able to complete the rest of the challenges almost without support: she completely understood the use of loop and procedure commands, and she was able to use them with only the explanations from the Spowy character.

No remarkable usability problems were observed during the test. Children were able to quickly test their programs and make corrections provided by the use of Tangible Interaction: they could easily remove, change or insert physical tokens on the tabletop surface, iterating their programs in short time. Moreover, two of the children claimed that when the programs were running, the spaceship movements were very slow, and they asked for being able to test their programs more quickly. In fact, the running of the code had been made slow on purpose to show the children how the code was running, outlining the token active at each time on the tabletop surface, and drawing the path followed by the spaceship on the wall projection. But in the test we realized that it was possible to fasten the testing of the code without children loosing track of the code execution.

On the negative side, little collaboration among children happened during the test. Collaborative behaviors were limited to a child, having collected all his stars so he had nothing to do, so he occasionally moved to other tabletop to give support to another child. Moreover, at the end of the session, the children were asked which aspects of the game they did not like. The 11 year-old child pointed out that, as he was nearly always the first one finishing the challenges, he had to wait for the other players to advance to the next challenge without anything to do, and that was boring. He commented that he could have progressed through challenges with independence of the rest of the players, and suggested that the game might have provided him with something to do during the waiting periods.

Even if *StarLoop* just made use of the Tangible Interaction paradigm, it was the first game that made use of the seven displays installed on the IS (the four tabletops screens plus the three projection screens) and that was fully developed with JUGUEMOS toolkit. However, the game was entirely developed by a programming expert, so we still needed to verify if the toolkit also allowed to lower at least a little the gap between developers and designers.

6.3 Multidisciplinary experience between designers and developers

The key to bridge the gap between the design and the development of hybrid games is to be able to quickly prototype and tweak game rules as well as the involved user interfaces and interaction devices [Ullmer and Ishii, 2000]. To achieve this goal, designers need conceptual models and methodologies to support the synthesis of new ideas; and developers need to get support from software and hardware toolkits that help the development of functional prototypes. JUGUEMOS IS and toolkit have also been designed with this purpose in mind: to provide multidisciplinary teams of designers and developers with the adequate tools to foster collaboration and creativity during the ideation, design and prototyping processes of innovative hybrid games. To prove their usefulness an experience with a multidisciplinary team was carried out in the IS [Marco et al., 2018].

The team was composed of five Graphic Design students of the 4th year at the Plymouth College of Art (UK) and six Computer Engineering students of the 4th year at the School of Engineering and Architecture (EINA). The Graphic Design students had previous skills on generating multimedia content for multimedia applications, but no experience in the design of interactive applications or hybrid games. The Computer Engineering students were all taking a User Center Design course, which provides them with skills to develop interactive multimedia applications, but they had no previous experience on ubiquitous technologies or on the prototyping of hybrid games. The experience was organized in four different sessions that are explained in the following subsections.

6.3.1 First session

The six Computer Engineering students attended a 3 hours practical session in the JUGUEMOS IS so that they could familiarize with the ubiquitous technologies involved and toolkit. The session was completely practical (see Fig. 6.12): each student, individually, had to follow a guided exercise in which they had to complete a simple hybrid game by using the Processing Development environment and the API. Students were provided with the official Processing documentation and with the JUGUEMOS toolkit documentation. The exercise was divided into four tasks that had to be completed in order to progress to the next one.

1. **Task 1**. Using a set of previously created graphic resources, they had to create a Processing code to compose a nature background (sky, fields and mountain) on the walls of the IS, and to animate a butterfly sprite. In this task the students gained skills on prototyping graphic applications with animations.
2. **Task 2**. They had to add 100 butterflies to the previous application and animate them with random movements. In this task, the students gained skills on managing multiple elements.
3. **Task 3**. They had to make the previous application interactive by sensing the audio of the IS, and "scaring" the butterflies (making them move faster) if the audio exceeded a

threshold. In this task, the students gained skills on managing audio and making the application react to different physical events.

4. **Task 4**. They had to make the butterflies follow the position of a user moving within the IS. For that purpose they had to integrate the RTLS sensor in order to extract the user's position. In this exercises, the students were improving their skills in getting the physical status on the IS and dealing with parallel interactions.

At the end of the 3 hours session, not all the students were able to complete the four tasks. Only two students completed all the tasks, and the others were able to finish the first three tasks but not the fourth. However, the main concepts and skills required to prototype a hybrid game in our IS using our toolkit were successfully learnt by all students as it was demonstrated in the fourth session.

Fig. 6.12 Computer Engineers session: **Left**: working on the practical exercise. **Right**: testing the functional hybrid game on the IS

6.3.2 Second session

We organized a 2 hours session with five Graphic Design students from the Plymouth College of Art. In this session, the students were introduced to the physical affordances of the ubiquitous technologies integrated in the IS, in order to bring physical interaction to hybrid games. We also showed them different examples of hybrid games developed for our IS (see Fig. 6.13).

Fig. 6.13 Different moments of the designer's session: **Left**: showing the interactive affordances of tabletop devices. **Right**: playing with a hybrid game example

They were also introduced to basic concepts of the Human-Computer Interaction field, including iterative and user-centered design, interaction styles, and design principles such as simplicity, consistency, visibility, affordance, and feedback. To do so, a critical discussion about the hybrid games previously shown was held. The goal was to provide students with a conceptual framework for understanding and evaluating Hybrid Games within the broader context of Human-Computer Interaction.

6.3.3 Third session

The third session lasted 3 hours and also took place in our IS. This time both computer engineers and design students worked together (see Fig. 6.14 Left). The eleven participants were distributed in two groups of 5 and 6 people respectively: 2 designers and 3 developers in one group, and 3 designers and 3 developers in another group. The designers were the ones in charge of thinking about the game concept, to choose the interaction paradigms that were going to be used, and to create the graphic resources of the games. Accordingly, the developers listened to the designers' ideas to decide if they were practical to be developed in the IS and within the three hours of the fourth session. The ideas that the two groups proposed are presented next. [The ideas that arose from the two groups are presented next.)

1. Car races (group 1): the designers came up with the definitive idea quite quickly. From the beginning they decided that they wanted to make a car race game for four players, by getting the best out of the four tabletops of the IS. Both designers and students had many doubts about the physical affordances of the tabletops despite the brief explanations of the previous sessions, so it was necessary to show them practical examples so that they understood what kind of interactions were supported by the tabletop (see Fig. 6.14 Right). The group defined the interaction with two physical objects to control the direction and the speed of the car, and we cleared up the developers' doubts about how to attach the fiducials to the physical objects that were going to be used as tangible tokens. Finally, the designers created the necessary graphical resources for the projection on screens and the tabletops with the technical support of the developers to choose the images resolutions and formats supported by the toolkit, a knowledge that the developers had acquired in the first session.

2. Building a car (group 2): originally, the idea was to make a construction game. The first idea was to build a house but the designers were having many doubts about the pieces that were going to compose it, so they eventually decided to build a car after learning about the concept that the other group had come up with. Regarding the possibility of using physical pieces the developers were not sure if Kinect was able to detect them, so it was necessary to clarify Kinect's affordances. We offered the second group the alternative of using visual recognition and to add fiducials to the objects to detect their movement in the IS. However, after some group discussion, the group chose not to use physical objects and to create a gesture interface based on the Kinect sensor. This time, the designers just had to create resources for the projection screen with the developer's technical support.

At the end of the third session, two perfectly defined concepts of games had been created. Since this was the last session in which the designers were going to participated, they gave us their opinion regarding the experience. They all agreed that they had learned a lot about the possibilities of the tangible user interface design, and that they would be interested in continuing working with the Computer Engineering students. One of them in fact said that he would like to learn about how the coding of the application had been made. Finally, they also commented that the IS was a great chance for the development of creative business.

Fig. 6.14 Different moments of the third session. **Left**: Intense multidisciplinary discussion of concepts. **Right**: Discussing physical interaction on the tabletops.

6.3.4 Fourth session

The fourth and last session was carried out only with the computer engineer students. They kept working divided in the groups that had been formed in the previous session, so that each group could work on the concept that they had developed with the designers. None of the students had any particular difficulties to integrate the different sensors necessary for their concept (tabletops for the first group and Kinect for the second group).

Figure 6.8 shows the developed games running in the IS. In the *Car races* game, players use the tabletops to drive their respective cars with two different objects that control the car's speed and direction (see Fig. 6.15 Top). In the *Building a car* game, players use their hands to "grab" the car pieces that appeared on the projection screen to "put" them on their corresponding place of the car shape (see Fig. 6.15 Bottom).

Fig. 6.15 Hybrid games created. **Top**: *Car races*. **Bottom**: *Building a car*

Regarding the game logic, the developers of the *Car races* had to receive the messages with the orientation of each controller placed on the tabletop ("rotate" 1D manipulation) and translate this data into two different values (see Fig. 6.16): one value corresponds to the rail where the car moves (upper, middle or lower rail), and the other to car speed (slow, normal or fast). In the of *Building a car*, the developers had to consider the messages that came from the Kinect that contained the (x, y) position of the player's hand ("move" 2D manipulation) to distinguish which car piece the player was selecting with his/her hand (see Fig. 6.17).

```
void eventoTAC(TAC lastTAC) {
 // tabletop1 has been touched
 if (lastTAC.getTokenName().equals("tabletop1") &&
     lastTAC.getConstraintName().equals("surface") &&
      lastTAC.getManipulation().equals("rotate")) {
         if (lastTAC.getSubtokenName().equals("control_speed_id")) {
                  // checking if the car goes slow, normal or fast
                  double angle=360-degrees(lastTac.getValores().get(0));
                  if (angle >= 90 && angle <= 135) veloc=6;          //fast
                  else if (angle > 135 && angle < 220) veloc=4;     //normal
                  else if (angle > 220 && angle <= 270) veloc=2;    //slow
          } // speed
         else if (lastTAC.getSubtokenName().equals("control_rail_id")) {
                  // checking if the car is in the upper or the lowe rail
                  double angle=360-degrees(lastTac.getValores().get(0));
                  if (angle >= 90 && angle <= 135) rail=1;          //upper
                  else if (angle > 135 && angle < 220) rail=2;      //middle
                  else if (angle > 220 && angle <= 270) rail=3;     //lower
         } // position
 } // lastTac
 …
  //The code for the rest of the Tabletops would be the same but changing the parameter of
 // the getTokenName() function:" tabletop2", "tabletop3", "tabletop4"
}
```

Fig. 6.16 Processing code to treat the events for the *Car races* game

```
void eventoTAC(TAC lastTAC) {
 // tabletop1 has been touched
 if (lastTAC.getTokenName().equals("Kinect") &&
     lastTAC.getSubtokenName().equals("rightHand") &&
      lastTAC.getManipulation().equals("move")) {
          if (lastTAC.getConstraintName().equals("wheel1")) {
                  // the hand has entered the wheel1 area
                  double x=lastTac.getValores().get(0);
                  double y=lastTac.getValores().get(1);
                  drawPiece(x,y);
          }
          //The code for the rest of the car pieces would be the same but changing the
          //parameter of the getConstraintName() function: "wheel2", "door", "carHood"…
 } // lastTac
}
```

Fig. 6.17 Processing code to treat the events for the "*Build a car*" game

As a result of this last session, thanks to the JUGUEMOS toolkit both groups managed to implement in three hours completely functional prototypes of the games based on the ideas provided by the designers. However, this was possible because the ideas presented by the designers were supported by the IS existing hardware: if different physical interactions had been proposed, the complexity would have notably increased since it would have been necessary to carry out the integration of new devices together with the programming of their corresponding Publishers. However, regarding the coding of the game, which is independent of the devices installed in the IS, the simplicity of the generated code indicates that it is to be expected that new design iterations can be carried out quite fast, which helps to lower the gap between designers and developers.

Videos of each concept were recorded and sent to the design students in Plymouth, who showed their satisfaction when seeing their concepts running. In case both groups were from the same city, more sessions could have been carried out, applying an iterative design process so that the designers could refine their concepts and explore more interaction possibilities.

6.4 Contributions Related to Chapter 6

Marco, J., Bonillo, C., Baldassarri, S., & Cerezo, E. (2018). Multidisciplinary Experience in the Creation of Pervasive Games for Interactive Spaces. In *Interactivity, Game Creation, Design, Learning, and Innovation* (pp. 182-187). Springer, Cham.

Marco, J., Bonillo, C., & Cerezo, E. (2017, October). A Tangible Interactive Space Odyssey to Support Children Learning of Computer Programming. In *Proceedings of the 2017 ACM International Conference on Interactive Surfaces and Spaces* (pp. 300-305). ACM.

CHAPTER 7:

CONCLUSIONS AND FUTURE WORK

7.1 Conclusions

The objectives planned for this Thesis and outlined in Section 1.2 have been successfully accomplished in the terms described below:

1) To go deeper into the use of tangible tabletops in therapy with children with special needs, and to extend their use to other collectives that may benefit from their characteristics, such as adults with cognitive impairments.

2) To develop the JUGUEMOS toolkit in order to facilitate the work of developers in the prototyping of hybrid games in interactive spaces, and to support different interaction styles, including (but not limited to) tangible interaction through tabletops.

Regarding the first objective:

- A state of the art about the inclusion of tangible tabletops with children with special needs and adults with cognitive impairments has been carried out, together with the analysis of toolkits aimed at therapists.
- In order to explore the use of tangible tabletops in therapy, we have used NIKVision [Marco et al., 2013a], a tangible tabletop device, and KitVision toolki, aimed at non-programming professionals. KitVision usefulness has been proved thanks to the collaboration with ASAPME, an association working with adults with cognitive impairments, where an occupational therapist spent a year using the toolkit on her workplace, including the NIKVision tabletop during her therapy sessions and creating new activities with KitVision.
- Activities specially oriented at children with development delays have been developed. Evaluations of these activities were also carried out in one of the centers of the Aragonese Institute of Social Service (IASS), which allowed to improve the KitVision toolkit thanks to the changes suggested.
- Thanks to a collaboration with Atenciona, a center aimed at working with Attention Deficit Hyperactivity Disorder (ADHD) children more evaluations were carried out which allowed us to extract a set of guidelines to design tangible activities for these children.

Regarding the second objective:

- The toolkit has been designed with developers in mind to address the three challenges that were extracted after analyzing hybrid games and toolkits aimed at their development: (1) to allow the easy integration of multiple devices, (2) to facilitate the coding of the game application, and (3) to support the management of multiple displays.
- Two game prototypes for the JUGUEMOS IS were created with the toolkit during the author’s research stays. In the first one the facility of integrating diverse devices in the JUGUEMOS IS was assessed, while in the second one a persuasive game was designed and created.
- Three use cases to validate either the usability of the generated tools as well as the potential of the developed games were carried out:
    1. An initial assessment of the toolkit usability was performed thanks to an evaluation carried out with Master Degree Students, where they had to design and implement a game prototype by using the toolkit.

2. When the toolkit was completely implemented, the *StarLoop* game was created: a game aimed to support middle-school children in the learning of programming and computational logic. *StarLoop* was the first complete game to have been developed with the JUGUEMOS toolkit.
3. A multidisciplinary experience with designers and developers was carried out, during which both groups collaborated to design and implement with the JUGUEMOS toolkit fully functional game prototypes for the JUGUEMOS IS.

Despite the initial objectives of this Thesis were fulfilled, there are some aspects that can be further worked on, as they are presented in the following section.

7.2 Future Work

There are three main lines of future work related to the JUGUEMOS toolkit:

- To carry out more intensive evaluations of the JUGUEMOS toolkit with developers: more formal quality-in-use models could be applied. The adaptation of metrics to evaluate this kind of tools could be an interesting research area.

- Development of more games for the JUGUEMOS IS: currently, a completely functional experience has been installed in Etopía, consisting of a hybrid game called *The Fantastic Journey*, fully implemented with the toolkit. However, more games should be developed to make the most of the potentialities that the JUGUEMOS IS offers.

- Explore intergenerational hybrid games for the JUGUEMOS IS: thanks to a new research project called PERGAMEX the creation of games aimed at children and elderly/old people is going to be studied and explored. JUGUEMOS toolkit will allow the implementation of the new games created in the context of this new project.

ANNEX 1:

ADDITIONAL EXPERIENCES USING JUGUEMOS TOOLKIT

A1.0 Annex Introduction

In this annex other activities and games developed with the JUGUEMOS toolkit are shown. The first shows the possibility of using the toolkit out of the JUGUEMOS IS. The second shows a complete one-hour interactive experience for children to be played in the JUGUEMOS IS.

A1.1 Activity in the Aragon School of Design (ESDA)

This experiencet was made possible thanks to a collaboration between the ESDA and our research group. The collaboration opened the opportunity for their students to explore the possibilities of advanced interactive installations and for us to continue to explore the expressivity of our toolkit and, besides, its capability to support interactive experiences outside our IS.

First, the ESDA organised a contest opened to all students, inviting to submit ideas for an interactive art installation suitable to be set up in the school hall. No indications were given except that the installation should transmit the idea of "Innovation". Five different concepts of interactive installations were submitted. An external team of professional designers judged the ideas from a pure design perspective (technical aspects were not judged), and one was chosen for its graphic approach to the "Innovation" concept.

The idea consisted of a room where visitors can enter to be reflected on the wall as a "cartoon" character. The virtual reflection mimics the visitor movements (see Fig. A1.1 Left). In addition, at the entrance of the room, a tactile screen lets visitors choose the virtual avatar they want to be reflected in the wall (see Fig. A1.1 Right)

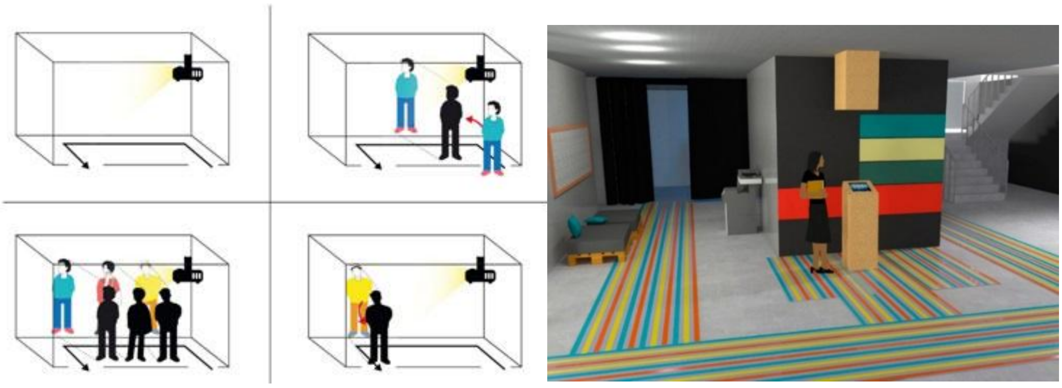


Fig. A1.1 Art concept of the installation. **Left**: Script. **Right**: Totem with tactile screen

A group of volunteer students and teachers from the different disciplines of the ESDA was formed with the aim of designing and implementing the final interactive installation; also, a research member of our group was involved to be in charge of the coding of the installation logic.

Several work sessions took place in our interactive space (see Fig. A1.2 Left). Our toolkit enabled us to quickly prototype the initial concept (see Fig. A1.2 Right). The tracking of the users' position was provided by a MS Kinect sensor. Two different displays were required: the wall display and the tactile screen. These last ones were solved using a 10' android Tablet.

Fig. A1.2 A work session in our interactive space. **Left**: Teachers and students from different design disciplines. **Right**: Students testing an early prototype of the art installation.

TUIML was used to model the different manipulations of the user's body parts (head, hands, feet …), and the different manipulations of touch actions on the tablet screen. This last one demanded to define several constraints associated with the buttons and sliders included in the graphic interface to be displayed on the tablet screen, which would enable users to choose a virtual avatar (see Fig. A1.3).

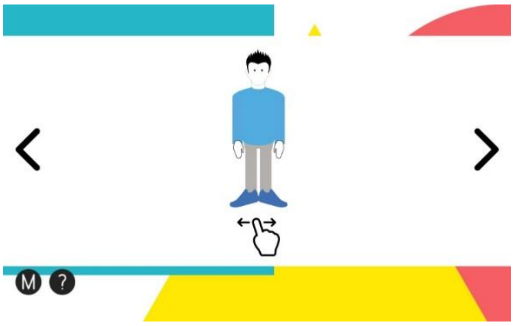


Fig. A1.3 Graphic Interface for the tablet screen. Each button and slider controller required to define a constraint to fingers subtokens in TUIML.

When the initial prototype was finished, the group was divided in different work teams depending on their design disciplines:

- Graphic designers were in charge of creating a collection of virtual avatars, and the graphic interface to be displayed on the tablet.
- Interior designers were in charge of building a dark room in the ESDA hall, and installing the hardware elements: video projector, Kinect sensor, and computers.
- The authors were in charge of implementing the game with the toolkit (see Fig. A1.4).
- Product designers were in charge of building a totem to accommodate the 10' Android Tablet (see Fig. A1.5 Left).

```
void eventoTAC(TAC lastTAC) {
// tablet has been touched
if (lastTAC.getTokenName().equals("tablet") && lastTAC.getSubtokenName().equals("finger")
&& lastTAC.getManipulation().equals("add")) {
if (lastTAC.getConstraintName().equals("rightArrow")) // user has touched the right arrow to select the
    avatar }
}
if (lastTAC.getTokenName().equals("tablet") && lastTAC.getSubtokenName().equals("finger")
&& lastTAC.getManipulation().equals("add")) {
if (lastTAC.getConstraintName().equals("characterArea")) // user has selected an avatar
}
```

```
… // events for each button of the tablet application
// user is moving
if (lastTAC.getTokenName().equals("Kinect") && lastTAC.getSubtokenName().equals("rightHand")
&& lastTAC.getManipulation().equals("move")) {
// checking if the car goes slow, normal or fast
double x=lastTac.getValores().get(0);
double y=lastTac.getValores().get(1);
drawBodyPart("rightHand", x,y);
} // lastTac
…
//The code for the rest of the body parts would be the same but changing the parameter of the
// getSubtokenName() and drawBodyPart() function by other body parts
}
```

Fig. A1.4 Processing code to treat the events for the ESDA game

Interconnectivity of the different elements of the installation (projector display, Android tablet, Kinect sensor, Broadcaster, and Host) was provided by installing a conventional Wi-Fi router . Finally, the interactive art installation could be enjoyed by ESDA students, staff and other visitors during a Design Week organized at the ESDA (see Fig. A1.5 Right).

Fig. A1.5 ESDA activity. **Left**: Totem designed to accommodate the Android tactile screen. **Right**: Interactive installation in the ESDA hall.

The students that took part in its development appreciated the experience. One of the students highlighted that the activity showed her a new application of design through new technologies. Also, she expressed her interest to learn more about coding for her future design career.

A1.2 *The Fantastic Journey* Game

This game is intended to be played in an interac-tive space placed in the Cesar-Etopia labs in Zaragoza, Spain. The game is directed towards children with ADHD, and it has been developed with pedagogues that have helped to establish the educational goals of the game [Gallardo et al., 2018].

A1.2.1 Justification and goals

The game is directed towards children with ADHD, who have problems of attention and concentration. The game helps to work these aspects in a fun way by means of the combination of different goals, devices and technologies. The educational goals of the game are the following:

- The development of selective, focused and maintained attention.
- The development of abilities of creation, organization and selection of the best strategy depending on the task.

- The planning of paths and processes linking space and time with the efficacy of the task.
- Listening in an active way.
- Solving problems using both oral and written information.
- Collaborating in an active and respectful way to achieve a common goal.
- Self-regulation of behavior in order to achieve the tasks in an effective way.

A1.2.2 Design of the game

The game is an adventure game, in which the protagonist has to progress over the story interacting with different characters and objects. It is multiplayer, as players will interact among them in a collaborative way to achieve a goal. The game is played between the real world and the virtual game. This implies that the game is hybrid mainly in the physical dimension, as players can freely move throughout the interac-tive space. It also could have some kind of social component, as players can inter-act with other people in the space and ask them for help.

The story is about a girl called Pipo, who has a dream in which she puts on a magic hat. With the hat on, she flies into the space, where she meets the Comet of Laughs, which delivers laughs all over the universe. During the encounter, Pipo gets lost with the bag of laughs, so she decides to travel through the space to find the comet and return the bag. The game uses the technologies present in the interactive space explained in Section 5.1. The target players of the game are aged between 7 and 12 years. The children will be accompanied by one of more mediators, which will supervise them, help them if they need it, or manipulate the progress of the game if the children find any difficulty. Before the start of every mission, a video with instructions is projected on the walls. The mediator has the option to replay it if needed.

The main elements that are present in the game are the following: the protagonist, the friends that will interact with her, the stars where the missions (challenges) take place and the sound, made up by a main theme and sound effects. The physiognomy and visual style of the protagonist have been designed by a product designer following the recommendations of the pedagogues related to which would work best with ADHD kids: smooth and round shapes, smooth and not loud colors, visually powerful but without adornment. The final appearance of the charac-ter is shown in Figure A1.6.

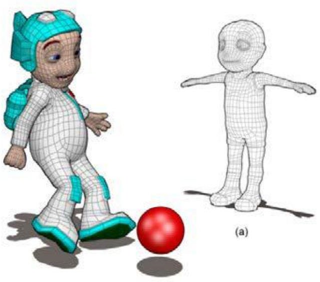


Fig. A1.6 Appearance of the protagonist of the game

Magic words: Here, children have to pay attention to the lyrics of a song and then, order the words that make up the chorus. This is made in the tabletop devices (see Fig. A2.13 Top-Left).

The Sun and the Moon: children have to make up the shapes of the sun and the moon (projected on a wall) by placing themselves (localization) in the interactive space (see Fig. A2.13 Top-Right).

<u>The search for the suitcase</u>: children have to find a suitcase and a key. The suitcase is a physical object that children have to find, whereas the key can be obtained by playing *StarLoop*, a game developed to improve computational thinking in kids [Marco et al., 2017] (Section 6.2).

<u>Keyword</u>: this mission allows working attention in both selective and global levels. Children will listen to a story in which a word is constantly repeated. Then, they will have to find the word in an alphabet soup that will appear on the tabletop devices.

<u>Indians</u>: this is *The Indian World* game that has been thoroughly explained in Chapter 5. The fact that children have to follow patterns allows to work successive processing and selective attention.

<u>Freeing the Stars</u>: the goal is to free three stars trapped in a spider web. Selective attention and simultaneous processing are the abilities devel-oped. The player has to select the elements required by means of gestural interaction (see Fig. A1.7 Bottom-Left).

<u>Meteorite attack</u>: this mission is about destroying a set of meteorites. It helps to work on selective attention and planning of time-space paths. The meteorites get destroyed by interacting with the tabletop devices (see Fig. A1.7 Bottom-Right).

<u>Butterflies</u>: children must stay quiet so that the butterflies that are pro-jected on the walls are placed on the flowers (Chapter 5). The idea is to work on the inhibition of impulsive behaviors and on self-control. When the players have been quiet for two minutes, the mission finishes.

<u>Encounter with the Comet of laughs</u>: the last phase of the game consists of a projection of the last scene, in which the protagonist meets the Comet of laughs, and of the playing of the song of the game, which will be sung and danced by the children.

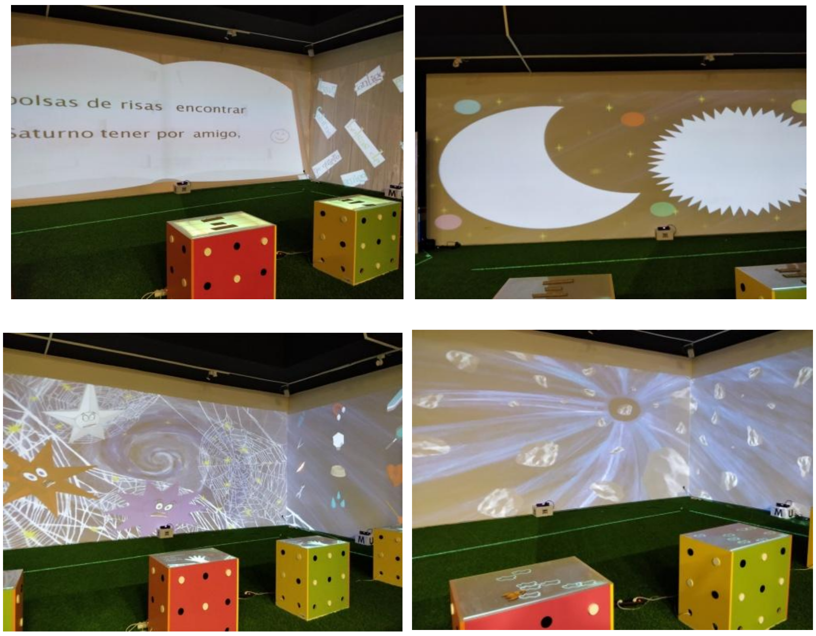


Fig. A1.7 Missions of *The Fantastic Journey*. **Top-Left**: Magic Words. **Top-Right**: The Sun and the Moon. **Bottom-Left**: Freeing the Stars. **Bottom-Right**: Meteorite attack.

Currently this game is in the process of being evaluated by educational experts, so the extraction of more formal results remains to be done.

ANNEX 2:

LEARNING PROCESS AND MEDIATION IN ADHD CHILDREN

A2.0 Annex Introduction

In this annex, a study of the learning processes of ADHD children, based on the PASS model, is presented. In these learning processes, mediation is also essential. Therefore, the interactions between the child, the facilitator (educator), and the interactive game are also analyzed in detail, delimiting the role of each and giving recommendations to achieve a good mediation process.

A2.1 The PASS Model: Fostering Learning Processes.

The PASS (Planning-Attention-Simultaneous-Successive) [Naglieri and Das, 1988] model combines neurological, psychological, and educational aspects and helps to understand how children behave during their learning process. In this section, we analyze how this model can help understand the behavior of children with attention deficit, hyperactive or not, when they face learning tasks, and also what factors are necessary to consider in order to fulfill their educational needs.

There are three functional units in the PASS model: attention (first functional unit), codification (second functional unit) and planning (third functional unit). There are two types of codification: simultaneous and successive; and there are three types of attention: arousal, selective and sustained. All these units are closely interrelated. Codification and planning interact to execute several actions and to facilitate knowledge acquisition and, at the same time, both these functional units depend on the existence of an adequate alert state (attention) so that learning can take place.

In the PASS model all the components act in an interactive way but, depending on the characteristics and requirements of the task to be performed, the participation of each process varies. The tasks can be codified in different manners, and the way to treat the information and how to perform the task are both forms of planning. Also, the intervention of attention is essential, and this must be sufficiently high so that the plans of action can be generated and used.

In fact, among these processes, attention has an important relevance in children with ADHD. It is composed of two other processes: one of them is automatic, does not require any effort and is not controlled (arousal); the other process is conscious, requires effort and is related to and depends not only on the attention functional unit but also on the planning functional unit. Arousal is related to being alert, and it can vary depending on external conditions (cold, heat, noise…) and internal conditions (affective and cognitive). Attention has been considered as an essential construct in psychology [James, 1890] and during recent years it has been an important research area in the context of learning difficulties [Mahapatra, 2016][Taddei et al., 2011]. These research studies have focused particularly on selective attention, which allows children to concentrate exclusively on the relevant stimuli, and sustained attention, which is related to the ability to maintain attention for a longer period of time. Technology may play a relevant role in both cases: a careful selection of different types of stimuli may help the child focus attention; and these stimuli may also improve motivation and engagement with the activity. In fact, in the case of tangible interaction, manipulative materials may be very attractive for children, adding a ludic component to the task. The task itself becomes a source of interest and motivation, activating the attentional process.

Children with poor attention skills are usually described as inattentive or as easily distracted. In general, they respond to a bigger number of stimuli, relevant or not, and are unable to concentrate during the performance of the task in hand. This results in an increase in their activity level which, in turn, can lead to a disruptive attitude at school. Consequently, these children develop behaviors that not only hinder their learning but also negatively affect their acceptance by teachers and schoolmates. However, the relationship between learning difficulties and attention problems is complex. In this context, Lahey et al. [1978] differentiate between behavior problems, learning difficulties, personality problems and hyperactive behavior. From this point of view, children with hyperactive behavior may (or not) display learning difficulties [Mayes et al., 2000].

As previously seen, planning is closely related with attention. In the PASS model, planning requires cognition and behavior to be active and strategic, instead of passive. In cases where there is too much information, or there are different processing options, it is necessary to make decisions, and this requires active and strategic thinking. Planning is necessary for solving new problems or tasks. Developing the planning functional unit will aid in managing children's inappropriate level of arousal, will facilitate plans for strategic performance, and will allow their self-regulation [Barkley, 2006]. Therefore, for children with poor attention skills, both the contents of the activities and the mediation and interaction processes that take place during the activities are essential.

Another essential issue to take into account is the social component. If the child can work the reflection skill about their own learning processes through a social act, this allows him/her to take joint decisions, enriched with different contributions. Moreover, the individual perception of the environment can be improved by sharing experiences with others, since other people can provide different views and perspectives that modify the child's comprehension, influencing his or her decision-making process. For a successful joint action, the aims, knowledge and beliefs of all participants must be considered, sharing them and working in groups and not individually, in order to achieve a greater benefit. In this way, the group thinks only as one and the individual is capable of communicating the thoughts and reflections of the whole group to other people [Frith, 2012]. Furthermore, the interaction and the joint action with colleagues improve problem solving when it is necessary to select data that provide specific knowledge. In this sense, it is essential to promote the interaction between children and the joint resolution of problems.

In conclusion, the PASS model explains how attention problems have consequences in all the processes involved in learning. In particular, attention can interfere in the planning process, which is responsible for the construction, execution and control of plans. Therefore, not only selective attention but also strategic behavior and metacognitive knowledge must be worked with these children, focusing on the planning process and promoting interaction. A technological device may have an important role in this process. In particular, we have seen that tangible interaction tabletops have several characteristics that make them potentially useful for the education of ADHD children: sensory engagement, accessibility and group learning. For a greater educative impact on the child, when designing activities it is necessary to:

- Focus specifically on selective attention and planning (**R7**).
- Design activities that bring cognitive challenges to the children, stimulating their attention and their development potential (**R8**).
- Develop activities that favor reflection on the consequences of their actions, considering alternatives and sharing their points of view with others (**R9**).
- Make the most of the manipulative possibilities of the tabletop as a resource to favor learning, interest, involvement and motivation of the children (**R10**).

A2.2 Mediation Process through Interactive Games

As we have seen, difficulties in attention processes affect other processes, especially those related to planning, so the internal construction of children's experience and their self-regulation are key aspects to consider. Through interaction, mediators generate opportunities to encourage abstract thinking by favoring news ways to perceive, challenge, and be open to other options and emphasize the process of change as a physical experience. Feuerstein et al. [1980] call this type of interaction "mediation" whenever it has a sense of change, what it is called "cognitive modifiability". This cognitive modifiability requires the mediator to work in Vygotsky's "Zone of Proximal Development" [1996].

Many studies have validated the potential of games for motivating learning and the improvement of academic performance [Bul et al., 2016][Erhel and Jamet, 2013][Haring et al., 2011], especially with children with resistance to change or with negative experiences in learning, as it uses to be in the case of children with ADHD. Games can be offered as a natural way to stimulate different cognitive processes, to enhance active and autonomous learning and to provide possible simulations that would be unachievable with other mediums. This way, they can be used as tools to encourage and facilitate mediation. Nevertheless, they have to be properly designed to avoid gamification pitfalls [Lee and Hammer, 2011].

With this idea in mind, starting from our tabletop experiences and taking Feuerstein's categories as a reference, we have made an in-depth study of the type of mediation appropriate for technology-supported activities, and whether it can be supported by the technology or not. We have arrived at a set of suggestions about the type of questions and requests that the mediator should make to encourage and to guide the learning process in technology-supported activities (see Table A2.1). In each case, mediation may be done either by a person (P), or the interactive game or the technology (T), or both (T-P). Besides, they are related to Feuerstein's categories.

Table A2.1 Mediation suggestions proposed for technology-supported activities. Highlighted those where Technology (T), and not only a person (P), may contribute.

	Mediation suggestions	**Med iator**	**Feuerstein's categories**
M.1.	Instructions should always be clear.	**T-P**	***Intentionality and reciprocity***
	It should be verified that children have understood the instructions and that they are able to express what they have to do.	**P**	
	Ask questions to help children focus their attention.	**T-P**	
M.2.	Ask questions to help children understand the context.	**T-P**	***Transcendence***
	Ask questions about the new principles that the children have connected from their experience.	**P**	
M.3.	Ask the children why.	**T-P**	***Meaning***
	Ask the children for precision about what they think and its meaning.	**P**	
M.4.	Adapt the tasks considering the age and experience of the children.	**T-P**	

	Cheer up.	**T-P**	***Feeling of competence***
	Ask how they make their decisions and how they have validated their hypothesis.	**P**	
	Ask the children how they make inferences and come to conclusions.	**P**	
	Ask about the satisfaction of the result.	**P**	
	Value positively a proper answer.	**T-P**	
	If the answer is not correct, ask the children what they would do in case of repeating the task.	**T-P**	
	Give children the option to test it after having thought of an alternative.	**T-P**	
M.5.	Ask about the causes and their relation with the consequences.	**P**	***Regulation and control of behavior***
M.6.	Encourage the children to think aloud (meta-cognition).	**P**	***Sharing behavior***
	Ask what they would do differently next time and about other ways to resolve the problem.	**T-P**	
M.7	Ask the children to justify their answers.	**T-P**	***Individual and physiological differentiation***
	Ask the children to express the difference between their responses and those of others.	**P**	
M.8.	Ask about the objective of the game, holding children's attention.	**T-P**	***Planning***
	Ask about the strategies used to achieve the game's goal.	**T-P**	
M.9.	Ask the children to express what new things they have done and what they have created.	**T-P**	***Challenge: Search for novelty and complexity***
	Ask the children to compare in order to discover what is new in their answers, and to accept the change.	**P**	
	Ask the children what new principles could be applied to new situations.	**P**	
M.10.	Ask the children what classification is being used and what this classification implies.	**T-P**	***Structural change***
	Ask the children about other possible classifications or criteria.	**P**	
M.11.	Ask the children about the results they expect.	**P**	***Search for an optimistic alternative***
	When children answer correctly, you must congratulate them	**T-P**	
	When they answer incorrectly, he/she/it must encourage them to continue with the activity	**T-P**	

Looking at Table A2.1, it can be concluded that although the technology and digital activities cannot completely replace the person or educator, they can be properly designed to have a relevant role as a complement and help for the educators. From a mediation perspective, it is necessary that the activities fulfill the following requirements:

- The design of the technological interaction has to facilitate the maintenance of the attention and interest, favoring the regulation of the impulsivity (**R11**).
- The activity should stimulate interaction among peers and with the person that facilitates the mediation (**R12**).
- The technological design has to be flexible and allow positive intervention of the mediator if needed, adapting to the each specific situation of the learning process and of the child's attitude (**R13**).

These mediation recommendations are consistent with the PASS model. They favor the attention process since they orientate the cognitive activity and the required response, and facilitate selective attention together with resistance to distractions. Regarding planning, they focus on problem solving, impulse control and processing.

All the recommendations presented in this Annex together with the ones obtained in the evaluation of tangible activities with ADHD children allowed the definition of guidelines presented in chapter 4 (Section 4.3.3).

ANNEX 3:

ASSESSMENT OF PERSUASIVENESS

A3.0 Annex Introduction

In this annex, the framework that we used to asses the persuasiveness of The Hidden Treasure game is presented, explaining the principles of the framework the game fulfills and also the ones it does not.

A3.1 *The Hidden Treasure* persuasiveness

The framework developed by Oinas-Kukkonen and Harjumaa [2018] takes some of the design principles established by Fogg as the base to establish their own, transforming Fogg's principles into system requirements so that developers can implement them directly as system features. The requirements are divided into four categories:

- **Primary task support** (1-7): the design principles in this category support the carrying out of the user's main goal when using the system.
- **Dialogue support** (8-14): this category covers the design principles related to the implementation of computer-human dialogue support, so that it helps users fulfill their goal or target behavior.
- **System credibility support** (15-21): the design principles in this category describe how to design a system so that it is more credible and persuasive.
- **Social support** (22-28): the design principles in this category describe how to design the system in order to motivate users by leveraging social influence.

Table A3.1 shows the requirements of persuasiveness that our game fulfills. The ones that appear with a ✖ are the ones our game does not fulfill.

Table A.3.1 Requirements of persuasive systems

	PRIMARY TASK SUPPORT		
	Principle	**Description**	**Game application**
R1	Reduction	*System should reduce effort that users have in regard to performing their target behavior.*	Children interact with the game easily by selecting the correct answer in the tabletops and by using the mobile.
R2	Tunneling	*System should guide users in the attitude change process by providing means for action that brings closer to the target behavior.*	Children are guided through a story where they have to intervene in order to achieve the good ending (finding the treasure).
R3	Tailoring	*System should provide tailored information for its user groups.*	The game has been created so that children work their social skills, by making use of a fantastic environment so that they do not associate the game with homework or school.
R4	Personalization	*System should offer personalized content and services for its users.*	The game has been created by having the final users (children) in mind.
R5	Self-monitoring	*System should provide means for users to track their performance or status.*	The game allows users to know how they are doing it by indicating when they give the correct/incorrect answers.
R6	Simulation	*System should provide means for observing the link between the cause and effect in regard to their behavior.*	The story allows children to see the effects of their actions depending on how they answer the game questions and how they solve the riddle.
R7	Rehearsal	*System should provide means for rehearsing a target behavior.*	The objective of the game is that children learn to behave correctly and to avoid bad habits like fighting, interrupting others

			and not listening to them.
DIALOGUE SUPPORT			
R8	Praise	*System should use praise via words, images, symbols, or sounds as a way to give positive feedback for a user.*	When children give a correct answer, the game congratulates them for it.
R9	Rewards	*System should provide virtual rewards for users in order to give credit for performing the target behavior.*	The reward of the whole game is to find the hidden treasure.
R10	Reminders	*System should remind users of their target behavior during the use of the system.*	Along the story, the children are reminded that the map is necessary to find the treasure, and that for that reason they must help stop the fight.
R11	Suggestion	*System should suggest users certain behaviors during the system use process.*	The game encourages children to listen to the story in order to answer the different questios correctly.
R12	Similarity	*System should imitate its users in some specific way.*	The game plot is based on fights that children may experience, like interrupting others and not knowing how to proceed when negative feelings such as anger are involved.
R13	Liking	*System should have a look and feel that appeals to its users*.	The images of the game and the objects are created to look appealing to the children.
R14	Social role	*System should adopt a social role*.	Children interact with the narrator of the story and also with Red and Green, who ask them for help to find the treasure.
SYSTEM CREDIBILITY SUPPORT			
R15	Trustworthiness	*System should provide information that is truthful, fair and unbiased.*	✘
R16	Expertise	*System should provide information showing expertise*.	✘
R17	Surface credibility	*System should have competent look and feel.*	The game has been created to be appealing to the children, and to avoid that they relate it to school related things.
R18	Real-world feel	*System should provide information of the organization and/or actual people behind its content and services.*	Such an information can be seen at the end of the game with the credits.
R19	Authority	*System should refer to people in the role of authority*.	✘
R20	Third-party endorsements	*System should provide endorsements from respected sources*.	✘
R21	Verifiability	*System should provide means to verify the accuracy of site content via outside sources.*	✘
SOCIAL SUPPORT			
R22	Social learning	*System should provide means to observe other users who are performing their target behaviors and to see the outcomes of their behavior.*	Children observe virtual characters to deal with a social situation.
R23	Social comparison	*System should provide means for comparing performance with the performance of other users*.	✘

R24	Normative influence	*System should provide means for gathering together people who have the same goal and get them to feel norms.*	The game is thought to be played for more than one child to achieve the same goal (encourage good social behavior).
R25	Social facilitation	*System should provide means for discerning other users who are performing the behavior.*	The game has been created to differentiate the children that play, thanks to the object they use to interact with the table and the RF beacon that locates them in the IS.
R26	Cooperation	*System should provide means for co-operation.*	Children cooperate to solve the final riddle.
R27	Competition	*System should provide means for competing with other users.*	✘
R28	Recognition	*System should provide public recognition for users who perform their target behavior.*	✘

From the 28 system requirements, 8 are not fulfilled by *The Hidden Treasure*. This is due to the fact that these principles have been designed to work for any kind of applications that aim to be persuasive. According to Fogg [2002], the design of systems can be done in different ways to influence people, depending on whether the system is designed to work as a *tool*, as *media,* or as a *social actor*.

When functioning as tools, the systems had to lead users through a process. Systems that belong to this category are computing programs whose objective is to provide an easy and intuitive interaction with the users, and that allow them to configure certain parameters to their liking, persuading them that way to keep using the application.

When working as media, the objective of the system is to persuade people by providing experiences that allow users to witness cause-and-effect relations based on their decisions. This category covers system based on simulations.

Finally, when working as social actors, the objective is to persuade the user by using the same principles humans use to persuade others, rewarding them with positive feedback and providing social support. The applications mentioned in the introduction section that encourage positive changes of behaviors by using scores and rewards are included in this category.

The Hidden Treasure case belongs to the second category, since the objective of the game is to offer an experience to children where they can see that their actions have consequences, and that a good social behavior usually leads to good things. For that reason, design principles based on providing trustworthy information (R15), expertise (R16), respect to the authorship of the system (R19), respect to its authority (R20) and verification of its accuracy (R21) correspond to the first category rather than to the second, where experiences are usually base don the entertainment to achieve their goal. The same way, design principles based on the comparison with other users' performances (R23 and R27) were not considered because with *The Hidden Treasure* we wanted to focus on collaboration rather than on competition. Finally, public recognition (R28) is more suitable for systems that work as social actors, to encourage the rewarded users to continue performing their target behavior adequately, and also to motivate others to do the same.

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