FINAL MASTER PROJECT THESIS

AR Learning Videogame For Kids With ADHD Symptoms

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July 2013
ACKNOWLEDGEMENTS

This work is dedicated to Alejandro, my nephew, a little always joyful child with Attention Deficit. *Alejo: I wish you a world where adults worry more about the learning of you and all the kids in the globe. I wish a world where you can develop all your potential.*

I would like to thank God, my family, my girlfriend and friends for their continued support.

Special thanks to Dr. Ramon Fabregat and Dr. Silvia Baldiris for their advice in this project.

Special thanks to Dr. Ferrán Viñas for his advice in ADHD-related issues for this project. Also, special thanks to Professor Maria Antonia Canals for their advice on mathematics pedagogy.

I would like to thank Colombian Ministry of ICT’s for the financing of my studies with the program “Talento Digital”.

This projects is supported by ARreLS – “Augmented Reality in Adaptive Learning Management Systems for All” project (TIN2011-23930) funded by the Spanish Ministry of Economy and Competitiveness.
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In this written memory are included the highlights of the project denominated “AR Learning Videogame for Kids with ADHD Symptoms.” The very nature of this project comes from a high worrying about the learning of digital natives, especially those affected with a very particular syndrome: The Attention Deficit Hyperactivity Disorder (ADHD). As the reader will find out, this syndrome comes with a lot of learning issues for kids, such as lack of attention and speech problems, among others. These problems are a high impasse for many families and the kids themselves. But today, there is hope because these kids are part of the so-called digital natives, this is, kids that were born in the last decade, and thus, they are very familiar with new technologies and learning methods.

As a matter of fact, based on this research’s background it can be noted that digital natives learn in new different ways, and maybe they are not able to learn by traditional methods because they don’t fit their special needs. However, kids do need to learn with and despite their condition.

So, to achieve that many questions rise: what are the motivators these kids can use to learn? What do they need to learn? How can they learn it? Of course, this project does not pretend to answer them all, but to have a first perspective on empirical and theoretical facts that give us a sight on the future applications of technology learning. Just to start, even today, it’s already a fact that with the advancement on new technologies and the rapid changing learners, nowadays teachers and instructor need to have the tools to improve their teachings, reach the maximum possibilities on their learners, and even more, amplify those capabilities.
So, in the search of answers to those questions, and in the looking for new tools that help special learners to learn, Digital Game Based Learning (DGBL or GBL) and Augmented Reality (AR) were found. In this research it is believed, as has already been demonstrated, that one of the main ways digital natives learn is by playing games. Of course is not the only one, but for this experience we decided to explore it. On the other hand, Augmented Reality seemed as a very handy technology, allowing items in real life to be augmented by computational systems for a better learning.

Briefly, those are the main reasons why this research aims to discover the considerations, practices and recommendations for teaching on special ADHD kids. As the research’s title suggest this study is looking to create an AR enriched videogame and applying it to kids with ADHD symptoms in order to explore its capabilities, elements and details to consider in the path to apply these technologies and methods in a real scenario or even in the classroom. As a case of study this research will center in the learning of mathematical skills in children.

Naturally, due to time and resources constraints, this study is not exhaustive, but empirical and exploratory. However, it is a supportive experience to further research on DGBL with AR. Also, this research will suffice some questions, but will sprout some others, such as: What are the main interaction features in an AR-Game-Learning session? Is AR-Game Learning really advantageous? How do ADHD kids improve with these technologies? Etc. These questions are left to future work.

This study was made as a Final Master Project, requisite to the title of Master in Information Technology and Automatics in the University of Girona (UdG). To contextualize the reader, the project had the following objectives:

**General Objective:**

- Create AR enriched videogame considering the principles of GBL for applying it to support some task developed by kids diagnosed with ADHD symptoms.

**Specific Objectives:**

- Build a state-of-art regarding AR Technologies and their applications on traditional Learning and GBL.
- Design an AR videogame applying GBL concepts and identified special necessities on ADHD-diagnosed kids.
- Develop the designed videogame.
- Design and execute an observation scenario with ADHD-diagnosed kids where they use the developed videogame.

As will be shown, these objectives were reached and for documenting purposes this memory is written. The document is organized as follows:

**Part two** including chapters 2, 3 and 4 describes the state of art.

**Chapter 2** shows the state of art regarding AR-Technologies. This chapter is meant to satisfy the first specific objective of the project in order to accomplish one of the objectives on ARreLS project, which this project is part of.
Chapter 2 shows the reader a brief about the characteristics of AR, its nature, software and hardware technologies and their applications. Also, the chapter includes examples on the application of AR to learning and videogames.

Chapter 3 describes state of art on Digital Game Based Learning, its description and most relevant concepts, to apply in the game. The chapter is meant to study the characteristics of GBL to be applied in the videogame as well to use the main strategies and adapt the principles proposed by main authors. The chapter also shows previous and recent experiences on the application of GBL to some learning cases.

Chapter 4 explores state of art in ADHD, its nature, its causes and the psychology point of view about the syndrome. The chapter is meant to establish the requisites for the game as taken from ADHD state of the art. These requisites are input for the game design this project involves. The chapter also shows some previous and recent examples on the application of technology, AR and videogames to the treatment of ADHD.

Part three including chapters 5, 6 and 7 shows the proposal of this project.

Chapter 5 shows the Game Design made in this project. The chapter shows the interviews had with expert while looking for input and recommendations. The chapter includes important considerations for the gameplay and some concepts conceived while designing the game. The chapter introduces the Game Design Document shown in Appendix B.

Chapter 6 shows the prototype’s description. The chapter describes the software building considerations taken in the process of building a prototype according to the game design shown in previous chapter. The chapter includes snapshots of the videogame and the description of software tools used and constructed to support the final product.

Chapter 7 shows the design and execution of the observation scenario as oriented by the psychology expert. The chapter shows main highlights on the planning of the scenario, guides for its assessment and the remarks of the execution itself. The chapter shows an analysis of the data gathered and some conclusions about the observations made.

Part four including chapters 8 and 9 summarizes the output and accomplishments of this project.

Chapter 8 shows the reasons why the project’s objectives are considered accomplished.

Chapter 9 shows conclusions and future work.
Augmented Reality (AR) is the technology chosen for enhancing the capabilities on the videogame this study develops. Since it is believed, and in this chapter it is explained why, this technology is able to offer broader means of interaction and exploration kids with ADHD need, in order to fully immerse in the object of learning.

AR is a term coined in 1992 by Caudell and Mizell (1992). They described a system built to help manufacturing process in aeronautics industry. It was basically a Head-Mounted Display connected to a computer in the waist, which functioned as a medium to display graphical guides for the worker’s duty. Fig. 1 shows a sketch presented on the paper.
For our days the system looks pretty tricky (given that today there are pocket-sized computers and glasses-shaped devices\(^1\)). However, the concept is still the same, Caudell and Mizell used AR to refer to a system that \textit{overlays computer presented material over the real world}.

Little they knew that this concept would become a nowadays trend and that it could be used even by children on a computer in their hands (As this will be shown here as an actual possibility nowadays).

Since this study pretends to create a DGBL videogame using AR, this chapter presents a state of art regarding AR technologies and their applications on both, traditional learning and Game Based Learning. This is meant to accomplish the first objective of this study.

For that, this chapter shows a brief commentary on AR technology and its current state in industry and academia. The chapter narrows later by showing the documentation found regarding themes of AR technologies, platforms, software, hardware, features and development tools. It also shows the AR experiences queried to explore previous and related work on AR applied to learning and videogames. All of this is used as requirements, benchmarking and opportunities for the game design.

\section*{2.1 AR TECHNOLOGY}

This section discusses the actual state of AR technology based on the revision of some papers, books and experiences. Evidently, there are many attempts on the world on advancing AR and making it more accessible. However, we highlight here the most relevant experiences for this study considering sameness, usefulness and reachability for the purposes of this study.

\footnote{\textsuperscript{1}For example, Google's “Google Glass”, a new technology capable of displaying Augmented Reality and other functionalities over a glasses-shaped system. \url{http://www.google.com/glass/start/}}
2.1.1 AUGMENTED REALITY CHARACTERISTICS

In this section is discussed the characteristics and features that an augmented reality system must have. This is to effectively characterize AR as a concept and as a real life applied technology. For that, here are shown the views of some important authors of this field and also some approaches regarding current applications, platforms, hardware and software available.

Two of the must-read documents in Augmented Reality are (R. T. Azuma, 1997a; R. Azuma et al., 2001) although kind of old, these two references are very important and highly cited because they shape augmented reality as a concept, as an applicable technology in many fields (including entertainment) and it describes some of the most important issues an AR system designer should have in mind as they are still main issues even nowadays.

Azuma states that a computer graphics computational system should be defined as such if it complies with the following (R. T. Azuma, 1997a, p. 2):

1. **Combines real [world] and virtual [environment]**: The system must be in the middle of the real environment – virtual environment spectrum (Milgram & Kishino, 1994) (Shown in Fig. 2). This is, that the system is not a mere visualization of the real world (such as a digital camera), but it is not a full virtual world (such as a Virtual Reality system).

   ![Image](image_url)

   **FIG. 2: THE REAL-VIRTUAL ENVIRONMENT CONTINUUM.**

2. **Interactive in real time**: This is said to differentiate from those systems that mix real world elements with rendered elements, such as those systems used in movies post-production.

3. **Registered in 3-D**: The system interacts with the real 3-D world by registering in it virtual elements. The word “registering” indicates that the system relates, somehow, those real elements with the virtual elements.

Those characteristics are (in essence) still up-to-date, however for example, it has been suggested that AR system can go further than the visual sense, to reach other senses such as hearing, and touching (even smelling) (R. Azuma et al., 2001 p. 1) but that is beyond the scope of this study, because the objective is to create a mainly visual augmented system (a videogame).

2.1.2 AUGMENTED REALITY HARDWARE

Hardware capabilities are growing, and they have definitely changed a lot since the first attempts on displaying augmented reality objects.
One of the main hardware aspects that an AR system designer must decide is the display. In (R. Azuma et al., 2001) was given a primary classification on display devices. The authors classified them among, Head-worn, Hand-held and Projective devices. However, later Van Krevelen and Poelman (2010) made a deeper classification of these devices, and they even offered a comparing view on their individual advantages.

Krevelen and Poelman propose these categories of display systems, based on their position respect to the user:

- **Head-worn**: A System the user mounts on their heads, providing imagery in front of their eyes (R. Azuma et al., 2001). Today these systems can be very small and lightweight, they make use of a battery and can have Wi-Fi or Bluetooth networking, however they are still not cheap enough to make a mass production, but commercial product such as the Goggle Glass are giving great expectations (Levy, 2013).

- **Hand-held**: A system the user can carry in their hands. Some use a flat screen to display video-see-through with a superimposed virtual layer. Compared to desktop computers its computing power can be smaller, however, nowadays with Smartphones being cheaper than ever and with the best processors ever, hand-held is the best option to introduce AR as a realistic mass-market opportunity. (Krevelen & Poelman, 2010)

- **Projective (Spatial)**: The system projects the virtual imagery over the real world registering the virtual images coplanar to the real objects. In this category, the displays are static (e.g. a TV, or PC monitor) and here are included the projective systems, in which a projector projects an image over a surface and those in which a monitor displays the images from a camera with a virtual layer superimposed. This is the technique used by, for example, show televisions where environments (like a swimming pool or a race track) can be easily augmented (Krevelen & Poelman, 2010).

Note that Krevelen and Poelman (2010) mention almost the same categories than Azuma (2001), however they rather call the Projective systems “Spatial” to include not only those that make use of a projector, but also the systems that recognize an element in the space by a fixed camera, and display the results on a fixed monitor.

Also the authors explain the three types of visual display:

- **Video**: The user sees a video of the real world (captured with a camera) with a superimposed virtual layer.

- **Optical See-Through**: The user sees through a transparent device, and the virtual elements are projected

- **Projective**: Augmented elements are projected over the real elements directly, user sees the virtual elements totally surrounded by the real environment without the use of other display system.

To summarize this, Table. 1 shows a hierarchy of these devices proportioning an example to each category.
In this sense, actually there are plenty of devices and platforms AR can be executed on. Of course, several of these are in development stages, others are laboratory exclusive and others are adaptations of current platforms (such as the PSP showed in the above table, adapted via a camera embedded in the “Invizimals” Game). Authors agree in that there is plenty of work to do before AR be broadly and socially accepted, but with phenomena such as ubiquitous computing and cloud computing, new efforts can be carried on.
Even so, authors agree that some of the system categories shown, like the fixed monitor display and Hand-held configurations, are already ready to offer commercial and mass-production systems to apply in different areas.

2.1.3 AUGMENTED REALITY SOFTWARE

In AR systems not only is important to assess the right hardware and interaction devices, but to consider the software platforms. Mainly, because the right software framework can mean a difference in registering, delay and tracking features. For this study was necessary to explore the commercial available software platforms that could be used to develop the game.

Of course, there are plenty of software tools that allow the development of AR systems. However this commentary will focus in those related to the development of games to standalone and Hand-held platforms as has already been mentioned. Also, this study is not a project aimed to a low-level effort on developing AR tools, but to effectively apply AR technology beyond the mere use of the technology. Ergo, the tools explored are high-level tools and frameworks that hopefully represent a time-saving resource for centering the work in other important aspects of the product, such as the content, the learning, and entertainment issues.

Also for that, simple marker-based AR was considered. A Marker-based AR system is that which makes use of Marker-based tracking. “Tracking” refers to the action of track the user's position and rotation according to the scene being observed. An AR system needs to know where the user is and what they are looking at (Krevelen & Poelman, 2010; Siltanen, 2012). Marker-based systems track the user by detecting the position of an easily detectable predefined sign (the marker) in an image captures by the camera. Once the sign is detected, it then defines both the correct scale and pose of the camera (Siltanen, 2012). Fig. 3 shows an image of Marker-recognition, note that Marker-based tracking is not limited by the display-device, for example, in the picture a Head-worn device is used.
Marker-based tracking is currently the easiest way to include AR technology in a software, since there are some toolkits and software aimed to facilitate the detection of the markers, by offering routines that run pattern-detection algorithms in the image captured by the camera.

While reviewing the literature and in the process of searching these toolkits, the ARToolkit (ARToolworks, 2013a) mentioned in (R. Azuma et al., 2001; Siltanen, 2012). This project, started in the early 2000's, is now a fully commercial product with open-source licenses and commercial licenses.

Many toolkits have been developed in the last decade to facilitate the production of AR Marker-based systems. Some of them are wrappers and API's for the ARToolkit’s algorithms. Several of these tools were reviewed for this study and Table. 2 summarizes and comments them.

TABLE. 2: AR SOFTWARE TOOLKITS

<table>
<thead>
<tr>
<th>Tool</th>
<th>Description</th>
<th>Commentary</th>
<th>Website</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARToolkit. (ARToolworks, 2013a)</td>
<td>It is one of the earliest of the commercial tools used to develop marker-based systems. It features several pattern recognition algorithms and OpenGL-based functionalities.</td>
<td>The toolkit has an open-source version. However, in it rawest form it is a low-level C++ tool, so other higher level tools and wrappers are preferred.</td>
<td><a href="http://www.hitl.washington.edu/artoolkit/">http://www.hitl.washington.edu/artoolkit/</a></td>
</tr>
<tr>
<td>UnityAR (GVU Center, 2013)</td>
<td>It is a set of plugins for the Unity3D Game Engine that allows users to easily</td>
<td></td>
<td><a href="https://research.cc.gatech.edu/uart/">https://research.cc.gatech.edu/uart/</a></td>
</tr>
<tr>
<td>Tool</td>
<td>Description</td>
<td>Features</td>
<td>Website</td>
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<tr>
<td>------</td>
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</tr>
<tr>
<td><strong>Vuflora</strong> (Qualcomm, 2013)</td>
<td>It is an AR Software Development Kit (SDK) for mobile devices that enables the creation of AR applications.</td>
<td>It has good pattern recognition features and API. It is exclusively for Han-held platforms IOS and Android. It has support for Unity3D.</td>
<td><a href="http://www.qualcomm.com/solutions/augmented-reality">http://www.qualcomm.com/solutions/augmented-reality</a></td>
</tr>
<tr>
<td><strong>NyARToolkit</strong> (NyARToolkit, 2013)</td>
<td>This is a Japanese project based on ARToolkit. It provides an API for visual AR.</td>
<td>This toolkit has support for many languages such as Java, C#, AS3 and it has a version with scripts for Unity3D. Fig. 5 shows a prototype made for this study on the exploration of this platform.</td>
<td><a href="http://nyatla.jp/nyartoolkit/">http://nyatla.jp/nyartoolkit/</a></td>
</tr>
<tr>
<td><strong>ARToolkit for Unity</strong> (ARToolworks, 2013b)</td>
<td>It is a plugin for the Unity game engine, which integrates the existing ARToolKit4 augmented reality tracking library with Unity’s graphics and game development features.</td>
<td>This is a fully featured ARToolkit for Unity3D. It can only be used with the acquisition of a commercial license to ARToolworks. There is not royalty-free version of this.</td>
<td><a href="http://www.artoolworks.com/support/library/ARToolKit_for_Unity">http://www.artoolworks.com/support/library/ARToolKit_for_Unity</a></td>
</tr>
<tr>
<td><strong>FLARToolkit</strong> (ARToolworks, 2013c)</td>
<td>It is the Flash Actionscript (v3) version of ARToolkit which can be used to quickly develop web-based AR experiences.</td>
<td>This is used with the Adobe Flash platform, and its best feature is that its deployment can be taken easily on web browsers.</td>
<td><a href="http://www.artoolworks.com/products/web/flartoolkit-2/">http://www.artoolworks.com/products/web/flartoolkit-2/</a></td>
</tr>
</tbody>
</table>

**FIG. 4:** One of the experiments made with UnityAR
Note that it has been remarked the compatibility with the Unity3D Game Engine (Unity Technologies, 2013) this is due to its easiness of use and experience of the main researcher on it. For this development, it was preferred a tool that allows easy 3D content integration and since the development is aimed to a standalone offline product it was no necessary the browser deployment. Hence, the final decision was to use NyARToolkit as the AR marker-tracking platform and Unity3D Game Engine as the content creation tool.

2.2 PREVIOUS EXPERIENCES WITH AR

To finalize this state of art, a review of the literature is shown here about previous applications and experiences on learning and gaming applying AR. This is to try and emulate significant experiences and feed this project’s game design. Therefore, it is not an exhaustive recompilation of all the experiences until today, but a brief commentary on previous experiences to benchmark.

2.2.1 AR ON LEARNING

From the documented experiences found in the literature review it can be easily concluded that AR has indeed been applied to several educational experiences. Those experiences are widely varied and they are aimed to accomplish small empirical situations to observe learner’s reaction and the outcome of this type of AR Application. For that, those experiences are introduced here, first to show that AR is a feasible technology to apply in the classroom. It is important to have in mind that yet AR it has its own issues, troubles and disadvantages (M Dunleavy & Dede, 2009) that schools and teachers need to know and overcome.

Nevertheless, AR has been considered as one of the emerging technologies of the last decade that are viable to apply to learning. It is mentioned in the 2010 Horizon Report (New Media
Consortium, 2010) that its adoption should be given in two to three years from 2010 (i.e. now) and they mention that:

“Augmented reality has strong potential to provide both powerful contextual, in situ learning experiences and serendipitous exploration and discovery of the connected nature of information in the real world” (Johnson, Levine, & Smith, n.d.)

Also, Augmented Reality is mentioned in the Handbook on IT for Education and Training (Adelsberger, H. H., Kinshuk, Pawlowsky, J. M., & Sampson, Adelsberger, Kinshuk, Pawlowsky, & Sampson, 2008) as:

“Virtual and augmented reality are deemed powerful learning tools because they allow, in principle, experiential learning without displacing the learner when real-experience environments are available”

This leads to think that most of the experiences had until now have been significant enough as to provide teachers and school managers with a new option for learning.

First of all, most experiences have shown the adequacy of AR applied to learning, as it consists of a series of elements that can lead the learner to start a constructive approach on their learning as it poses the learner on a physical and social context where to observe, experiment and learn (Matt Dunleavy & Dede, 2009). Dunleavy and Dede (2009) list some of the most important experiences until 2009, including among others:

- **Environmental Detectives** (Klopfer, 2008): A multi-player, handheld AR simulation game designed to support learning in advanced introductory (late high school and early college) environmental science. In this study, authors also explored the gaming and learning issues of Hand-held AR systems, establishing a framework for its use.
- **Mad-City Mystery** (Squire & Jan, 2007): An AR application where users investigate a murder mystery involving environmental toxins

All the experiences revised have the common feature, that user immerse themselves in a world, augmented from the real world in order to solve or do something by themselves, with just an indirect coaching from the guide or teacher.

AR has also been used in other kind of learning experiences, such as museums (Woods et al., 2004), English Learning Systems (Liu, Tan, & Chu, 2007), Virtual Learning Environments (Muñoz-cristóbal, Prieto, Asensio-pérez, Jorrín-abellán, & Dimitriadis, 2012), Mobile Outdoor Learning (Ronen & Cohen, 2012), and Learning Objects-based Learning (Figueroa, 2012).

As has been said, mobile Hand-held devices are the start of AR mass appropriation; some studies have already stated the opportunities on the mobile AR trending for education (FitzGerald, Adams, Ferguson, & Gaved, 2012; Ifenthaler & Eseryel, 2013; Wu, Lee, Chang, & Liang, 2013).

There are plenty of interesting, conclusive and important experiences that have been had with AR on learning that are worth to revise. Of course, they are mentioned here only to carry a firm conclusion in that, as can be evidenced by the huge amount of literature out there, AR is currently a technology that, although is not being widely applied or adopted by schools, is a
new IT important effort on the learning objective, and that justifies this project’s selection of it to the learning application.

### 2.2.2 AR ON GAMES

Similar to the application of AR to learning, AR as a technology has entered the world of entertainment, as it’s one of its fundamental applications (Krevelen & Poelman, 2010). Since this is essentially a project oriented to develop a game and perform a game session, it’s important to revise some previous experiences to benchmark and support this study.

In the academic side of this literature review, it was found some interest in the construction of games as experiences, and there are some attempts to standardize the process, and to establish frameworks for this work. For example, the already cited work of van Krevelen and Poelman (Krevelen & Poelman, 2010) reviews some games with AR technology.

- **ARQuake**: A game where mobile users fight virtual enemies in a real environment.
- **Game-City**: A ubiquitous large-area multi-interface mixed reality game.
- **Sky-Invaders**: A 3D game where the user has to protect the Earth from invading aliens by shooting down waves of UFOs (Avery & Piekarski, 2006)
- **Aqua-Gauntlet**: A multiplayer game where users wear a video see-through HMD and shoot monsters (Avery & Piekarski, 2006).

Above described works learning experiences include also a game-like application. Games such as *The Eduventure* (Ferdinand, Müller, & Ritschel, 2005) *Environmental Detectives* (Klopfer, 2008) and *Mad-City Mystery* (Squire & Jan, 2007) include gameplay experiences where the learner has a set of mechanics and rules to play.

Those laboratory experiences may seem tricky nowadays, since some of them require outdoor AR game hardware as the one shown in Fig. 6.
Nonetheless, with the advancement of Smartphones hardware and software, the most popular games today for Android and IOS, the leading platforms on mobile technology today, include AR game experiences and games that require merely of the cam embedded in the phone, sometimes some markers, or a GPS for the tracking.

"Hot Top Tens" web page (Dagatan, 2012) ranks among the best AR games currently, the following:

- **Ingress** (Niantic Labs, 2013): It is a novel game played using an Android smartphone. It features a complex backstory, and players are given a “side” (blues & greens) the objective is to gain as most parts of the earth (visualized with Google Maps).
- **ARDefender** (Int13, 2013): It is a Tower-defense-like game where the player has to defend a virtual fortress placed in a real environment.
- **Droid Shooting**: One of the most popular game (because it is free, not because it is the best) for Android. Its premise is simple; the user shoots some androids in 3D, while moving around the real space.

Other platforms besides the mobile ones are entering in the production of AR games. For example, Sony in collaboration with SCE London Studio developed an AR game called *Wonderbook: Book of spells*. A game where the player uses the “PlayStation move” (PS move) and a marker-printed book. The player sees themselves and the virtual elements rising from the book’s position and they can casts spells using the real PS move that turns into a “wand” in the virtual world. Fig. 7 shows an example of the *Wonderbook*. Also, Sony has plans to release new titles that make use of the *Wonderbook* (Reynolds, 2012).

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2 The PlayStation move is a motion-sensing game controller platform for the PlayStation 3. [http://playstationmove.com/](http://playstationmove.com/)
2.3 CONCLUSIONS

- Is easy to conclude this chapter by saying that even with the natural, technological and social issues AR has, it is surely giving great steps. From the perspective of the very nature of the concept has not changed a lot. However, last decade’s advancements seem to suggest AR is to be applied now and in the future, always with the main issues in mind.

- Nonetheless, several efforts have been applied in AR in general, but also in Learning and Games. Which indicates this is a good point to start studying applications on AR and Learning with Games. In hope with a generalized normativity in the future for AR, for outdoor, indoor, and mobile out and in the classroom.

- This chapter has given the main considerations on the field of AR; it has also given several important experiences in both, the learning and the gaming areas. Which is important, since that way, the decisions in the project are broadly informed.

- In this study, it was decided to develop for a spatial or Hand-held approach, this due to time and resources restrictions since most projective, head-worn or optical devices are in fact expensive and difficult to develop. In fact, for this project it was decided to use a spatial, marker-based, NyArToolkit based approach. Also, inspiration on the videogames revised and the state-of-the-art wonderbook was had as input to the game design.
Digital Game Based Learning (DGBL) is the “marriage” between educational content and computer games (Prensky, 2001 p. 145). In the last decade it’s been studied that games are pretty useful for learning and training. And as a matter of fact, it has been said that it can have greater advantages in many learning scenarios with digital natives (Prensky, 2001 p. 146). DGBL is today being considered as a main tool to be adopted by schools in the following two to three years, as the Horizon Report claims (Johnson, Adams, & Cummins, 2012):

*Research and interest in the potential of gaming on learning has exploded, as has the diversity of games themselves, with the emergence of serious games as a genre, the proliferation of gaming platforms, and the evolution of games on mobile devices.*

For this project it was decided to consider some principles for the game design, given the advancement on DGBL. Thus, a literature review was made in order to find some concepts, approaches or techniques appropriate to apply in this project’s proposal.

In this chapter the findings of that literature review are shown. DGBL concept is described, and some experiences and author’s statements are shown. From this literature review, design
principles were extracted to guide the game design, according with DGBL principles and successful experiences.

3.1 DGBL CONCEPTS

Until now, most DGBL concepts come from dozens of essays and articles published by education experts (Eck, 2006). In this section are reviewed some of them, considered the most important for this study. However, DGBL is still a paradigm under construction, thus most of the principles here, constitute an advice on the construction of actual games for learning in the hope of experiences that concrete the paradigm in the classroom in a near future.

3.1.1 FUN: THE GREATEST MOTIVATOR

Marc Prensky proposed DGBL in his 2001 book Digital Game Based Learning (Prensky, 2001) believing that this is a must-apply strategy to significant learning in the future. Prensky says that mainly because of its effectiveness, versatility and adaptability to almost any learning content. Also DGBL theorists say that DGBL works because of the motivation learners find in learning with digital games: Fun (J P Gee, 2006; J. Gee, 2005; Prensky, 2001; Trybus, 2012).

Fun is probably the most found word among DGBL works. This is allegedly because nowadays learners have changed radically; today's students are no longer the people our educational system was designed to teach. Ergo, It suggests that new efforts on researching the way nowadays’ learners learn.

Of course fun cannot function by itself. For learning there has to be other considerations involved. Authors believe that orchestrating appropriately those elements in a stimulatory context fit into what is constituted now as a new paradigm on learning.

3.1.2 LEARNING PRINCIPLES

James Paul Gee in his essays Good Videogames and Good Learning (J. Gee, 2005) stated 16 learning principles a good learning videogame should consider. The work describes them more precisely, but they are summarized here:

1. **Identity**: The learner commits with the game.
2. **Interaction**: Games allow the learner to interact, something a book doesn’t
3. **Production**: Players no only consume games, they “produce” them in many ways by playing and taking actions.
4. **Risk taking**: Games allow players to fail with little consequences, something real life may not afford.
5. **Customization**: Usually players customize their game, thus making it “theirs”
6. **Agency**: The sense of control
7. **Well-ordered problems**: Games are constantly giving players “Cognitive conflicts”. Player put hands-on the problems with the tools it offers which leads to solutions and learning.
8. **Challenge and Consolidation**: Challenges are accepted by players, player must acquire abilities to surpass them, and when that happens, and after some repetition that ability is consolidated.

9. **Just in Time, On Demand**: Videogames give players information when they ask and just in time. Unlike books that give lots of words out of context.

10. **Situated Meanings**: Meanings come with relation between words and experiences. Videogames give both, unlike definitions or simple concepts in words.

11. **Pleasantly Frustrating**: School is often too easy or too hard for different students, however good learning videogames let the player feel challenged but at the same time they feel they can do it.

12. **System Thinking**: Thinking on elements, relationships, events, facts, skills, etc is important to learning. Videogames encourage that.

13. **Explore, Think Laterally, And Rethink Goals**: Exploration, experimentation, hypothesis stating. Videogames encourage the player to think out-of-the-box. Something traditional learning doesn’t by preferring “Linear thinking”.

14. **Smart Tools and Distributed Knowledge**: Elements in game (such as characters) have often “skills” they lend to the player; they can be called “smart tools”. Then the player is encouraged to use those elements and skills and distribute the knowledge among his “smart tools”. Tool-use and knowledge distribution are very important in training.

15. **Cross Functional Teams**: Applicable to games where teams can be formed. These types of games encourage team making ad team commitment to achieve goals.

16. **Performance before competence**: Unlike traditional learning, Videogame prefer the player to do, before be competent. This is important for hands-on learning.

All of these principles were considered for the game design. Of course, their meaning and applications are extremely broad; however, each principle complies with the spirit of the paradigm.

### 3.1.3 LEVELS OF LEARNING

Mark Prensky, the main author on DGBL has proposed that this new paradigm is not only useful to bring contents to children, but that it is useful for many “levels of learning” (Prensky, 2004) that is, the different cognitive layers a learner can obtain by playing. This includes “How to”, “When to”, “Why” and “Where”. These levels apply for most of the learning, and the author explains that they can be fostered when using games, and that that improvement can be applied also on real-world applications and themes (e.g. Math-skills). This is very convenient for this study and the experiment, because this proves that videogames can be very useful and it shows what can learn a kid with it.

### 3.1.4 GOOD LEARNING PROPERTIES IN A GAME

It has been said also that not any game is ideally fitted for any learning since it has to be well designed for the learning needs. These considerations are listed by James Paul Gee (Gee,
2009) about what properties a good learning game should have, and these are accomplished when the game:

1. Allows the player to take advantage of the game system to obtain their goals
2. Offers microcontrol mechanics to enhance the intimacy feeling of the player
3. Offers Experiences to the learner for good learning
4. Uses modeling, as for model the situations in game or those from the real world.
5. Allows the player to enact their own trajectory through the game

All of this leads us to think that the game design must be well informed on the tasks, and good learning centers on the learners and their needs as reflected by Gee’s properties

3.2 DGBL EXPERIENCES

Above mentioned concepts and principles are extracted from a series of writing by industrials and academics in the field of DGBL. Of course, there is still much work to do until arriving to a highly recognized standard on practices, techniques and strategies for building significant videogame experiences for learning. Even so, and similarly to traditional game Design, there may be not an all-knowing “Formula” for building game learning experiences (or non-learning videogames for that matters)

Anyways, there have been some classroom and laboratory DGBL experiences that suggest DGBL as a very effective tool for learning. Those efforts are cited here as a means of justifying this paradigm selection for this study.

For a start, Gee (2009a) presented commercial game Portal as a learning experience by stating its characteristics of a “Problem game set in an interesting world”. Gee states in this game (and those of the same kind) present an engaging environment for learning and skill training as they put the player to solve one specific class of problems with a specific tool, something that is of course, the purpose of many training courses. Gee also makes an interesting comparison of popular games such as TCG³ YuGiOh with the purpose of stating the similarities between a session of learning and a session of play, to end saying that’s why people learn by playing.

Given the newly-formed interest around DGBL, academic researchers have done experiments and data collections to support theorists’ claims on the goods of DGBL. It is the case of the work of Blunt (Blunt, 2007) an experiment applied on college students, using a management videogame that showed significant improvements in students who used the game over students who did not. Fig. 8 shows a plot on Blunt’s study that shows an important difference in students using the game (blue bars) and those who do not (red bars) (grading uses American letter grading where A is the best and F is the worst grade)

³ Trading Card Game
These kinds of studies are still but a few and they need to be more generalized to achieve a broader acceptation on the paradigm. Of course, this study aims to be one of those experiences that help to clarify this.

Other works such as (Bober, 2010) have extracted from an experimental point of view, some other game design principles to consider:

- Challenge
- Fantasy
- Feedback
- Goals
- Sensorial Stimuli
- Community
- Active Learning
- Adaptability
- Assessment
- Authenticity
- Competition

- Control
- Creativity
- Curiosity/Mystery
- Puzzles
- Decisions Making
- Reward
- Role
- Rules
- Safety
- Transfer

These principles were extracted from observation on teachers using game experiences and interviews with experts in the field. Also the principles were tested in real-life gaming experiences in (Kirkland, Ulicsak, & Harlington, 2010) a workshop were students and professor participated prioritizing the principles to find concordances among what students look for and what teachers offer. Concluding that there are differences among student ad teachers that can be overcome but further research is to be done until arriving to a framework for assessing that.

To finalize, currently exists such as 3D-Game Lab (3-D Game Lab, 2013) a guild-like community centered in developing learning quest-like 3D experiences and the Future Lab (National Foundation for Educational Research, 2013) a groups of researchers at UK’s NFER
centered in developing learning experiences using new technologies. They are developing new experiences and carrying experiments for findings in the field.

3.3 CONCLUSIONS

- DGBL is a new paradigm, a paradigm that is still under construction, looking for new experiences that make use of new technologies and new learning models to stress out the limits of the learning using games.
- As it has been stated, DGBL believers think this paradigm can shift traditional learning into a more effective significant experience for digital learning. This has been highly demonstrated, however, there are still efforts that need to be done in the IT field and in the education and pedagogy field to achieve a higher acceptance of DGBL among schools and institutions.
- Also, researchers have found plenty of principles, techniques, strategies and recommendations that have been exposed here, aiming to support and use as an input for this project’s game design. Furthermore, experiences on the DGBL field have been shown as interesting and important experiences that support this work.
- Of course, as this is not an exact science and is still under paradigm creation and understanding, not all works have been cited here, but those that were considered the most relevant. Nevertheless, it is considered that the principles exposed here are sufficient and help to this project.
The Attention Deficit Hyperactivity Disorder (ADHD) is the neuropsychological disorder this research aims to study in order to analyze the implication and use of AR-enriched videogames on learning of ADHD-symptomatic kids.

Next, it is shown the bibliography findings on ADHD properly spoke, the nature of the disorder, its causes, symptoms and cognitive models of the disorder.

Also, as a way to explore the advancements made on IT area and ADHD, the findings regarding the technology applied to ADHD until today are shown, making special emphasis on videogames. Since this study pretends to create an AR enriched videogame, also the findings on this area related to ADHD are shown.

Finally, and since this study aims to create a videogame for Game-Based-Learning on ADHD-symptomatic kids, the experiences found in literature about the application of games to support tasks on kids with ADHD, specially, those oriented to learning are mentioned.
ADHD – THE DISORDER

According to the American Psychological Association (American Psychological Association, 2000a):

**ADHD**, or attention-deficit hyperactivity disorder, is a behavioral condition that makes focusing on everyday requests and routines challenging.

*People with ADHD typically have trouble getting organized, staying focused, making realistic plans and thinking before acting. They may be fidgety, noisy and unable to adapt to changing situations.*

*Children with ADHD can be defiant, socially inept or aggressive.*

On the queried bibliography was found a very contextualizing report made by colleague and UdG’s researcher Laura Mancera Valett’s on ADHD for her work (Mancera Valetts, 2012). Next are commented the highlights found on this report that were considered useful for this study. This is to contextualize the reader on the issues of ADHD.

In the report, it can be inferred most psychologist agree that ADHD represents a challenge for families of children having ADHD, since it becomes a problem ever growing. Kids having ADHD reflect a higher difficulty for staying focused (Attention deficit) on a particular task, than other children. This is observed mainly on tasks that offer low stimulation. On the other hand, kids show a lack of inhibition and low cognitive control over impulses frequently associated with restlessness (Hyperactivity-Impulsivity). Later the disorder becomes a problem for the child, because other disorders arise. These related disorders include:

- Language-related disorders
- Receptive/Motor system
- Learning disabilities
- Tics
- Anxiety and affective disorders
- Emotional Alterations
- Emotional stimuli recognition
- Emotions Regulation and Expression

**4.1.1 TYPES OF ADHD**

The Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV) (American Psychological Association, 2000b) states that there are three different types of ADHD incidence. Also, the DSM5 (American Psychiatric Association, 2013) , the new 2013 version, features a new ADHD subtype the **Attention Lacking (restrictive)** (Fig. 9 shows icons for each type):

1. **The Inattentive Predominant**: When the attention deficit symptoms show off but not enough of those related to Hyperactivity-Impulsivity.
2. **The Hyperactive-Impulsive Predominant**: When the Hyperactivity-Impulsivity symptoms show off but not enough of those related to Inattention.
3. **The Combined Type:** When symptoms of both categories show off.
4. **The Attention Lacking (Restrictive):** When most of the attention symptoms are identified but 2 or less of the hyperactivity symptoms are identified, the patients is classified as attention-lacking only.

![The Types of ADHD](image)

**FIG. 9: THE TYPES OF ADHD**

4.1.2 **ADHD SYMPTOMS**

DSM IV (American Psychological Association, 2000b) also shows the symptoms for diagnosing ADHD for inattention type diagnosing hyperactivity and diagnosing impulsivity. They are shown in
4.1.3 ADHD EXPLAINING THEORIES

The work of Mancera (Mancera Valetts, 2012) addresses and explains some ADHD explaining theories. Most of them are from the cognitive view. Such theories area called “Cognitive Models”. They try to explain the origin of ADHD from a cognitive development perspective. Here there is a brief summary and comment of these models to gain a better understanding of the disorder causes. Fig. 10 shows the classification of this model.

**FIG. 10: ADHD EXPLAINING THEORIES**

These are the explaining theories of ADHD:

- **Executive Function Model**: (Barkley, 1997) It states that ADHD comes from a dysfunction on the executive functions, which are functions of the mental apparatus that control other functions. These functions include:
  - Inhibition Control
  - Working Memory
  - Planning
  - Cognitive Flexibility
  - Fluency

Nevertheless, although this model is highly recognized by the psychologist community it is subject of criticism, since some argue that this model emphasizes that the only reason for ADHD is the impairment on executive function, but there have been cases in which people diagnosed with the disorder who complied with the criteria in the DSM IV didn’t have impairments on their executive functions. Those who defend this model state that an individual diagnosed with ADHD must have some impairment on their executive functions. These two views are highly discussed on (Brown, 2006).
Inhibition/Activation Behavioral Model: (Quay, 1997) This model states that the disorder comes from impairment on the BIS (Behavioral Inhibition System) and the BAS (Behavioral Activation System). Thus, affected individuals have problems in their BAS and BIS have issued regarding their emotional control.

Delay Aversion Model: (Sonuga-Barke, 2002) This model states that ADHD comes from an aversion of the individual to delay on tasks. Such delay evolves in an attentions disorder because the individual prefers to respond to immediate reward and disconnects if the process takes too long or the gratification is not immediate.

Cognitive-Energetic Model: (Sergeant, 2000) This model is based in the inefficiency of information processing at different cognitive models.

Sonuga-Barke: (Sonuga-Barke, 2002) This model states that ADHD comes from a dysfunction on two sides, the cognitive and the motivational. On one hand, the individual has in fact, problems in its executive functions, but also, there is evidence about difficulties for expecting a good result from a person with ADHD when the work implies a long time span.

Some other models exists for explaining ADHD, and there are attempts for create a unifying theory but that is out of the reach of this research.

4.2 ADHD AND INFORMATION TECHNOLOGY

ADHD is a nowadays problem, like for most of them, some efforts have been addressed to resolve it using Information Technology (IT). Here, are commented some of these efforts, describing technological efforts, making special emphasis on videogames an augmented reality since they are fundamental in this study.

4.2.1 IT APPLIED TO ADHD

IT is one of the most used types of technology nowadays used to resolve problems around the world. As stated in (McGraw, Burdette, & Chadwick, 2005) “[Interventions on ADHD] operate on the physiological level and, therefore, lend themselves to technology-based applications”. For example in the work (Solomonidou, Garagouni-Areou, & Zafiropoulou, n.d.) it’s found that in the application of IT on ADHD diagnosed students, some tasks improved attention more than others, and also it was found that ADHD kids prefer short contents (text, audio, video) when working on the computer.

As a matter of fact, such IT efforts have taken the form of software and hardware tools. Some of these tools and efforts that have been applied to ADHD are commented here. This is to know the state-of-art in technology used for ADHD treatment and ADHD-related learning. Table. 3 resumes the technology found in Bibliography applied to ADHD. Some of these are extracted from (Mancera Valetts, 2012 . p. 34) and some others come from this research.
### TABLE. 3: LIST OF IT TOOLS APPLIED TO ADHD

<table>
<thead>
<tr>
<th>Tool</th>
<th>Description</th>
<th>Aids on</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FastForWord</strong></td>
<td><em>FastForWord</em> is a set of games created to help remedy impairments in speech and audition. <a href="http://www.fastforword.com.au/">http://www.fastforword.com.au/</a></td>
<td>Speech and Audition</td>
<td>Some efficacy tests have shown that <em>FastForWord</em> kids show gain in speech and syntax, but unfortunately these gains did not last long (Hook, Macaruso, &amp; Jones, 2001).</td>
</tr>
<tr>
<td><strong>PlayAttention - Attention Trainer</strong></td>
<td>It is a system that uses <em>Neurofeedback</em> (Neurobit, 2012), a state-of-the-art technology that makes use of brain wave scanning to manipulate the computer. At <em>Play Attention</em> system the user can use a set of games, specifically designed for attention training on ADHD.</td>
<td>Attention</td>
<td>The system <em>PlayAttention</em> is a powerful highly cited tool for treating ADHD. However it remains in the realm of therapy but doesn’t go further on learning issues.</td>
</tr>
<tr>
<td><strong>Metranome</strong></td>
<td><em>Metranome</em> is a PC version of a musical Metronome, adding some interactive utilities. Since the traditional Metronome has been used to treat learning disabilities, this educational tool enhances that use by using the capabilities of the computer (Shaffer et al., 1995).</td>
<td>Learning</td>
<td>The system is out-of-date, but is an example that some efforts have been made even before XXI century.</td>
</tr>
<tr>
<td><strong>Nanny's Circle</strong></td>
<td>It’s a tool for Schedule management and alerts for the whole family and the individual with ADHD.</td>
<td>Planning</td>
<td></td>
</tr>
</tbody>
</table>

#### 4.2.1.1 VIDEOGAMES AND ADHD

As has been stated, this study aims to create a videogame enriched with AR in order to apply it to learning on kids with ADHD symptoms. Because of that, in this part is shown a brief state of art of videogames applied to ADHD, a description and comments are provided of such games. This will serve as an inspiration and benchmarking for the videogame design, as well as to revise the efforts an experiences regarding important aspects of kids’ interaction and responses to videogames.

First, a remarkable work from McGraw et al (McGraw et al., 2005) showed significant improvement on Receptive Coding and Finger Sense Recognition skills, both tested with an
standard test (pre and post treatment) on kids with ADHD. The researchers found that kids who played *Dance Dance Revolution: Disney’s Mix* fostered their language and reading skills.

In Mancera’s report says: “Informatics videogames with therapeutic and entertaining objectives have demonstrated being a good resource in psychological intervention processes on ADHD kids”. The term “entertainment” remains subtle since most ADHD applied videogames were custom-built for treatment purposes letting entertainment in a secondary level. This is because not all videogames represent a help for ADHD children. In fact, in (Swing, Gentile, Anderson, & Walsh, 2010) and (Bioulac, Arfi, & Bouvard, n.d) is found that videogames (irresponsibly taken) could represent greater attention problems.

Also, although GBL has been highly developed in the last decade (as will be discussed later), this research found none or poor literature related to the application of learning videogames to ADHD-related problems.

All of this suggests that deeper, longitudinal, and other types of research have to be made in the spectrum of videogames and ADHD learning of kids with the disorder. This has to be assessed realizing that the children have to learn despite the ADHD problem and with the objective of improve their life quality.

Anyways, some videogame-natured tools have been created until today to address the problem of ADHD. They are briefly commented in Table. 4 :

<table>
<thead>
<tr>
<th>Tool</th>
<th>Description</th>
<th>Aids on</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>PlayAttention Suite</em></td>
<td>As mentioned in Table. 3 <em>PlayAttention</em> is in fact, a suit of games in which players train their mind and has a system of scores and gaming rules.</td>
<td>Attention</td>
<td>The objectives of the games are mainly mental training, since it uses the Neurofeedback helmet.</td>
</tr>
<tr>
<td><em>SuperMarket Game</em></td>
<td>(Vasconcelos De Andrade et al., 2006) It is a game oriented to diagnose executive functions of the individual affected. The game proposes the player to gather the products in a list from a labyrinthine supermarket. So, the player has to plan and execute the plan (a hard work for some ADHD kids)</td>
<td>Planning and Diagnosis</td>
<td>The game adapts to planning skills of the user. Very important when dealing with ADHD symptoms.</td>
</tr>
<tr>
<td><em>Self-Esteem Games</em></td>
<td>(Dandeneau &amp; Baldwin, 2004) It is a game that pretends to help people feel more secure and confident. <a href="http://selfesteemgames.mcgill.ca/">http://selfesteemgames.mcgill.ca/</a></td>
<td>Self-Confidence</td>
<td>This is not specifically aimed to ADHD people, but could help on motivational and emotional problems.</td>
</tr>
</tbody>
</table>

To conclude, some of these tools results very convenient, because, in general, it seems that kids respond positively to videogames, and they tend to improve their skills. However, most of the games showed here are quite therapy-oriented and aren’t aimed to learning. Therefore, further research in interaction, game design considerations, usability issues, and of course, game development experiences have to be done.

4.2.1.2 AR AND ADHD

This study aims to create a videogame for kids with ADHD symptoms, using Augmented Reality (AR). AR was chosen as a focus and experimental technology because it allows the user to fully immerse in the system (videogame, etc.) by superposing virtual elements with elements from the real world (R. T. Azuma, 1997b). In fact, in past years, AR has been suggested as assistive technology (Gaukrodger & Lintott, 2007). Of course, although AR is not a new technology, (or a concept for that matters), it still needs refinement and further research. However, some studies have shown that the usage of augmented reality in education receives positive feedback from students and teachers. Also, students seems to be excited on the interactive aspect of AR and the freedom to explore the subject of study (Aziz, Aziz, Paul, Yusof, & Noor, 2012). In other words, AR seems pretty suitable for ADHD kids learning, and that has yet to be studied.

The literature query for this research found few examples and background about the application of AR on ADHD. Thus, it indicates the timeliness of this study. Nevertheless, Table 5 shows a brief comment on related work found.

**TABLE 5: RELATED WORK ON ADHD AND AR**

<table>
<thead>
<tr>
<th>Work</th>
<th>Description</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Augmented reality and applications for assistive technology (Gaukrodger &amp; Lintott, 2007)</td>
<td>Some years ago in 2007 these authors showed AR as a suitable technology for assistance, including ADHD assistance.</td>
<td>Authors conclude that AR technology has lots of obstacles to be applied, and that the big challenge is not newer devices but assisters to handle well AR applications.</td>
</tr>
<tr>
<td>Les apports de la réalité virtuelle en neuropsychologie : l’exemple de la mémoire prospective (Lecouvey, Gonneaud, Eustache, &amp; Desgranges, 2012)</td>
<td>In this paper, the authors remark the applications of Virtual Reality (VR) and its advantages on the prospective memory</td>
<td>The prospective memory is one of the issues of ADHD, however. The work deals only with a tangential technology (VR) and it is not aimed specifically to ADHD. However is noted here, because the relation of AR and VR on the Virtual-Reality continuum and the implications of memory treatments.</td>
</tr>
<tr>
<td>Teaching ADHD Children using AR (ADHD-Edu) (Mohd Azmidi Bin Abdullah,</td>
<td>In this paper, authors argue that using ADHD-Edu educational software that</td>
<td>The paper is strongly related to this work.</td>
</tr>
</tbody>
</table>
This work explores the possibility of using AR for learning on students with attention deficit. It shows some important related work and it also states the challenges for this field of study.

The paper is oriented to learning via Cloud Computing which is not related to this study, however there are many interesting points related to ADHD learning and AR.

### 4.3 CONCLUSIONS

- A review of the literature has been made to obtain input for the game design and to observe the state of art on ADHD. Literature shows that ADHD is a nowadays focus of attention of both psychology and technology experts as evidenced by the studied shown.

- The review shown here shows ADHD as a syndrome that is an obstacle in the life of many children, and since it has a lot of possible causes, not always easy to find, treatments are often hard for families.

- Nonetheless, the recent interest in ADHD has led to apply technology to many ADHD situations, especially on elementary-school kids. However, few efforts on learning technologies for ADHD kids were found. Naturally ADHD kids have to learn with and despite their condition, so this suggests that further efforts have yet to be applied on ADHD kids learning.

- Videogames and AR have been applied to ADHD as evidence suggests. Also, these technologies have shown recent advancements in ADHD related issues rendering this study important and justified.

- For the game design of this project, the input shown in this chapter was useful in that knowing executive functions lacking in children with ADHD led to design games to satisfy their special needs.
One of the main objectives of this study is to develop a game considering the necessities and characteristics of both ADHD condition and AR technology, for learning. Naturally, in the path to a significant and useful construction of the software as a product it is important to design the game considering the elements discussed in previous chapter, as well as raw game design concepts and practices. Because of that, in this chapter it is shown the remarks of the design process that was conducted in this study prior to the development. It is important to note that Game Design is an iterative discipline and most authors agree (Asuncion, Socha, Sung, & Berfield, n.d.; Luton, 2012; Park, 2009; Van-Slyke, 2008) that first decisions not always reach the final stage, but that design often accompanies development. Thus, some of the highlights in this chapter may seem changed in the final product.

5.1 INTERVIEW WITH THE EXPERTS: SPECIAL NEEDS AND LEARNING OBJECTIVES

Prior to the game design it was necessary to collect the requirements for the videogame. Part of that was made with the review of literature. Nonetheless, It was considered important to interview ADHD and pedagogy experts so the design was accord to the special needs and learning ADHD kids have, and the learning objectives they need to reach.
For that, Dr. Ferrán Viñas, UdG’s associated expert on ADHD was interviewed. Also, here are the results of the interview had with Maria Antonia Canals, UdG’s Professor Emeritus and highly recognized teacher in the field of mathematics didactics. Professor Canals talked about the learning objectives needed to be satisfied for the kids in an observation scenario with the videogame.

All the items discussed here will serve as input, constraints and requirements for the videogame design and development process.

Next, are listed some highlights of the interview had with the ADHD expert, held on 2013-02-25:

- First the present project was detailed to Dr. Viñas. It was emphasized the need to research about AR, ADHD, and GBL as inputs for the Videogame and the Observation Scenario.
- Dr. Viñas was asked to tell the special needs the videogame should consider.
- Dr. Viñas answered undoubtedly that the game should pay special attention to the attention deficit (the kid will lose interest easily) and to the hyperactivity issue (Once the kid gains interest, they will behave hyperactive and impulsive). Dr. Viñas stated that those are the main special needs and they can be assessed by using Self-Instructions.
- As Dr. Viñas explained later, Self-Instructions are a technique of psychological intervention in which the patients instruct themselves the action elements to complete a task.
- According to Banús (Banús Llort, 2013) Self-Instructions can be addressed in these steps:
  1. The therapist or monitor acts as a model and carries out the task, while speaking aloud what they are doing.
  2. The kid carries out the task instructed by the therapist.
  3. The kid does it again by directing himself speaking aloud.
  4. The kid does it again but now verbalizing in a low tone.
  5. The kid guides his own behavior by intern autoinstruction while carrying out the task.

This technique should be taken into account for the Game Design considerations as they are used in real world therapist learning sessions with ADHD kids.
- Operant Conditioning was another technique suggested to consider in the Videogame. Operant Conditioning is a term coined in 1938 by Burrhus Frederic Skinner, and according to McLeod (2007):

  "[Operant Conditioning] means roughly changing of behavior by the use of reinforcement which is given after the desired response"

A classic example of this is the Skinner Box: An experimental apparatus used to study behavior in animals. It consists of a box in which experimenters place an animal (typically a mouse). The animal is able to look at food, but initially it cannot reach the food, so it has to find a way to solve the problem. Casually the animal founds that pushing a lever when certain light activates, provides food. However, the animal learns also, that pushing the lever when other light activates (different color or position) discharges an electrical shock from the metallic floor.
It has been shown that in this context, positive behavior seems to become more frequent (pushing the lever at the right time) when positive reinforcement is given (food). Also, negative behavior (pushing the lever out of time) decreases when negative reinforcement is given (electrical shock). Fig. 11 shows a schema of the Skinner box.

![Skinner Box Diagram](image)

**Fig. 11: A Skinner Box Schema**

The Skinner Box and *Operant Conditioning* comes in handy for this study since the relation between Game Design and Behavioral Psychology has been already explored (Hopson, 2001) and it seems as a perfect tool to use in the Game Design, and Of Course to improve ADHD kids behavior using games.

Dr. Viñas stated that for this case, the better is to opt for the technique called *Tokens Economy*, which is an *Operant Conditioning* technique.

As Navarra’s Center for Resources in Special Education states in an example document (CREENA, n.d.) provided by Dr. Viñas:

“[Tokens Economy technique] consists in providing reinforcers such as points, tokens, cards, etc. associated to the realization of desired behavior”

More in detail, the technique should be applied in such a way that the kid earns the tokens whenever they accomplish the assigned tasks with the desired behavior. Later, these tokens could be used in a “currency” fashion to acquire prizes. The prizes should be appraised by the kid and the price (in terms of tokens) of them should be proportional to the effort needs to gain the tokens. Fig. 12 summarizes the *Tokens Economy* technique.
FIG. 12: THE TOKENS ECONOMY TECHNIQUE EXPLAINED

As a matter of fact, this resembles a lot the traditional system of scores used by videogames. This makes this technique very suitable to apply in the game design.

- Dr. Viñas also suggested Meditation (Harrison, 2004) a technique that has shown important improvements in kids non-pharmacological treatment. Meditation helps to keep Sustained Attention (Barkley, 1997) on the kid so he can achieve the learning goals by completing the task.
- It was required that the game should not reinforce negative behavior on the kid. For example, aversion delay must not be encouraged by giving the kid immediate rewards always.

Next, are shown the highlights of the interview had with professor Maria Antonia Canals on the meeting held on 2013-04-03.

- Professor Canals started by showing us the Cabinet of Materials and Research for Math at School - GAMAR (its acronym in Catalan). GAMAR is a space for practice and thinking around mathematics on elementary and high school students (Universitat de Girona, 2013). The place was crowded with lots of didactic materials and exercises aimed to foster elementary math skills on kids.
- Professor Canals was very emphatic in saying that those materials weren’t intended to “teach” but to “guide towards the self-acquired learning” on kids. This is that most of math skills can be achieved by the very experience of the learner based on their development of moral reason. She cited the psychology theories of Jean Piaget as an example of how a kid can learn by their own experience to take decisions and construct knowledge when properly oriented. In fact, Piaget observed this on kids playing games (Pressley & McCormick, 2007 p. 74) which feeds this study, because we
intend to build games for learning based on the reasoning and judgment of kids who tend to go their own way.

- When the projects was explained to professor Canals, she stated that she has developed the materials and sorted them among several categories, she showed materials for:
  - Development of Abilities and Competences
  - Logic
  - Concept Generation
  - Consolidation of concepts and/or competences
  - Abstract thinking as preparation for algebra

She suggested, that games are appropriate to apply in the fourth category “Consolidation of Concepts and/or competences”, but that properly adjusted a game can be applied in any category for elementary math skills fostering in kids.

- Professor Canals told that a didactic material (such as a learning game) related to mathematics should guide the kid to reason, compare, relate, and conclude by themselves. She told that educators should avoid “mechanical math learning” this is that learners won’t win anything by learning step by step but that math processes should be acquired by the learner's introspection on a guided experience.

- To illustrate this, professor Canals demonstrated the use of one of the materials designed by her. She began by stating that these materials weren’t intended to apply to every child, but that the teacher is encouraged to select the most appropriate material according to the development of the child. She said that as a fervent follower of the Montessori Method (Montessori, 1918) she agrees that the material and the environment are to be suited to the child’s needs, context and psychological development and that learning occurs after a good relation with the material and the adult (teacher, instructor, parents) guidance. With that in mind she showed a material similar to this:

![FIG. 13: AN SCHEMA OF A CANAL'S DIDACTIC MATERIAL AT GAMAR](image)

The exercise is meant to foster two skills: To learn “mathematical equivalence relationships” by means of *pairing* and to foster “mathematical order relationships” by means of *relating*. The material (that is not a game but could be converted into one) consists in a long plastic carpet with separated cells for each number (Fig. 13 shows it red with yellow cells) and a set of separated cardboards in a gray scale sequence (as showed in the gray squares on Fig. 13).

The exercise goes as follows:
1. The teacher guides the kid by counting aloud the numbers on each cardboard and pointing the kid’s finger on each card. It is expected that the kid by themselves relate the gray colors as a sequence and to the magnitude of the numbers.

2. The teacher asks the kid to count aloud by themselves as it has been showed by the instructor.

3. When the teacher identifies this realization by the kid, he starts control exercises by asking questions like:
   - Which number is the clearest cardboard?
   - Which number is the darkest cardboard?
   - Where does this (pointing to a cardboard) belong?
   - Secretly remove one cardboard and asks what number is missing.
   - The kids answers by interacting with the material (e.g. placing the cardboard)

The material is aimed to develop logical thinking on the infant and it is not meant to be applied unless the kid selects it and wants to explore it. Children’s wrong answers are not punished but achievements are celebrated.

Professor Canals showed other didactic materials from GAMAR. However these are not to be showed here but can be consulted in (Canals, 2009, 2010).

Is noteworthy that not all elements shown in this section were used in the videogame designed for this project. Although, most of the indications from the experts were considered when brainstorming ideas for the game concepts. For example, one of the games designed included an activity for ordering elements similar to the exercise shown by professor Canals. Note that in next section, suggestions made by Dr. Viñas were considered in the principles adopted for the design.
5.2 GAME DESIGN PRINCIPLES

The design process began once the game requisites and considerations were got from the psychology and pedagogy experts as shown in this chapter, as well as the literature review regarding AR and DGBL was made the Game Design started.

For the design, the input from the experts and the conclusions from the state of art, as well as the selection of the interaction were considered to obtain the concept of game. As a first attempt, a brainstorming was carried on observing the main principles concluded from the research as shown by Fig. 14.

![Diagram of Game Design Principles](image)

FIG. 14: GAME DESIGN’S PRINCIPLES

The considered principles are explained here:

- **Complies with Gee’s properties**: The game should comply with James Paul Gee’s properties (James Paul Gee, 2009b) as shown previously.
- **Learner Centered**: The Game should be centered on the player, according to their background and context and should be aware of their actions. The game should let the player micro-control (Gee, 2009 p. 67) the game, and also, should let a time for reflection about the learning (Prensky, 2001 p. 168). Content-centered games should be avoided. Instead, Player/Learner centered games are preferred. However, in some cases, content is very important, so designer should not forget it.
- **Fun/Appealing**: The game should be as fun for the kid, as possible. Because fun is the best motivator DGBL experts recommend (Prensky, 2001 p. 107) Also, the likes of the kid should be taken into account (i.e. Games and Games genres the kid likes from previous experiences).
- **Augmented**: This game should augment some things from the real world, especially if they represent something important for the learning or if it allows a better control within the game.
- **Considers Executive Functions**: The designer should have in mind, the lack of attention, problems in retention, and delay aversion ADHD kids show frequently (Brown, 2006).
• **Avoid Frustration:** If frustration comes, the kid will likely abandon the game session, ergo, a highly usable, interesting gameplay and appropriate satisfaction should be offered within the game.

• **Rewards by Token Economy:** As has been shown, some sort of economy must be had into the game. One that allows the kid to exchange tokens (coins, points, stars) into new items, prizes or scenes.

• **Self-Learning:** The kid should be as autonomous as possible in the game session, interacting exclusively with the games and other players. Also the game should allow the kid to think about what they have learned and to have meaningful experiences that allows learning by means of cognitive conflict solutions. Step-wise games are recommended for self-instructions, in such a way that the game performs an action and the kid re-enacts it by repeating constantly into a game mechanic.

• **Induces operant conditioning.** The game should reward desired actions on the game that conduct to learning. When the game detects the kid is learning content related or in-game stuff, they should be rewarded.

### 5.3 TYPE OF THE GAME

Before the start of the game design it was necessary to abstract from the review of the literature, presented in chapter 2, the possible type of the game. Once the possible types of games were abstracted, then it was possible to select the type of interaction, and then the designers and the psychology expert would be informed in a broader way.

For that, a classification of AR games types and a classification of AR interaction types were done and are presented in this section.

### 5.3.1 TYPES OF AR GAMES

One of the purposes of reviewing existing AR gaming experiences was to discover what types of games could be done with actual technology. Based on what has been shown until now, the following types of games where classified:

• **Marker-based Mobile Game:** This is a game where the user points their mobile device (Phone, Tablet or Game console) to a predefined and pre-printed set of Markers. Augmented objects appear over those markers in the Virtual environment of the game. Fig. 15 shows a schema of this. Examples of this type of game include: *Invizimals, PulzAR, Fireworks, ARDefender* and the “Table” series of SONY PSVITA *Table Hockey, Table Mini golf, Table Top Tank.*
• **Accelerometer/Gyroscope Tracked AR Game**: In this type of games, user doesn’t require any markers (that is why sometimes they are called “Markerless” games). However the user needs a portable device with a camera and an Accelerometer or Gyroscope able to measure position and orientation in 6 degrees of freedom (Position x, y, z axis and Rotation pitch, yaw and roll amount). In these games augmented objects appear projected in the real world projected by the virtual world on the images captured by the camera. Fig. 16 shows a schema of this showing a variation of this using a tablet/phone device (image a) or a Head-worn system (image b). Examples of this type are *Droid Shooting*, *ARQuake* and *ARWars*.  

![Diagram of Accelerometer/Gyroscope Tracked AR Game](image)
- **GPS-tracked AR Game:** In this type of games user uses their GPS-able device to track their position on the globe and the game registers augmented objects over global positions and display them, often, in a map (like Google Maps). Usually these types of games don’t make use of the device’s camera, but the action occurs in real-time by updating constantly the player’s and object’s information (position, etc.). Fig. 17 shows a schema of this. Examples of this type of games are *Ingress, Zombies, Run!* And *Parallel Kingdom*.

![FIG. 17: GPS-TRACKED AR GAME](image)

- **Spatial AR-Game:** In this type of games, user stands in front of a camera and a monitor (usually the camera is in the same position and orientation than the monitor). Interaction occurs with player facing markers toward the camera, or using other controller-like device (like PS Move). Augmented Objects appear in the monitor over the mentioned markers. Usually players see themselves in the monitor and some games have featured controlling by hand gestures. Fig. 18 shows and schema of this. Examples of this include *PS3 Bok of Spells, NightCrawler Diggs* and *Augmented Reality 3D Pong*. 

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As it can be seen, the last decade had many advancements and efforts on the development of AR Games, even to the point that AR games are now freely downloadable from the internet, played in a mobile device or a home-console without the need of complicated hardware and with little configuration (such as the printing of markers). Those efforts are to be held in mind when developing AR gaming experiences since they help to shape the future of AR Gaming. Also it suggests that gradually, and thanks to technology advancement, AR is being accepted by players around the world which is important to this study and the upcoming ones regarding learning with games and AR.

5.3.2 INTERACTION TYPES IN SPATIAL AR GAMES

As presented in above section, there are some types of AR Games classified. However, because of time and resources constraints, the design was oriented to build a spatial video display Marker-tracked AR Game, with the tools mentioned in chapter 2. For that, a classification of interaction types on this type of games was extracted and it is presented in this section.

In order to offer a broader choice of interaction and types of videogames to the expert, a set of interaction types were abstracted from the possibilities of toolkits, available hardware and production constraints. These set of interaction types were considered prior to the game concept approaches. At the end of the day, the preliminary high concepts considered all of the
possible interaction types, so to offer the possible videogames and as the orientation for the prototype constructed.

The three possible interaction types extracted are presented here abstractly, and later the concepts show them in an actual game were the interaction is implemented.

**Marker for drag & dropping**

This type of interaction uses a marker as a mean to drag & drop virtual objects. Fig. 19 shows the regular steps on a drag & drop interaction:

1. The user approaches an already existing virtual object with the marker.
2. The virtual object is attached to the marker. Ergo, the virtual object moves with it.
3. Later, the user can move the marker (with the object attached) to a previously disposed virtual available “landing position”
4. When the marker approaches the landing position the virtual object stays there, remaining available for Dragging again.

This type of interaction can be repeated if the user moves the marker’s virtual position away from the landing position, and then return to try and drag the virtual object, thus repeating the steps from step 1.

![Fig. 19: Schema for drag & dropping interaction type](image)

**Marker for placing virtual objects in a concrete position**

In this type of interaction the augmented object shows over the marker always (unlike abovementioned type in which user has to approach the marker). Typical configuration features a fixed camera for a spatial-video-display type of AR, where the user has to bring near the marker to a real landing place. That leads to the virtual object to move to a virtual landing place, where often something happens (The system reacts). Note that the marker never leaves the virtual objects, hence, if the user moves the marker away so does the object. Fig. 20 shows a schema of this.
Marker for manipulating gameplay object’s transform\(^5\)

In this type of interaction the system tracks the marker and registers a virtual object with the marker’s transform respect to the camera. Thus, it can be said that the user manipulates the position and rotation of the object to perform interaction with the system. This interaction is often directly related to the game mechanics and gameplay objectives. Fig. 21 shows a schema of this.

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\(^5\) Transform or 3D-transform refers to the geometry concept: A 4x4 matrix that stores an object's position and rotation.
Once these types of interaction were abstracted, they were used in the conception of the game concepts shown next.

## 5.4 AR ENRICHED VIDEOGAME HIGH CONCEPTS

Considering the already shown principles, the game design started by observing Canals (2009) book. In it, she explains the main logical skills an infant should learn and exercise, and shows some didactic materials and activities for teachers to use. This game design was based on those didactic materials.

In the abovementioned book there are plenty of didactics activities covering many areas of logical reasoning. However the design was centered on *Ordering, Classification, Equivalences and Pairing* as basic skills, mainly because they are fundamental and they are aimed to children ages 3 to 7.

With this input, some Game Concepts were obtained from the Brainstorming. And they were taken for Dr. Ferran’s consideration. These Game concepts are presented here with their respective High Concept and some preliminary illustration of the game screen.

### 5.4.1 GREMLINGS IN MY MIRROR

In “Gremlings in my Mirror”, the kids see themselves reflected in a “mirror”. Their job is to control the elements in the game using AR markers in order to accomplish the missions using the gremlings in screen. The game features minigames. In each minigame, the game mechanics are meant to foster one logical math-skill. Main minigames include «It’s raining Gremlings! » and «The Gremlvolution», explained later.

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6 A High Concept (Bates, 2004) is an outline of the game in the form of text. It tries to answer: *What is the Game?*
In this game, there is a mini-economy, because whenever the kid does a rewarding action (i.e. winning a stage) they receive coins that can be used to purchase items or advance to new scenes.

In Gremlings in my mirror there are some minigames. Two of them are explained here:

**IT’S RAINING GREMLINGS!**

In the minigame “It’s raining Gremlings!” Gremlings are falling from above the mirror, and kids must guide the Gremlings to their correct destinations by moving some platforms using their AR markers. The Gremlings must fall in their respective Big-Gremling. Big Gremlings are down in the mirror, waiting to catch the little gremlings. Each gremling has some features (color, size, and attitude) that correspond to one of the Big-Gremlings down in the mirror.

The game is aimed to foster math skills, regarding logical relationships by means of pairing. Hence, in each stage the game becomes more difficult. For example, in the first level, there are only some easily identifiable features such as color, and they are easy to pair. However in later stages, gremlings are more varied and also Big-Gremlings switch positions.

<table>
<thead>
<tr>
<th>Ages</th>
<th>3 to 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background</td>
<td>Almost None, but it is preferable that the kid has some experience with games or any interactive media.</td>
</tr>
<tr>
<td>Features</td>
<td>Ordering, Pairing, skills.</td>
</tr>
</tbody>
</table>
THE GREMVIOLATION

In the minigame “The Gremvolution” the kid has to order adequately the different evolutions of a Gremling as asked by the game. Different evolutions of the same gremling vary in one characteristic (mainly brightness and size). The kid is presented with a set of gremlings to choose from and they have to place them ordered in the switch that turn-off the bomb that is about to explode. Thus, to avoid the Gremling fortress from exploding the kids has to realize how to correctly order the gremlings.

The game is step-wise, this is that in the first stages the kid will learn to drag, drop & place, but later he has to realize the correct order and select the respective gremlings for each switch. The game is aimed to foster equivalence relationships and mathematical ordering skills.
5.4.2 GARDEN DEFENSE

“GARden Defense” is about a battle between plants and insects. In this game, insects come from above to eat the plants below which the kid has to defend. Both insects and plants have each an attack number. The kid has to place adequately the plants on a one-on-one basis using their markers in order to destroy the insects coming. The deal is that only plants with a higher attack number can destroy insects, however each turn the kid is given only a limited set of plants so they have to think wisely a strategy to avoid the insects. Whenever the kid destroys an insect, they win coins equal to the difference between the plant’s attack number and the insect attack number.

Insects move towards the plants at a given speed, ergo, the kid is also constrained by a specific time, until the insect eats the garden. Each scene is higher in difficulty, by featuring swifter insects or different attack value combinations.

This videogame is played with a top-camera attached to a support as shown by Fig. 25.

This game is aimed to foster numerical relationships and rapid-strategic thinking.
In this game, the kid has to use his markers (numbered 1 to 5) to capture some floating pieces in order to place them in their corresponding place in the wrecked-cannon of a space ship. The objective in each scene is to fix the cannon by placing the pieces correctly (ordered). When this is done the cannon shoots and destroys the upcoming aliens. Coins are earned to buy better cannons and ship-parts.

When the cannon shoots the kid wins a number of coins equal to the destroyed aliens.
5.4.4 COCIN-AR

This game consists on a virtual kitchen with elements like food and tools controlled by AR markers. The objective in each scene is to attend the clients that ask for one specific meal. The game first shows the steps to make the recipe, and then the kid does it in a step-wise fashion. Each recipe consists on a classification exercise of the elements by a common attribute.

Every client has a waiting time and they leave if they don’t get attended. If the kid has success is rewarded with coins that can be used to purchase new scenes.

<table>
<thead>
<tr>
<th>Ages</th>
<th>3 to 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background</td>
<td>Previous interactions with games by the kid are desirable.</td>
</tr>
<tr>
<td>Features</td>
<td>Classification skills.</td>
</tr>
</tbody>
</table>

FIG. 27: COCIN-AR

5.4.5 LA GRANJA

This game’s objective is to gather the farm items the farmer asks. The kid is given a set of three AR-controlled baskets. Each basket can hold only to a maximum of 1, 2 and 3 items respectively. In each scene, the farmer asks for a number of items, thus the kid has to think how to gather the items strategically to use the baskets given.

Each scene ends with the farmer task accomplished; the kid is rewarded with coins.
Once the concepts were considered and approved, it was decided to test the interaction forms stated by designing and developing "Gremlings in my Mirror", the first videogame described in previous section.

For this, a Game Design Document (GDD) following indications on (Bates, 2004; Fullerton, 2008; Mazza, 2012; Ryan, 1999) was constructed for an initial prototype (v 0.1) and due to its longitude and detail it is not included in this memory. However the GDD is annexed to this document in Appendix B.
FIG. 29: GAME DESIGN DOCUMENT FOR “GREMLINGS IN MY MIRROR”

This GDD features two minigames “It’s raining Gremlings” and “The Gremvolution” explained exhaustively and designed following the principles above stated.

Table 6 summarizes the application of the principles in the minigames since they contain the main gameplay on the videogame.

**TABLE. 6: APPLICATION OF PRINCIPLES IN THE GAME DESIGNED**

<table>
<thead>
<tr>
<th>Principle</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Complies with Gee’s Properties.</strong></td>
<td>Gee’s Properties are applied as follows:</td>
</tr>
<tr>
<td></td>
<td><em>Take advantage of rules:</em> For example in the game “It’s raining Gremlings”, the kid can push gremlings to their destination using the platforms. This is not taught by the game but it’s a way to reach the objectives. Is expected that curious kid do it.</td>
</tr>
<tr>
<td></td>
<td><em>Microcontrolling:</em> The AR-Platforms and Objects are one-on-one to the kid’s hand movement</td>
</tr>
<tr>
<td></td>
<td><em>Experiences:</em> Every aspect of the game is learned by trial and error, from rules to prizes.</td>
</tr>
</tbody>
</table>
- **Modeling**: The game itself is a model of the real world, since it features a “mirror”. Also, gremlings are meant to be paired and stealth learning leads to fostering in general pairing skills by similar characteristics.
- **Enact Trajectory**: Since every aspect of the game is meant to be learned by experience and the gremling themed game offers a narrative-like schema, kids are expected to be able to tell their own story with the game.

<table>
<thead>
<tr>
<th>Learner Centered</th>
<th>The game’s main protagonist is the player themselves, since they see themselves in the &quot;mirror&quot;. Also, the game doesn’t feature content “explainers” and gremlings are merely operable objects.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fun</td>
<td>The game is fun (Tests needed)</td>
</tr>
<tr>
<td>Augmented</td>
<td>The game used Simple AR marker-tracked objects.</td>
</tr>
<tr>
<td>Considers</td>
<td>The game is meant to be easy in the first scenes. Not much planning is needed and rewards are evidenced. This advances in later scenes to be harder when the kid has got used to the game.</td>
</tr>
<tr>
<td>Executive</td>
<td></td>
</tr>
<tr>
<td>Functions</td>
<td></td>
</tr>
<tr>
<td>Avoid Frustration</td>
<td>The game gives hints and feedback if there is any AR-related error.</td>
</tr>
<tr>
<td>Rewards</td>
<td>Coins are needed to advance to new stages and coins are won inside the minigames.</td>
</tr>
<tr>
<td>Token Economy</td>
<td></td>
</tr>
<tr>
<td>Self-Learning</td>
<td>The game is designed to not need a teacher or counselor, mechanics are quite simple so the kid can learn by itself, and it gives time to reflex on next action to take in order to pair or ordering gremlings. Also, “good” actions in the game give rewards, while “non-good” actions have not consequences.</td>
</tr>
<tr>
<td>Operant Conditioning</td>
<td></td>
</tr>
</tbody>
</table>

### 5.6 GAME DESIGN CONCLUSION

The game design phase ended with the GDD proposal, most of its elements were proposed according to the game principles, the types of interaction and the input from the experts. The GDD was refined to be more adequate to development restrictions for the first prototype such as technology and schedule requirements.

With the GDD built, the process for develop a first prototype version of the videogame “Gremlings in my mirror” started. The game was developed using the latest version of the Unity3D Game Engine and the development followed the game design goals the GDD explains that are tightly related to the game principles adopted.

The game prototype and its development process are described in next chapter.
For the Game development objective of this Project a Game Digital prototype was constructed in order to test the principles defined and to take observations on the players and their behavior. The game chosen to develop is “Gremlings in my mirror” including the two main minigames “It’s Raining Gremlings” and “The Gremvolution” (described in the chapter above). The Game prototype followed uprightly the Game Design stated in the Game Design Document already presented with minor changes in mechanics and/or gameplay. The reader can has access to the prototype, its source code and the assets used in the game URL at http://bcds.udg.edu/Gremlings/7.

In this chapter the prototype is describe as well as its software design, Hardware/Software and architectural considerations and the tools built prior to the game prototype building.

6.1 SOFTWARE ANALYSIS

Most of the analysis on the gameplay has been done in the Game Design phase described in the previous chapter. Nonetheless, from a Software perspective analysis on the gameplay requisites evidenced that game development would find technological impasses that should be assessed in order to construct the prototype with the least technological obstacles.

7 Every reference to the Project’s URL in this chapter refers to this URL
First, a Use-Case Model was built to observe player’s interaction needs and functionalities to construct. Fig. 30 shows the User-Case Diagram.

FIG. 30: USE-CASE DIAGRAM

Definitely the model showed that the game had few functionalities requisites as shown by the next Use-Case description:

- **Select Minigame**: Using the marker, the player selects the minigame to be played.
- **Move Platform**: Using the marker, the player moves around the platform in “It’s raining gremlings”
- **Drag/Place Gremling**: Using the marker, the player can take Gremlings from one to another place in “The Gremvolution”

Not to be confused, these few functionalities are far from easy to develop, since they all rely on the user’s interaction with the game elements, using the AR-Marker exclusively.
Note that in this game, users interact solely by the game AR-marker via the abstract rules identified in the “Possible Interaction types defined above”. Thus, after software analysis, the idea of constructing a middle layer software to support interaction types in an abstract manner, so that game could be constructed leaving AR-interaction aside and to focus on game rules.

That middle layer came to be called “AR interaction framework” which was built upon the NyARToolkit AR framework and using the capabilities of the Unity3D Game Engine. The relationships including these layers and the Game software properly spoken are shown in the software architecture described in next section.

6.2 SOFTWARE ARCHITECTURE

Here it is shown the resulting software architecture upon which the prototype was constructed.

Fig. 31 shows the package diagram for the multi-layer architecture thought and implemented in the system. The highlighted layers are the ones used in the built system. The more transparent ones represent the platforms over which the system was built.

FIG. 31: SOFTWARE ARCHITECTURE FOR THE PROTOTYPE
As it can be seen, the software architecture planned for the prototypes relies heavily on the Unity 3D API. However, observe that in this project the Unity3D game engine capabilities were mixed up with the ARToolkit marker recognition features, via the NyARToolkit.

Also the “AR Interaction Framework” was constructed thinking on future projects as it complies with the features of the possible interaction types (Marker Drag&Dropping, Marker for Manipulating Transform and Marker for Placing Objects).

With this framework constructed, the platform was ready to start programming the gameplay according to rules defined in game design.

Note that the little layer “Common Objects” defines some objects that are shared among the scenes and minigames on the prototype.

Upper Layer contains logic for the game itself, and note it has some inner packages for each minigame (the ones already considered and other to implement in the future).

### 6.3 SOFTWARE PLATFORMS

**Unity3D** was chosen as the main game engine due to its current popularity and easiness of deployment for various operating systems. Since the design considered a future web-version for the game, it comes in handy the use of the Unity3D web player, accessible via a web-browser. Nonetheless, current NyARToolkit versions rely on external calls to DLL’s which bring several issues when deploying for web-browsers. Thus, future web version will assess this in order to obtain a stable web-version of the prototype.

**NyARToolkit** was chosen as the ARToolkit wrapper for Unity3D, since it has a free-royalty version and it has a simple API to acquire AR-Marker transforms that are very important for the game logic.

Also, **ARToolKit** is capable of identifying several AR-Markers, even user-defined ones. As stated in (ARToolkit, 2013) some markers were created, printed and attached to cardboards. And then, the system was trained to recognize them. Fig. 32 shows the markers used in experiments prior to the prototype.
Several sizes were tested as well as newly designed markers in order to prove robustness and usability with early versions of the software.

Experiments carried with the NyARToolkit API concluded that the platform is very stable and easy to use. However, the platform is for general application on detecting AR-markers, thus none interaction features that facilitate the game construction are implemented. For that, the AR Interaction Framework was built and it is describes in the next section.

### 6.3.1 AR INTERACTION FRAMEWORK FOR UNITY3D

The AR Interaction Framework was created to facilitate the use of the interaction types abstracted in the game design.

This framework consists on a set of reusable and extensible classes meant to implement AR interaction types using Unity3D Game Objects, and easy-to-use prefabricated elements called “Prefabs”\(^8\) that require little or none programming.

Fig. 33 shows the class diagram of the framework as it was designed. Here are some important highlights on it:

---

\(^8\) For more information on prefabs, please refer to: [http://docs.unity3d.com/Documentation/Manual/Prefabs.html](http://docs.unity3d.com/Documentation/Manual/Prefabs.html)
In the class diagram is noteworthy that a central class named "MarkerTrackedAugmentedObject" represents GameObjects in unity that can be interacted with, via AR-Markers.

Also note that two other classes extend the MarkerTrackedAugmentedObject class, these are "DragDropperAugmentedObject" and "NormalPlacerAugmentedObject". These three mentioned classed were constructed to define the three Interaction types defined in the design.

The diagram implies that Drag&Dropper Augmented Object interaction and Normal Placer interaction are Specializations of the more general interaction type: the transform modifier (implemented via the class MarkerTrackedAugmentedObject).

Note that external Unity3D classes are stereotyped with a "Unity3D" identifier as well as NyARToolkit classes.

Most classes extend "MonoBehaviour" as it is the main class to script GameObjects in Unity3D.

Observe that a Marker-Tracker augmented object associates with a “ARMarker” Object, which in turn associates with a Texture2D object that identifies the image to be recognized by the system. This is to facilitate the Framework user with an easily definable marker to be handled just by feeding the system with a Texture2D (simply a bitmap image with a format supported by Unity3D)

The Place class represents a place where an object can be putted.

The MarkerSystem Singleton class holds the initial NyARToolkit initialization and methods to relate markers with the image recognition algorithms provided by ARToolkit.
FIG. 33: CLASS DIAGRAM FOR THE AR INTERACTION FRAMEWORK FOR UNITY3D
For a better detailed explanation of each class and its features, please refer to the source code in the project0's URL. The code was created self-documented with the MonoDevelop/.Net commentary notation.

Examples of each interaction accompany the source code as standalone Unity3D scenes.

### 6.4 Gremlings in my mirror

Over the framework created and the platforms selected, the software development started finalizing with the product “Gremlings in my mirror”. The prototype presented with this memory stands for a software prototype that include the main gameplay of the main minigames “It’s raining Gremlings” and “The Gremvolution”. The built products can be played in the product’s URL and a printing of the main AR-Marker (also available in the URL).

The following figures (presented in Fig. 34, Fig. 35 and Fig. 36) are snapshots of the videogame in its current version. Note that this preliminary version includes preliminary art assets that are meant to be refined for future versions.

![Gremlings in my mirror main menu](image_url)

**FIG. 34: GREMLINGS IN MY MIRROR MAIN MENU**
FIG. 35: "IT'S RAINING GREMLINGS" RUNNING

FIG. 36: "THE GREMVOLUTION" RUNNING
The final objective for this project was to establish an observation scenario to carry on observations about the kids’ behavior when playing the game. For this, it was necessary to design and plan the observations to make, execute the scenario and document the observations to further analysis.

In this chapter it is shown the design of the observation scenario in which participants used the videogame, as well as the remarks of the scenario execution. In the scenario, for control purposes, the videogame was played by a set of voluntary adults. In the session, time-related data was gathered and remarks were noted about their play session. The same was done applying the game to elementary-school-aged kids.

### 7.1 Observation Scenario Design

First, the observation scenario started by considering the characteristics of the prototype built and the learning objectives desired.

As for the prototype, if the reader watches closely the levels on the videogame and the videogame design goals, it will be noted that the game does not explain anything directly to the player. This is, the game does not focus efforts on explaining gameplay or even concepts to the player. This was on purpose, since the game was meant to be a “Stealth Learning Game”.

“Stealth Learning Game” is just an adaptation of “Stealth learning”, a concept introduced by Prensky (Prensky, 2001) in which learning comes by the very nature of playing and the player “doesn’t realize” they have learned.

Because of that, the game guides the player by certain “hints” (such as highlighting an important object). However, the player is encouraged to learn to play by trial and error. For this, the observation scenario was meant to be such that the researcher would not explain how to play, or how to win, not even “What to do” when asked for Augmented Reality Interaction Issues. This was to stress to the maximum the learning of the player and see if Self-Learning can really occur. With this in mind, qualitative observations were meant to be around:

- **Interest**: Whether the player plays by themselves even if not “pushed” to play (as professor Canals suggested, the kid should learn by their own interest). And if the learner plays even if they encounter interaction and gameplay problems.

- **Satisfaction**: Whether the player seems satisfied with the accomplishments within the game. This comes related to the “Fun” principle adopted.

- **Learning**: Learning was meant to be judged by the speed of level advancing in the game. As has been mentioned, the game does not explain anything to the player. However, by using hints and step-by-step advancing, the game proposes a constructivist advancing in which anything learned in previous levels can (and must) be used to advance to higher levels.

### 7.1.1 OBSERVATION SCENARIO GUIDELINES

A set of guidelines meant to be applied in the observation scenario execution were defined as follows:

1. Setup the videogame, if an external PC-monitor is to be used, the camera should be placed accordingly in such a way that the player see themselves “reflected” in the external monitor seamlessly.
2. Setup the AR-Camera.
3. Setup a video-recorder to register the session.
4. Place some different AR-Markers in front of the PC. The deal is to let the players use the correct marker by identifying the requirements in the game screen.
5. Start the game and make sure not to explain the game functionality.
6. Let the players play, however they want, and the timespan they want. Advise only if it is needed.
7. For each minigame, keep note and, with the help of a chronometer, register the timestamps whenever some of this happens:
   a. The player first learns how to handle AR in-game stuff (i.e. the platforms in “It’s raining Gremlings”)
   b. The player accomplishes a rewarding task (such as ending a level)
   c. The player finishes a scene
   d. The player seems uninterested and/or abandons game
   e. The players seems interested and having fun

---

9 Mostly, if technical issues happen caused by the early version of the prototype.
Other annotations can be made by the researcher's consideration. Always, aiming to observe the interest, satisfaction and learning.

8. Important observations on kids with ADHD include:
   a. Whether and when they abandon the game.
   b. Whether and when the felt frustrated and how they manifested it.
   c. What were the main distractors. If it was the case.
   d. Depending on the age, if there were obstacles based on their age level mathematical skills.
   e. Whether the kid called for any kind of satisfaction other than the game itself.
   f. Special demands within the game session. These can be recorded textually.

9. When the play session ends, keep note of the player's age and other important characteristics.

7.1.2 TEMPLATE TO REGISTER OBSERVATIONS

Along with the guidelines a template to register the observations during the observation scenario was designed. The template was meant to compile the timestamps of each playing session as well as any remarks on interest, satisfaction and learning.

The template is a simple table. Table. 7 shows the template.

<table>
<thead>
<tr>
<th>Play Session Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date and Time</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Remarks on time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timestamp</td>
</tr>
</tbody>
</table>

| Additional observations and highlights |

7.2 EXECUTION OF THE OBSERVATION SCENARIO

The execution of the observation scenario designed involved 3 adults in the control group and 2 kids in the observation group. First, the adults were exposed to the game in the same conditions established for the kids (none explanation, timestamp observations). These adult-oriented play sessions were meant to have control data to compare with the performance on the kid-oriented play sessions.
The scenario was made totally with native Spanish and Catalan speakers, but the game is totally in English language. This helped to make clearer the observations since the sessions were meant to be non-explained.

The observation scenario was then executed according to the guidelines established in the scenario design, in this way:

1. The Executing computer and the external monitor were setup as shown in Fig. 37.
2. The AR Camera (Embedded to the laptop shown in Fig. 37) was setup to face the player.
3. A video of the kid-oriented session was recorded (it can be found in the project’s URL)
4. Several and different AR-Markers were disposed randomly in front of the game, so the player could choose as shown in Fig. 38.
5. Players were invited to play.
6. The game was freely displayed in the PC-external monitor. However, kids were not forced to play it and luckily enough, they seemed excited about it and they asked to play.
7. With the help of a chronometer, highlights of each session were registered as shown in Fig. 39 using the Observation Scenario Templates. Transcripts of them can be found in Appendix C.
8. In adult-oriented sessions, session ended when asked. In the case of kids, sessions ended when kids willingly said they wanted to do something else.
FIG. 37: GAME DISPLAY SETUP

FIG. 38: AR-MARKERS DISPOSITION

FIG. 39: RECORDING MAIN OBSERVATIONS
7.3 ANALYSIS OF THE RESULTS

Appendix C shows the data gathered in the gameplay sessions for the observation scenario, using the Observation Scenario Templates. Those templates show all the data and the observation made; however, in this section some important milestones have been selected from the observation scenario with analysis and comparing purposes.

First, the most important milestones for learning (tagged with an M in the templates) and the most important highlights were selected and they were plotted in the time charts shown in this section.

For each figure, some remarks and analysis have been done as shown next:

For “It’s Raining Gremlings” Fig. 40 shows a plot of the performance on players (Adults and Kids) judging by the timestamps they achieved a set of selected commons action milestones. The milestones selection was made, by recognizing that such actions are necessary for the learning about in-game stuff. Also, note that all the actions represented by the milestones are goals the player should achieve by themselves, since the sessions were strictly non-explained. Ergo, it is considered that these milestones are an indicator of the performance of the player their self-learning and advancement along the game session.

The milestones chosen are:

- Access to the game
- Uses the marker
- Moves the platform
- Guides first gremlin
- Finish Level1
- Finish Level2
- Finish Level3
- Finish Level4
- Finish Level5
- Finish Game

Some remarks about Plot in Fig. 40 are as follows:

For the Kids Timestamps vs. Milestones time chart:

- K1 (aged 6) was pretty quick in learning main core mechanics in the game as evidenced by the short time it took to him to get on Level 4.
- However, on level 4, K1 got stuck and after a series of hints could surpass the level, which gave advantage for K2 (aged 8) who, in general, had it easier to advance on the levels.
- Kids had it relatively easy to learn main game mechanics as evidenced by the time they took to the first Gremling guided (the main objective on the game)
- Dotted line shows the average timespans in milestones for kids

For the adults Timestamps vs. Milestones time chart:
Some adults had considerable better performance than others. For example, A1 and A2 had finished the game in a shorter timespan than A3. Also, A1 and A2 showed a quicker understanding of the in-game desired strategies. This is evidenced by the quicker advancing in levels 1 to 5 as opposes to the longer time it took to A3 to do the same. Nonetheless, trivial milestones (the ones at the beginning of the game) were learned by all adults at mostly the same time; the big time difference occurred later when a greater expertise, thinking, and strategic reflection was needed within the game. Dotted line shows the average timespans in milestones for adults.

For the Adults vs. Kids timestamps time chart:

Clearly, in average, it took adults less time to reach the final goal: Finish the game. However, kids had some advantage before level 3. This suggests that either level 4 is too hard or there were notable usability issues that were pretty hard to overcome by children as opposed to adults

Fig. 41 shows the plot for the minigame “The Gremvolution”. A similar dataset was gathered using the following milestones:

- Gathers first drag&drop gremling
- Places first gremling
- Finishes Level 1
- Orders correctly the Gremlings
- Finishes Level 2
- Finishes Level 3
- Finishes Level 4
- Finishes Level 5

For the kids’ session:

- It is clear that K2 had always a better performance than K1. Note however, that K1 is 6 years old and K2 8 years old.
- Since K1 is younger than K2 it was harder to him find out that the gremlings should be ordered as evidenced by the long line joining the first and the second level.
- Nonetheless, while it was harder to K2 to overcome level 4 and 5, after K1 noted the ordering requisite it was easier to him to overcome higher levels as showed by the short distance joining levels 3,4 and 5
- The time taken in this minigame is considerably lower than “It’s raining gremlings” session

For the adults’ session:

- Note that, in this occasion, it was easy to A3 to overcome the challenges of this minigame. On the other hand it was more difficult to A2 to overcome the levels.
- As in the previous minigame, A1 showed the best performance.
• Note that, even that different participants took different times to understand main mechanics and overcome first levels, all of them finished at the same time. Also higher levels showed to be finished in short timespans. That suggests that this game, once understood, is easy to overcome.

For the comparison between adults and kids:

• As expected, kids took a longer time than adults, generally speaking. However the difference is no that substantial as in the case of “It’s raining Gremlings”.
• On the other hands, surprisingly, in average, kids were able to finish level one quicker than adults. Note that level one’s challenge is only to drag & drop an item. But, later, the items must be ordered, and kids may not have yet realized that to overcome higher levels as adults.
• At the end of the day, both adults and kids realize the strategy and the game requirements and they fulfill quite easy the game’s goals.
FIG. 40: PLOTS SHOWING PLAYERS PERFORMANCE IN “IT’S RAINING GREMLINGS” GAME SESSIONS (JUDGING BY TIMESTAMP VS MILESTONES SELECTED)
FIG. 41: PLOTS SHOWING PLAYERS PERFORMANCE IN “THE GREMVOLUTION” GAME SESSIONS (JUDGING BY TIMESTAMP VS MILESTONES SELECTED)
7.4 CONCLUSIONS

- An observation scenario has been designed and executed to obtain important observation on players playing the game developed.
- The observation scenario was designed to stress the principles of the game, to obtain feedback on the system itself and to observe important variables regarding learning, fun, satisfaction and performance at playing the game.
- It is important to note that due to external restrictions the observation scenario was not assessed with ADHD kids. However observations were made on regular elementary school children and they were compared to adult performance on the same games.
- More research has to be done to stress out the features of the game proposed as well as to evaluate the principles stated in the game design.
- The observation scenario has yet to be applied on ADHD kids, to analyze its outcomes and to obtain more conclusive observations. Nonetheless, the observations and conclusions showed here are meant to be used as control data for a future experiment.
- The scenario showed here has yet to be analyzed by psychology and pedagogy experts to assess the experiments and give their appreciations and conclusions.
- The scenario involving adults and kids as participants showed that the videogame offers a fun way to explore mathematical logical skills.
- The analysis shows that this type of Stealth Learning Game is able to be finished even when in a non-explanation context.
- The scenario showed several usability issues that need to be repaired in the game to be more satisfying and easy to use.
- The data gathered using milestones and timestamps suggests that there is a difference between kids and adults, as the first can finish the game but with a longer time span.
- The game evaluated is a spatial marker-tracked AR game. The experience showed that AR can bring problems with the control of the elements in-screen by inexperienced children which is a problem to fulfill Gee’s property of microcontrol.
- On the other hand, AR showed to be very appealing to children and adults alike, since its augmenting and visual stimuli features are novel and worth exploring.
For summarization purposes, this chapter shows how the present memory compiles the most relevant artifacts and activities that led to the accomplishment of the original project’s objectives.

The accomplishments are ordered here, first by the specific objectives and its corresponding tasks, and then it is shown the accomplishment of the general objective.

8.1 OBJECTIVE 1

The first objective read:

*Build a state-of-art regarding AR Technologies and their applications on traditional Learning and Game-Based Learning*

This objective is considered accomplished because:
A library with documentation regarding themes of AR technologies, platforms, software and hardware was built. The library was built upon Mendeley reference manager and it was used to redact the highlights shown in chapter 2.

The AR was characterized and the most relevant current efforts were summarized as shown in chapter 1.

Chapter 1 shows plenty of previous experiences and state-of-art technologies.

The application of AR on Learning was queried and it threw very interesting success cases shown in section 2.2.1

The application of AR on Games was queried and it threw very interesting success cases shown in section 2.2.2

The results of the state-of-art were used to benchmark experiences before building this project’s videogame.

The state-of-art helped to characterize the main types of AR videogames as shown in section 2.2.2, which were used to see in a clearer way the possibilities for this and futures projects.

8.2 OBJECTIVE 2

The second objective read:

Design an AR videogame applying GBL concepts and identified special necessities on ADHD-diagnosed kids.

This objective is considered accomplished because:

- As an input to the game design the most relevant concepts (techniques, approaches and strategies) for build Game Based Learning Games were extracted from the most relevant sources and bibliography from last decade. This extraction and summarization is shown in chapter 2.
- As a mean to understand better the ADHD syndrome a review of the literature was made as shown in chapter 3.
- State-of-art experiences on technology (videogames and other learning tools) applied to ADHD were queried and are shown in section 4.2
- Since the videogame design required the expertise of professionals in the field of psychology and pedagogy, two experts: Dr. Ferrán Viñas and Professor María Canals were interviewed to identify the special needs and learning objectives for the videogame.
- 3 types of interaction in AR games were abstracted and described as shown in section 5.3
- Some Game Design principles for AR games for ADHD symptomatic kids were abstracted and are recommended in chapter 4.
- The videogame “Gremlings in my Mirror” was designed as shown in the Game Design Document explained in chapter 4
8.3 OBJECTIVE 3

The third objective read:

*Develop the designed videogame*

This objective is considered accomplished because:

- The videogame “Gremlings in my mirror” was developed according to the design established.
- The videogame developed is described in chapter 5.
- An “AR interaction framework” to work with NyARToolkit was developed for further developments.
- The videogame developed is available at this project’s URL.

8.4 OBJECTIVE 4

The fourth objective read:

*Design and execute an observation scenario with ADHD-diagnosed kids where they use the developed videogame.*

This objective is considered accomplished because:

- The observation scenario that used the designed videogame was designed, considering the characteristics of the game and the aspects to observe as shown in chapter 6.
- The observation scenario design included a template to fill in, in the play session.
- The observation scenario design included a set of guidelines to perform the observation scenario.
- The observation scenario was executed as evidenced in section 7.2.
- Analysis of the data recollected with kids and adults participants was made as shown in section 7.3.

8.5 GENERAL OBJECTIVE

The general objective of this project was:

*To create an Augmented Reality (AR) enriched videogame considering the principles of Game Based Learning (GBL) for applying it to support some task developed by kids diagnosed with Attention Deficit Hyperactivity Disorder (ADHD) symptoms.*

This objective is considered accomplished since “Gremlings in my mirror”:
• is an AR enriched videogame
• was designed based on the principles abstracted from the review of the literature, which were based on the principles of GBL
• is aimed to support and foster mathematical skills which are considered main tasks in elementary aged kids
• is aimed to support tasks of ADHD kids since it has been developed considering the characteristics of the syndrome.

With all of this said, the objectives of the present project are considered accomplished, satisfying the project’s requisites.
9 CONCLUSIONS AND FUTURE WORK

9.1 CONCLUSIONS

- An AR enriched videogame named “Gremlings in my Mirror” has been built applying GBL concepts. The game is aimed to foster mathematical logical skills in kids with ADHD. The process for design and develop this game consisted in an exhaustive review of the literature for useful concepts and interesting previous experiences on both AR and GBL as well as input and considerations from psychology and pedagogy experts.

- The review of literature regarding themes of AR, learning and videogames suggests that AR technology used in conjunction is a feasible way to apply on learning processes. This is mainly because there are some types of AR videogames that can be developed in a relatively easy way as this and some others experiences have shown.

- The literature review on AR shown that the field of AR is very broad regarding the types of displays and registering technologies. However, some technologies are still far from being easy to adapt and adopt. On the other hand, some other technologies, such as simple AR and mobile marker and GPS tracked technologies are very easy to adapt and are being mass-adopted by society.
A classification of 4 types of AR Games has been proposed based on the review of the literature. This classification was made based on the type of display and rtracking technology. The classification included:
- Marker Based Mobile Game
- Acelerometer/Gyroscope tracked AR Mobile Game
- GPS-tracked game
- Spatial AR Game

A review of the literature showing the most relevant concepts until today has been done. DGBL has been used in the game design of “Gremlings in my mirror”.

The review of the literature regarding DGBL suggests that this technology is to be used in the near future. However, some issues (both technological and social) still exist for its complete adaptation and acceptation.

DGBL suggests that nowadays learners, namely “Digital Natives” rather to learn via personal experiences that include learning using digital media. Videogames are an excellent way to implement this, since their ludic nature and safe content-rich environment.

Until now, authors have claimed lots of principles to implement DGBL that need to be tested. This project presented a newly experience on DGBL using state-of-art technologies.

A review of literature was made regarding ADHD as a syndrome and previous efforts on how to apply to technology to it. The review of the literature seems to suggest that in the last decades there have been a higher concern on ADHD and that technology has been applied on the treatment. Nonetheless, few efforts were found on the learning aspect of such affected people.

A Game Design Document was built to show the considerations on the design of “Gremlings in my mirror”. This document is meant to be an example on the design of learning games for ADHD children.

3 types of AR interactions have been proposed based on the necessities found on designing spatial Marker-based AR games. This types are:
- Marker for Drag & Dropping virtual Objects
- Marker for placing objects
- Marker for manipulate transform

A fully-functional videogame was constructed following the game design done. The Game development was made using Unity3D Game Engine and the NyARToolkit. This study concludes that these two tools are very recommendable due to their stability and high compatibility and easiness of deployment. This experience is a technological test that these two tools work perfect with each other.

An “AR interaction framework” for work with Unity3D and NyARToolkit was built and it is proposed to use in future works for an easier manipulation of AR interaction objects.

An observation scenario was carried on to observe player’s behavior using the videogame developed. The observation scenario was carried over adult and regular (non ADHD affected) kids. However, the findings of the observation scenario suggest that kids and adults alike are able to complete the videogame without being explained about how to use it. Of course, to obtain more conclusive data more scenarios have yet to be carried on. And naturally, ADHD kids have yet to be assessed in order to
compare to regular kids and to reach important observations on their reaction to the game developed.

9.2 FUTURE WORK

- Experiments have yet to be assessed using the videogame developed to stress out its features and to know the reactions of both regular and ADHD affected kids.
- The observation scenario guidelines and templates have yet to be tuned and refined to include other important observation variables and aspects unnoticed here.
- Data gathered, observations made and conclusions shown are yet to be proposed on to psychology and pedagogy experts for their consideration.
- The videogame has to be tuned-up to repair usability issues, include further the principles stated as well as to include final arts and mechanics included in GDD.
- The Game Design has to be updated according to findings in the observation scenario. The findings include both, systematical and design issues.
- The game design principles have yet to be stressed and tested to be tuned-up by testing developed games with ADHD kids.
- The forms of interaction are to be proposed to other developers and scientist to arbiter their validity.
- The undeveloped concepts proposed have yet to be developed.
- The AR interaction framework has to be upgraded to overcome usability and implementation issues. It also has to be published.
- Completion of the videogame has to be done, then its viability to be applied on real contexts such as schools or technologic centers can be evaluated.
APPENDIXES
Table 8 shows the DSM-IV diagnosis criteria for ADHD.

**TABLE 8: ADHD DIAGNOSIS CRITERIA**

<table>
<thead>
<tr>
<th>For Diagnosing ADHD – Inattention Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Six or more of the following symptoms of inattention have persisted for at least six months to a degree that is maladaptive and inconsistent with the developmental level:</td>
</tr>
<tr>
<td>1. often fails to give close attention to details or makes careless mistakes in schoolwork, work, or other activities</td>
</tr>
<tr>
<td>2. often has difficulty sustaining attention in tasks or play activities</td>
</tr>
<tr>
<td>3. often does not seem to listen when spoken to directly</td>
</tr>
<tr>
<td>4. often does not follow through on instructions and fails to finish schoolwork, chores, or duties in the workplace (not due to oppositional behavior or failure of comprehension)</td>
</tr>
<tr>
<td>5. often has difficulty organizing tasks and activities</td>
</tr>
<tr>
<td>6. often avoids, dislikes, or is reluctant to engage in tasks that require sustained mental effort (such as schoolwork or homework)</td>
</tr>
<tr>
<td>7. often loses things necessary for tasks or activities at school or at home (e.g. toys, pencils, books, assignments)</td>
</tr>
<tr>
<td>8. is often easily distracted by extraneous stimuli</td>
</tr>
<tr>
<td>9. is often forgetful in daily activities</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>For Diagnosing Hyperactivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Six or more of the following symptoms of hyperactivity have persisted for at least 6 months to a degree that is maladaptive and inconsistent with the developmental level:</td>
</tr>
<tr>
<td>1. often fidgets with hands or feet or squirms in seat</td>
</tr>
<tr>
<td>2. often leaves seat in classroom or in other situations in which remaining seated is expected</td>
</tr>
<tr>
<td>3. often runs about or climbs excessively in situations in which it is inappropriate (in adolescents or adults, may be limited to subjective feelings of restlessness)</td>
</tr>
<tr>
<td>4. often has difficulty playing or engaging in leisure activities quietly</td>
</tr>
<tr>
<td>5. often talks excessively</td>
</tr>
<tr>
<td>6. is often ‘on the go’ or often acts as if ‘driven by a motor’</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>For diagnosing Impulsivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Six or more of the following symptoms of impulsivity have persisted for at least 6 months to a degree that is maladaptive and inconsistent with the developmental level:</td>
</tr>
<tr>
<td>1. often has difficulty awaiting turn in games or group situations</td>
</tr>
<tr>
<td>2. often blurts out answers to questions before they have been completed</td>
</tr>
<tr>
<td>3. often interrupts or intrudes on others, e.g. butts into other children’s games</td>
</tr>
</tbody>
</table>
**Summary:**

Gremlings in my Mirror is an Augmented Reality (AR) enriched videogame aimed to foster mathematical skills on children. The game uses a webcam to feature a mirror where the kids see themselves. It also features a set of minigames each aimed to a different logical skill. Kids’ objective is to manipulate AR-markers to play with the gremlings in the mirror.
SECTI0N 1 - Summary
Game Concept

In “Gremlings in my Mirror”, the kids see themselves reflected in a “mirror”. Their job is to control the elements in the game using AR markers in order to accomplish the missions using the gremlings in screen. The game features minigames. In each minigame, the game mechanics are meant to foster one logical math-skill. Main minigames include «It’s raining Gremlings!» and «The Gremvolution», explained later.

---

Features.
The game is a 3-D game for Stand-Alone platform. PC, Linux, Mac.
The game has planned a Web-Browser version
The exclusive input devices are simple AR-markers\(^\text{10}\), the kid uses to control elements in screen. Simple AR-Markers are like the one shown in Fig 1.

\(^{10}\) Refer to [http://www.artoolworks.com/support/library/Creatin%20g_and%20training%20new%20ARTool%20Markers](http://www.artoolworks.com/support/library/Creatin%20g_and%20training%20new%20ARTool%20Markers) for more information.
In this game the system detects the marker position and rotation in the image captured by the camera. Thus, the kid can manipulate 3-D elements. Shows an example.

**Genre**

This is a **Stealth Learning Game**, a Game meant to learn by playing and not oriented to content. This is, in this game, learning occurs by mere playing and objective accomplishments. This game is based on didactic Materials by Maria Antonia Canals (Canals, 2009).

The main objective of this game is the learning but via fun. This is not a content-oriented game, thus this game doesn’t “explain” or “teach” concepts via virtual tutoring.

This game is a minigame-based game. Some games are action-based, others are far more reflexive and others are puzzles.

**Audience**

Elementary School kids ages 3 to 7.

**Visual Style**

This is a 3-D game with simple cartoony graphics. Models textures, GUI elements and Sprites have very saturated colors. Also it uses a simple color palette of primary hues. “Powerpuff girls” is an example of highly saturated, simple hue palette:

![Fig 3 Reference for color](image)

Models are very low-poly. Characters are low-detailed. And the few details found are implemented via textures. Models are flat shaded.

Textures are very simple, and do not contain much detail. This is important to avoid kid’s distraction on details. This monster is an example of flat shaded low poly:
This game has a Side-view perspective projected view of the scene. Elements in the game are mostly in the same depth position, however this is not an orthographic perspective game. Muffin Knight is an example of the perspective for this game:

![Fig 4 Reference for Low-Poly modeling and Texturing](image)

**Fig 4 Reference for Low-Poly modeling and Texturing**

In this version, the game will not feature 3-D Models. However GUI, 2-D elements and simple 3-D elements are meant to be final. For this version we will use 2-D vector graphics sprites instead of 3-D models. This is an example of what we will be using:

![Fig 5 Reference for perspective](image)

**Fig 5 Reference for perspective**

For this version, no Menu is meant to be. Only a gameplay prototype for the two main minigames is required. Nonetheless, the game is meant to be fully-functional regarding rules and mechanics. In this version there will be the first scene of the two main minigames “It’s raining Gremlings” and “The Gremvolution”.

---

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This version will include preliminary sound effects and music. Sound effects are 8-bits sample rate.

Section 2 – Game Flow

--This section is left to be described later--

SECTION 3 – GAMEPLAY
In this section is explained the gameplay for the minigames.

Conventions:
- Blue words are Game Objects.
- Bold Red words are Game Goals.
- Green words are Game Object’s actions
- Yellow words are Game Object’s Attributes
- Orange words are Game Object’s Attribute’s Values
- Bold Italics words are Variables
- Purple words are Sounds or Music
- This is an implementation Hint
- “Quoted Green Italics Text” is an “Animation”

Ctrl-Click on Hyperlinks to open web browser with example resources and definitions.

GAMEPLAY

Minigame Concept

Gremlings fall from the sky, they move across the platforms with a random behavior, Kids guide the gremlings using platforms. Then Gremlings fall in the Big-Gremlings down in the mirror. When the correct gremlings fall into the correct Big-Gremlings, kid wins coins.

The game ends when a number \( N \) of gremlings have fallen, if the kid has paired \( n \) gremlings correctly, they can go to the next stage (they win) otherwise they have to repeat the stage (they lose).

Fig 6 illustrates the concept:
In the Figure:

A. **Fixed Platforms**: Each scene has a set of fixed platforms, they don’t move nor they can be moved using Markers. When Gremlings fall upon them they can walk.

B. **Gremlings**: A gremling is a little creature that appear in the mirror from Gremling Spawn Points, they have different Behaviours. The most simple behavior is to walk over platforms. First, they fall from sky and their fall stops when they fall over a platform. Then they start walking, when they are walking if they front-hit a platform, they turn around (much like “mini-marios” or “Lemmings”). If they fall into their corresponding Big-Gremling, player earns coins. If they fall on incorrect Big-Gremlings none coins are won.

C. **Coins**: coins are the score for this game, in this figure this indicator shows a pile of coins with an “x number_of_coins”, next to it. As bigger the number of coins the icons shows more coins. We can use something like this:

D. **Mirror**: The mirror is just a 2D sprite that covers the screen, its frame’s design is like those old mirrors, it shouldn’t occupy much of the screen. The background of the mirror displays the image from the camera “mirrored”.

E. **AR-Platforms**: These are just platforms, like the above described. However these platforms copy the position and rotation of the AR Marker. Thus, the kid controls these platforms to guide the Gremlings.

F. **Background**: The background of the mirror displays the image taken from the camera. Note the image is mirrored, this is that the background shows the inverse image the camera takes.

G. **Big-Gremlings**: Big gremlings are creatures similar to the falling gremlings, but bigger. They don’t move from their initial position, they limit themselves to stay until receiving a falling gremling. Each Big-Gremling (and Little Gremlings) has some distinctive features (color, attitude, etc) so that a gremling only belongs to a Big-Gremling if their features match. Whenever a Big-Gremling catches a matching gremling, the kid wins coins.
Objectives

Move the Platforms: Gremlings are falling from above the Mirror, and kids must guide the Gremlings to their correct destinations by moving some platforms using their AR markers.

Guide the Gremlings: The Gremlings must fall in their respective Big-Gremlings. Big Gremlings are down in the mirror, waiting to catch the little gremlings. Each gremling has some features (color, size, and attitude) that correspond to one of the Big-Gremlings down in the mirror.

Think about correct pairing. The game is aimed to foster math skills, regarding logical relationships by means of pairing. Hence, in each stage the game becomes more difficult. For example, in the first level, there are only some easily identifiable features such as color, and they are easy to pair. However in later stages, gremlings are more varied and also Big-Gremlings switch positions.

Earn prizes: Whenever the kid pairs correctly the gremlings they receive coins

Design Goals

The design goals for this minigame are:

Avoid Frustration with Usability: This game is intended to be proven with little kids, who use computers, however if they feel frustrated by the game’s usability we will not achieve the learning objectives.

Feedback when AR-related errors come: This is an AR-Game, so, it may be difficult at first to learn how to play. We must do something to avoid frustration with the marker not recognizing and other issues.

Stealth Learning: The player will learn how to play, how to win, and how to do logical relationships, by playing, we will avoid explaining texts and so on, because maybe they can’t or don’t want to read.

Microcontrol: The kid should feel they have total control on the elements assigned to them, i.e. the platforms. The platforms move as smoothly as possible.

Make the Gremlings appear smoothly: The gremlings are slow at first to allow the kid to think how to guide them. The gremlings are somewhat like lemmings in their movements.

Win coins: When coins are won and a pairing is done correctly coins are very evident. The kid should be as aware as possible of what they do well.

Game Mechanics

Here are defined the Game Mechanics that define each of the Game Elements and Game Rules.

Game Elements

Scene

When the Scene’s number of Gremlings is reached (or surpassed) a Star appears behind the coins icon, indicating the objective has been acquired. Then after a few seconds a “Greetings” Screen shows and the game continues to the next scene. This screen plays an applause and a “congratulations music”

If on the contrary, all the Spawn Points reach their maximum capacities, and the number of Gremlings is not reached, the game shows a “Fail!” screen, and the same stage reappear. This screen plays a “Fail Music”.

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Platforms

Platforms are where Gremlings walk on. They all have the same height and depth, but their width changes. In Fig 7 there are some examples of platforms, with different colors. Platforms can be:

- **Statical**: They don’t move
- **Dynamic**: They move from one point to another. They move smoothly from point A, then, they stay there for a given time, then, move to point B stay for the same given time then move to A and repeat.

A and B points are a parameter for each platform, but they don’t change during the game.

- **AR**: These are the platforms the player controls. They are located in the same Z depth position than the other elements. However their X and Y position varies according to kid control. Remember this must be as precise as possible. Also, this platform takes rotation from the marker.

There are different types of platforms, and each of them has a different behavior.

- **Standard**: Standard platform has a texture like this:

And as its name suggests is pretty standard, it’s static so it doesn’t move. However Gremlings can walk on them normally:

- **Bouncy**: These are pretty much like Standard, however their texture is like a rubber, something like this would do the trick:
Bouncy platforms are bouncy (of course) so when gremlings fall they bounce. We can use Unity’s physics materials.

- When a gremling hits a bouncy platform a “boing” sound plays.
- **Wall**: walls are a constraining element, similar to a standard platform but placed vertically and with a rock-like texture, Gremlings can’t walk on them, nor they can pass through them. They are placed to be a colliding point where walking gremlings turn around. A standard parallelepiped with a brick texture will do the trick.

**Gremlings**

Gremlings are the central game element in this game. Gremlings are little 3-dimensional creatures that appear spontaneously from the Gremling Spawn Points around the scene.

- Gremlings fall until they find a platform to walk on.
- If Gremlings find a wall, or hit one of the AR platforms they turn and start walking the other way.

- When Gremlings fall into Big-Gremlings kid wins coins
- There are different types of gremlings and they each have different values for their features.

**Attributes**

- **Features**: Each gremling has a set of features: alignment, color, and attitude.
  - **Alignment** is the attribute that defines the gremlings as good or bad, it has for this version only two values: Good and Bad (Shocking! :P). These are the two main sketches for good and bad gremlings:

- **Color**: for this version we have only 4 different colors for Gremlings: These are: Green, Red, Blue and White.
- **Attitude**: For this version we have two attitudes Happy and Sad.
- **Speed**: All the Gremlings have the same walking speed.

Then, for this version the possible Gremlings are:
Actions

**Appear**: A Gremling appears spawned from a Gremling Spawn Point. When it appears it starts falling. Appearance occurs with a little dust-like explosion with the color of the gremling appearing. ([A simple rapid Particle System will do])

**Fall**: After a Gremling appears next thing it does is falling until it finds a platform or it has fallen too far so to disappear.

**Walk**: Gremlings walk similar to Lemmings and Minimarios. When it touches a platform after falling it starts walking in random direction (left or right) (50% each).
- If it touches a wall or front-hits a platform it turns to walk to the other direction.
- If it falls from the platform it starts falling
- If it reaches a Big-Gremling and it matches the same features coins coins are rewarded and 1 is added to the total of saved gremlings.
- If it has fallen too far it disappears

**Turn**: When a Gremling hits a wall or front-hits a platform, it turns to the other side much like lemmings and/or mini-marios

**Arrive to Big-Gremling**: When the gremling meets a Big-Gremling (by touching it) it checks if there's a match if matches coins are awarded and a “coin sound” plays and the Total of Saved Gremlings Count sums up on one. else nothing happens. After all it disappears.

**Disappear**: The Game element is destroyed from the scene, this happens when the gremling arrives to a Big-Gremling or it falls too far.

**Big-Gremlings**

Big-Gremlings are this big creatures that reside down in the mirror.
- They have a position, but they never move from there.
- They meet Gremlings when they touch them

There are the same number of Bg-gremling types than the gremlings types (16). Since they share the same attributes (color, attitude, alignment)

When a Gremling is touched by a Big-Gremling it Animates with the animation “Bouncing”. The “Bouncing” Animation is similar to the Bouncing a Gossip Stone from The Legend of Zelda: Ocarina of Time does.
When a Big-gremling is touched by a matching gremling, the *counter of Matches* increments. This means the player gets closer to the goal of saving a *number of gremlings* per scene.

*Something like:*

![Gremlings Image](image1)

*These stones do a Bouncing effect similar to the want I want:*

![Bouncing Effect Image](image2)

**Gremling Spawn Point**

- Gremling Spawn Points are invisible points in the scene where Gremlings appear randomly.
- Each Spawn Point has a *spawning speed*, measured in Gremlings per second.

Every 1/spawning speed seconds a Gremling is Spawned

- Gremling Spawn Point can have one or more *type of gremling* to spawn or be completely random.
- The spawned gremling depends on the *types* active for the Gremling Spawn Point
- If the Spawn Point is random, then it *spawns* a random gremling with one of the active types (features) the active types, each with the same probability of spawning.

**Attributes**

- **Spawning Speed**: a real number that states how many gremlings are spawned within a second by this Point.
- **Position**: The position of this spawn Point is the same position a Gremling appears spawned (Instantiated)
- **Active Types**: Each Spawning point has a set of variables to state if this Point is capable of spawning a given type The types are:
  - Evil Happy
  - Evil Sad
  - Good Happy
  - Good Sad
- **Color**: Gremlings spawned from this Point are of this color. The colors are the same available from Gremlings *(see here)*.
- **Waiting Time**: the time the Spawning Point has to wait until spawning the first Gremling.
**Gremlin Limit**: This *spawn point* only spawns a maximum of this integral value. If the spawning point has already *spawned* this limit it doesn’t *spawn* anymore.

**Actions**

- **Spawn**: A *gremlin* of one of the available *types* is *instantiated* in the position of the *Spawning Point*. The *type* is chosen randomly from the types active. The color of the *gremlin* is *color*.
  - If the *Gremling Limit* has been reached *(keep a counter, gremlin counter)* then *spawning* doesn’t happen
  - When the *Gremling* is effectively *spawned* the *gremlin counter* increments in one.
  - When the gremlin appears a “Spawn” sound plays. It is something like the Gremling talking or saying something short like “wah!” “wehh!” or so…
- **Wait**: The *Spawning point* waits *Waiting Time* seconds until doing the first *spawn*.

**Player Mechanics.**

Player’s main core mechanics is to use cardboard AR-Markers attached to their hands to control related platforms. An AR Platform is attached to the position of the marker using a *NormalMarkerTrackedAugmentedObject*.

For all the purposes the Platform attached to the AR marker (and the player’s hand) is a normal platform.

Player can use the platform to guide Gremlings or to bounce (if it is a Bouncing platform).

---

**SECTION 4 – GAME NARRATIVE.**

This game doesn’t have a complex story aside from the fact that gremlings in the mirror are to be saved for any reasons.

---This section is left to be described later---

**SECTION 5 - LEVELS.**

In this section the levels of the game are described. However, the game’s levels are the levels of each minigame, thus this section is divided by minigames:

**First Scene:**
The first scene has something special. It shows a MarkerTexture fading in and out in the center of the screen. All the scene lighting is attenuated. This indicates the marker to use. The game only
begins when the marker is detected on screen, which removes the fading texture in the screen and returns lights back to normal.

**Level 1:**
The first scene is the easiest of all. It actually is meant only for learning the use of AR markers to move the platform.
The scene initially is:
- The SpawnPoint only spawns Good White Happy Gremlings.
- The gremlings fall, unless the AR platform is correctly places like this:
- The Spawn Point has a Gremling Limit of 20
- The Number of gremlings in the scene is 10
- The speed of the spawnpoint is 1 gremling per second.

**Level 2:**
The blue-print for level 2 is the following. The expected position of the AR-Marker is marked with a red square:
- The spawnpoints only spawns Happy Evil Red Gremlings.
- Without the intervention of the players, red little gremlings will fall over white Big-Gremling. Evidencing that nothing happens and the kid will want to pair to the correcting colored Gremling.
- Number of Gremlings: 10
- Spawn Gremling Limit: 20
**Level 3:**

In this level, the novelty is the use of a bouncing platform to guide gremlings.

Both SpawnPoints spawn random from active types: Good Happy White, Evil Happy Red.

Gremling limit: 30-

Gremling number: 15

---

**Level 4:**

---

**SECTION 5 – INTERFACES**

--This section is left to be described later--

**SECTION 6 – Resources**

--This section is left to be described later--

**SECTION 7 – Technical Issues**

**Device**

The Game will be played in a PC. Linux or Mac. With a WebCam. The WebBrowser version uses a WebBrowser with th Unity Web Player Plugin.
Development Hardware and Software
We will build this game using Standard Computers with a front-facing HD web camera (laptop Camera) for Gremlings in my Mirror. And an HD, USB, detachable camera for The Gremvolution.
The gremvolution's camera is fixed in a wooden structure where below lays a gameboard for placing AR markers.
The game will be made using Unity3D Game engine, The NyARToolkit and a proprietary framework for ARGame interaction with AR Markers.
The development will count with Unity3D’s version management software installed on a server.
APPENDIX C: OBSERVATION SCENARIO RECORDS

In this appendix, the transcripts of the observations made in the observation scenario are shown. The observations are presented using the Observation Scenario Template presented in Table. 7.

Tags are used as follows:

- **UI**: The remark contains a Usability Issue. It should be resolved.
- **M**: Milestone. It marks an important milestone on the learning of in-game stuff.
- **PI**: Player interacts with researcher.
- **S**: Player speaks, either to themselves or to others, in a social way.
- **T&E**: Player uses Trial & Error approaches.
- **H**: Players is given a Hint.
- **A**: Abandons and/or stops playing for a moment
- **R**: Player resumes a previously stopped session.

ADULT-ORIENTED SESSIONS RECORDS

TABLE. 9: RECORDS FOR ADULT PLAYER 1

<table>
<thead>
<tr>
<th>Play Session Observations</th>
<th>Remarks on time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Remarks on time</strong></td>
<td><strong>Game: “The Gremvolution”</strong></td>
</tr>
<tr>
<td><strong>Date and Time</strong></td>
<td>2013-07-05 04:30:00 p.m.</td>
</tr>
<tr>
<td><strong>Player’s age</strong></td>
<td>26</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Timestamp</th>
<th>In level</th>
<th>Observation</th>
<th>Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:02</td>
<td></td>
<td>Access to game using correct AR-Marker</td>
<td>M</td>
</tr>
<tr>
<td>00:04</td>
<td></td>
<td>Gathers first drag&amp;drop gremling</td>
<td>M</td>
</tr>
<tr>
<td>00:07</td>
<td></td>
<td>Places first gremling</td>
<td>M</td>
</tr>
<tr>
<td>00:09</td>
<td></td>
<td>Finishes Level 1</td>
<td></td>
</tr>
<tr>
<td>00:13</td>
<td></td>
<td>Orders correctly the Gremlings</td>
<td>M</td>
</tr>
<tr>
<td>00:18</td>
<td></td>
<td>Finishes Level 2</td>
<td></td>
</tr>
<tr>
<td>00:42</td>
<td></td>
<td>Finishes Level 3</td>
<td></td>
</tr>
<tr>
<td>01:00</td>
<td></td>
<td>Finishes Level 4</td>
<td></td>
</tr>
<tr>
<td>01:28</td>
<td></td>
<td>Finishes Level 5</td>
<td></td>
</tr>
<tr>
<td>02:00</td>
<td></td>
<td>Loses Level 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Has problems with usability by crashing Gremlings with Holders</td>
<td>UI</td>
</tr>
<tr>
<td>02:57</td>
<td></td>
<td>Loses Level 6</td>
<td></td>
</tr>
<tr>
<td>03:28</td>
<td></td>
<td>Loses Level 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Still having problems with Holders</td>
<td>UI</td>
</tr>
<tr>
<td>03:58</td>
<td></td>
<td>Finishes Level 6</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Additional Observations and Highlights</th>
<th>Remarks on time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Remarks on time</strong></td>
<td><strong>Game: “It’s Raining Gremlings”</strong></td>
</tr>
<tr>
<td><strong>Timestamp</strong></td>
<td>In level</td>
</tr>
<tr>
<td>00:01</td>
<td></td>
</tr>
<tr>
<td>00:06</td>
<td></td>
</tr>
<tr>
<td>00:08</td>
<td></td>
</tr>
<tr>
<td>00:38</td>
<td></td>
</tr>
<tr>
<td>00:42</td>
<td></td>
</tr>
</tbody>
</table>
TABLE. 10: RECORDS FOR ADULT PLAYER 2

<table>
<thead>
<tr>
<th>Date and Time</th>
<th>2013-07-05 04:45:00 p.m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Player's age</td>
<td>27</td>
</tr>
</tbody>
</table>

**Remarks on time**

**Game: “The Gremvolution”**

<table>
<thead>
<tr>
<th>Timestamp</th>
<th>In level</th>
<th>Observation</th>
<th>Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:02</td>
<td></td>
<td>Player asks “What do I have to do?” She receives not answer from researcher.</td>
<td>PI</td>
</tr>
<tr>
<td>00:20</td>
<td></td>
<td>Loses Level 1</td>
<td></td>
</tr>
<tr>
<td>01:00</td>
<td></td>
<td>Loses Level 1</td>
<td></td>
</tr>
<tr>
<td>01:02</td>
<td></td>
<td>Player tries to use another marker, unsuccessful trial, then returns to original marker.</td>
<td>T&amp;E</td>
</tr>
<tr>
<td>01:06</td>
<td></td>
<td>Gathers first drag&amp;drop gremling</td>
<td>M</td>
</tr>
<tr>
<td>01:15</td>
<td></td>
<td>Places first gremling</td>
<td>M</td>
</tr>
<tr>
<td>02:00</td>
<td></td>
<td>Finishes Level 1</td>
<td></td>
</tr>
<tr>
<td>02:35</td>
<td></td>
<td>Finishes Level 2</td>
<td></td>
</tr>
<tr>
<td>03:06</td>
<td></td>
<td>Finishes Level 3</td>
<td></td>
</tr>
<tr>
<td>03:34</td>
<td></td>
<td>Finishes Level 4</td>
<td></td>
</tr>
<tr>
<td>03:55</td>
<td></td>
<td>Finishes Level 5</td>
<td></td>
</tr>
<tr>
<td>04:04</td>
<td></td>
<td>Finishes Game</td>
<td></td>
</tr>
</tbody>
</table>

**Additional Observations and Highlights**

Due to researcher’s mistake, this player was near to player 1 during his sessions. So, maybe, player 2 may have been hearing or watching player 1’s actions which may have led to a quicker understanding of gameplay.

TABLE. 11: RECORDS FOR ADULT PLAYER 3

<table>
<thead>
<tr>
<th>Date and Time</th>
<th>2013-07-05 05:15:00 p.m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Player's age</td>
<td>28</td>
</tr>
</tbody>
</table>

**Remarks on time**

**Game: “It’s Raining Gremlings”**

<table>
<thead>
<tr>
<th>Timestamp</th>
<th>In level</th>
<th>Observation</th>
<th>Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:01</td>
<td></td>
<td>Player gains access to the game</td>
<td>M</td>
</tr>
<tr>
<td>00:05</td>
<td></td>
<td>Uses correctly the marker</td>
<td>M</td>
</tr>
<tr>
<td>00:07</td>
<td></td>
<td>Moves platform for the first time</td>
<td>M</td>
</tr>
<tr>
<td>00:10</td>
<td></td>
<td>Guides correctly the first gremling</td>
<td>M</td>
</tr>
<tr>
<td>00:18</td>
<td></td>
<td>Finishes Level 1</td>
<td>M</td>
</tr>
<tr>
<td>00:30</td>
<td></td>
<td>Finishes Level 2</td>
<td></td>
</tr>
<tr>
<td>00:50</td>
<td></td>
<td>Finishes Level 3</td>
<td></td>
</tr>
<tr>
<td>02:22</td>
<td></td>
<td>Finishes Level 4</td>
<td></td>
</tr>
<tr>
<td>03:11</td>
<td></td>
<td>Finishes Level 5</td>
<td></td>
</tr>
<tr>
<td>04:16</td>
<td></td>
<td>Finishes Game</td>
<td></td>
</tr>
</tbody>
</table>
### Game: “The Gremvolution”

<table>
<thead>
<tr>
<th>Timestamp</th>
<th>In level</th>
<th>Observation</th>
<th>Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:05</td>
<td></td>
<td>Player gains access to the game</td>
<td></td>
</tr>
<tr>
<td>00:15</td>
<td></td>
<td>Player grabs successfully the first drag&amp;drop Gremling.</td>
<td>M</td>
</tr>
<tr>
<td>00:20</td>
<td></td>
<td>Places correctly the gremling</td>
<td>M</td>
</tr>
<tr>
<td>00:25</td>
<td></td>
<td>Finishes Level 1</td>
<td></td>
</tr>
<tr>
<td>00:27</td>
<td></td>
<td>Orders correctly the gremlings</td>
<td>M</td>
</tr>
<tr>
<td>00:30</td>
<td></td>
<td>Finishes Level 2</td>
<td></td>
</tr>
<tr>
<td>01:09</td>
<td></td>
<td>Loses Level 3</td>
<td></td>
</tr>
<tr>
<td>01:27</td>
<td></td>
<td>Finishes Level 3</td>
<td></td>
</tr>
<tr>
<td>02:01</td>
<td></td>
<td>Loses level 4</td>
<td></td>
</tr>
<tr>
<td>03:02</td>
<td></td>
<td>Finishes Level 4</td>
<td></td>
</tr>
<tr>
<td>03:20</td>
<td></td>
<td>Finishes Level 5</td>
<td></td>
</tr>
<tr>
<td>03:50</td>
<td></td>
<td>Finishes Game</td>
<td></td>
</tr>
</tbody>
</table>

**Additional Observations and Highlights**

This minigame was played after “It’s raining Gremlings” showed below. In this part of the session player seems more secure and seemed to have fun, presumably since she had gained expertise on AR-elements control.

### Remarks on time

**Game: “It’s Raining Gremlings”**

<table>
<thead>
<tr>
<th>Timestamp</th>
<th>In level</th>
<th>Observation</th>
<th>Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:20</td>
<td></td>
<td>Player gains access to the game</td>
<td>M</td>
</tr>
<tr>
<td>00:21</td>
<td></td>
<td>Uses correctly the marker</td>
<td>M</td>
</tr>
<tr>
<td>00:22</td>
<td></td>
<td>Moves platform for the first time</td>
<td>M</td>
</tr>
<tr>
<td>00:31</td>
<td></td>
<td>Guides correctly the first gremling</td>
<td>M</td>
</tr>
<tr>
<td>01:04</td>
<td></td>
<td>Player tries to accommodate the AR-camera in an attempt to get more responsiveness from the system.</td>
<td>T&amp;E</td>
</tr>
<tr>
<td>02:07</td>
<td></td>
<td>Marker shows unresponsive; it may be due to lack of lightning in that precise moment. Player tries to use other marker.</td>
<td>UI, T&amp;E</td>
</tr>
<tr>
<td>02:49</td>
<td></td>
<td>Finishes Level 1</td>
<td></td>
</tr>
<tr>
<td>03:16</td>
<td></td>
<td>Finishes Level 2</td>
<td></td>
</tr>
<tr>
<td>03:37</td>
<td></td>
<td>Finishes Level 3 and player discovers Gremlings “go by themselves in this level” so player has only to place the platform in a fix spot.</td>
<td>S</td>
</tr>
<tr>
<td>04:40</td>
<td></td>
<td>Player argues that when marker leaves screen and 321 count starts: “The letters can’t be understood”</td>
<td>UI</td>
</tr>
<tr>
<td>05:33</td>
<td></td>
<td>Finishes Level 4</td>
<td></td>
</tr>
<tr>
<td>07:20</td>
<td></td>
<td>Player abandons level, arguing she cannot surpass it.</td>
<td>A</td>
</tr>
<tr>
<td>08:40</td>
<td></td>
<td>Player continues</td>
<td>R</td>
</tr>
<tr>
<td>10:00</td>
<td></td>
<td>Finishes Level 5</td>
<td></td>
</tr>
<tr>
<td>11:11</td>
<td></td>
<td>Finishes Level 6 and Game</td>
<td></td>
</tr>
</tbody>
</table>

**Additional Observations and Highlights**

This player argues not being an active videogame player. Also she looks pretty bored after minute 7, probably because frustration on level 5.

Player thinks she lost the game since the final screen says “Game Over”. Future versions changed this for a “Thank you for Playing”.

### KID-ORIENTED SESSIONS RECORDS

**TABLE. 12: RECORDS FOR KID PLAYER 1**

<table>
<thead>
<tr>
<th>Play Session Observations</th>
<th>Remarks on time</th>
<th>Game: “The Gremvolution”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date and Time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Player's age</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

108
<table>
<thead>
<tr>
<th>Timestamp</th>
<th>Observation</th>
<th>Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:01</td>
<td>Player gains access to the game</td>
<td>M</td>
</tr>
<tr>
<td>00:15</td>
<td>Player grabs successfully the first drag&amp;drop Gremling.</td>
<td>M</td>
</tr>
<tr>
<td>00:23</td>
<td>Loses Level 1</td>
<td>S</td>
</tr>
<tr>
<td>00:29</td>
<td>Places correctly the gremling</td>
<td>S</td>
</tr>
<tr>
<td>00:32</td>
<td>Finishes Level 1</td>
<td>S</td>
</tr>
<tr>
<td>01:10</td>
<td>Loses Level 2. With the belief that it is enough to place the gremlings, Player says &quot;It was right&quot;. However he knows it was not right since he lost.</td>
<td>S</td>
</tr>
<tr>
<td>02:15</td>
<td>Loses Level 2. Player theorizes about what needs to be done. He says &quot;Do I have to put them in order?&quot;, he is right</td>
<td>S</td>
</tr>
<tr>
<td>03:26</td>
<td>Player describes his actions &quot;I have to put this, here, and this, there...&quot;</td>
<td>S</td>
</tr>
<tr>
<td>03:27</td>
<td>Orders Correctly</td>
<td>S</td>
</tr>
<tr>
<td>03:58</td>
<td>Finishes Level 2. He says &quot;It was so fun!&quot;</td>
<td>S</td>
</tr>
<tr>
<td>04:15</td>
<td>Finishes Level 3</td>
<td>S</td>
</tr>
<tr>
<td>04:20</td>
<td>Finishes Level 4</td>
<td>S</td>
</tr>
<tr>
<td>04:56</td>
<td>Finishes Level 5</td>
<td>S</td>
</tr>
<tr>
<td>05:33</td>
<td>Loses Level 6.</td>
<td>S</td>
</tr>
<tr>
<td>05:40</td>
<td>Player realizes the importance of ordering by saying “So, they had to be ordered”</td>
<td>S</td>
</tr>
<tr>
<td>06:27</td>
<td>Finishes Level 6 and Game</td>
<td>S</td>
</tr>
</tbody>
</table>

**Additional Observations and Highlights**

The player (a kid) was not explained how to play or how to win. However, it was very interesting to observe the kid theorize and reflex about what he needed to do. At the end, the kid found what to do by self-reflecting and auto-instructing.

For this minigame it was also, very satisfying that once finished the game for the first time, he wanted to play again with the expertise found. The kid played the same levels and the other minigame for a bit, until he bored, he was rewarded with some candy and he left.

**Remarks on time**

Game: "It’s Raining Gremlings"

<table>
<thead>
<tr>
<th>Timestamp</th>
<th>Observation</th>
<th>Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:01</td>
<td>Player gains access to the game</td>
<td>M</td>
</tr>
<tr>
<td>00:02</td>
<td>Uses correctly the marker</td>
<td>M</td>
</tr>
<tr>
<td>00:04</td>
<td>Moves platform for the first time</td>
<td>M</td>
</tr>
<tr>
<td>00:07</td>
<td>Guides correctly the first gremling</td>
<td>M</td>
</tr>
<tr>
<td>00:26</td>
<td>Finishes Level 1</td>
<td>S</td>
</tr>
<tr>
<td>00:47</td>
<td>Player tries to &quot;push&quot; gremlings to their destination by using the marker as a &quot;shovel&quot;. The attempt is unsuccessful since gremlings do not respond to that.</td>
<td>T&amp;E</td>
</tr>
<tr>
<td>01:00</td>
<td>Finishes Level 2</td>
<td>T&amp;E</td>
</tr>
<tr>
<td>01:23</td>
<td>Player keeps on “pushing” gremling even since he has seen it is not fructiferous.</td>
<td>T&amp;E</td>
</tr>
<tr>
<td>01:33</td>
<td>Player realizes he has not why to &quot;push&quot; gremlings since it’s enough with letting the platform fix for the gremlings to walk over. Player uses it strategically.</td>
<td>M</td>
</tr>
<tr>
<td>01:48</td>
<td>Finishes Level 3</td>
<td>M</td>
</tr>
<tr>
<td>02:20</td>
<td>Finishes Level 4. Although the player is doing a great work within the game, he tries with the smaller version of the marker he already has and he sees it also works. He also tries with other markers; they do not work, so he returns to the first marker.</td>
<td>T&amp;E</td>
</tr>
<tr>
<td>02:57</td>
<td>Player finds trouble with level 5, so he asks “What to do?” They only receive a “What do you think you must do” from researcher since the game is not meant to be explained.</td>
<td>PI</td>
</tr>
<tr>
<td>04:44</td>
<td>Player keeps on trying with other markers</td>
<td>T&amp;E</td>
</tr>
<tr>
<td>05:14</td>
<td>Player says to himself: &quot;I don’t know what to do, but I have to think...&quot;</td>
<td>S</td>
</tr>
<tr>
<td>06:08</td>
<td>Player is questioned to know if he knows what to do.</td>
<td>PI</td>
</tr>
</tbody>
</table>
Evidently he knows, he has to match the colors, however, there is a little gap the white gremlings need to overcome to arrive to white Big Gremling. Player seems not to know how to overpass the gap.

06:28 Player seems stresses for not knowing how to win this level.
08:00 Player asks for help. Researcher gives a little hint. H
10:40 Player seems about to lose patience.
12:15 Researcher exemplifies what to do, however, nothing is explained. H
14:43 Finishes Level 5
16:28 Player tries to use both marker at the same time T&E
17:00 Player finishes game

Additional Observations and Highlights
When session ended, the player was asked how he felt, he said "it was so fun, although there was one very hard part and other were very easy".

At the end of the whole session, the player (since a kid) was rewarded with something to eat. When researcher went to look for the food, it was quite surprise to find the kid playing again even though he was not asked to. He seemed to had gain a lot of expertise and he managed to complete the same levels with the following timestamps:

- Level 1: 00:10
- Level 2: 00:17
- Level 3: 01:38
- Level 4: 02:56
- Level 5: 03:32

### TABLE. 13: RECORDS FOR KID PLAYER 2

#### Play Session Observations

<table>
<thead>
<tr>
<th>Date and Time</th>
<th>2013-07-08 04:15:00 p.m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Player's age</td>
<td>8</td>
</tr>
<tr>
<td>Remarks on time</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Game: &quot;The Gremvolution&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timestamp</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>00:02</td>
</tr>
<tr>
<td>00:04</td>
</tr>
<tr>
<td>00:05</td>
</tr>
<tr>
<td>00:06</td>
</tr>
<tr>
<td>00:10</td>
</tr>
<tr>
<td>00:28</td>
</tr>
<tr>
<td>00:47</td>
</tr>
<tr>
<td>01:19</td>
</tr>
<tr>
<td>01:47</td>
</tr>
<tr>
<td>02:49</td>
</tr>
<tr>
<td>03:15</td>
</tr>
<tr>
<td>03:24</td>
</tr>
</tbody>
</table>

#### Additional Observations and Highlights

For this particular game and player is noteworthy that the kid was 8 years old, thus it Is likely that ordering skills were already learned thus not ordering-related issues appeared, Also, the kid was not explained the functionalities of the game, however the kid seemed to have it very easy to finish levels.

The kid was congratulated when finished a level, but when he lost a level he was not punished whatsoever.

<table>
<thead>
<tr>
<th>Remarks on time</th>
<th></th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Game: &quot;It's Raining Gremlings&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timestamp</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>00:05</td>
</tr>
<tr>
<td>00:09</td>
</tr>
<tr>
<td>00:10</td>
</tr>
<tr>
<td>Time</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>00:39</td>
</tr>
<tr>
<td>01:06</td>
</tr>
<tr>
<td>01:23</td>
</tr>
<tr>
<td>02:25</td>
</tr>
<tr>
<td>03:03</td>
</tr>
<tr>
<td>04:25</td>
</tr>
<tr>
<td>06:27</td>
</tr>
<tr>
<td>06:48</td>
</tr>
<tr>
<td>07:22</td>
</tr>
<tr>
<td>08:09</td>
</tr>
<tr>
<td>09:29</td>
</tr>
</tbody>
</table>

**Additional Observations and Highlights**

After finishing this minigame, The game entered the same minigame by a systems fault or maybe because the marker was placed in the minigame selection position of the minigame selection screen. In any case, the kid, when he saw this, started playing the game again, although not asked to. He said it was fun and wanted to try it again.


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