Augmented Reality Game-Based Learning for Mathematics Skills Training in Inclusive Contexts

Hendrys Tobar-Muñoz, Ramon Fabregat, Silvia Baldiris

Institut d'Informàtica i Aplicacions
C/ Emili Grahit, 91, 17003, Girona, Catalonia, Spain
u1918137@campus.udg.edu, ramon.fabregat@udg.edu , baldiris@eia.udg.edu

Resumen: La Realidad Aumentada (RA) y el Aprendizaje Basado en Juegos Digitales (DGBL) son dos tendencias que están siendo aplicadas a la educación alrededor del mundo. Sin embargo, las implicaciones relacionadas con la aplicación de ambas tendencias simultáneamente al aprendizaje inclusivo es aún algo por observar. Hemos diseñado un videojuego inclusivo con RA para el aprendizaje de Habilidades de Lógica Matemática. Probamos el juego con un conjunto de 20 estudiantes con diversas necesidades de aprendizaje. Nuestro experimento mostró que el desempeño durante el juego es similar para niños con distintas necesidades. Los resultados y la realimentación por parte del personal docente nos sugieren que la RA y el DGBL permiten la integración de niños con necesidades especiales en el proceso formativo.
Palabras clave: Aprendizaje Basado en Juegos Digitales, TDAH, Videojuego, Realidad Aumentada, Aprendizaje Inclusivo, Matemáticas, Aprendizaje.

Abstract: Augmented Reality (AR) and Digital Game Based Learning (DGBL) are two tendencies being applied broadly in education around the globe. However, the implications on a simultaneous application of them to inclusive learning have yet to be observed. We designed an inclusive AR-enriched videogame for Logical Math Skills Learning. We tested the game with a set of 20 students with diverse learning needs. Our experiment showed that the performance on the game is similar for kids with different needs. The results and feedback from teaching staff suggest that AR and DGBL allow the integration of children with special needs into the learning process.
Keywords: Digital Game Based Learning, ADHD, Videogame, Augmented Reality, Inclusive Learning, Mathematics, Learning.

1. Introduction

In the last decade, Digital Game Based Learning (DGBL), the "marriage" between educational content and computer games [Prensky 01a] has started to be applied in instruction and curriculums around the globe. This new educational paradigm proposes games as pretty useful tools and vehicles of content 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 01a]. 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 2012 claims [Johnson et al. 12].

Also, Augmented Reality (AR), a currently trending technology that mixes virtual elements registered along real world objects [Azuma et al. 01], is nowadays being introduced as an open, massively-used technology, especially by mobile users around the world [Wu et al. 13]. Simple AR, the type of Augmented Reality that uses relatively simple devices and techniques has also been proposed as a technology for learning by the Horizon Report 2010 [New Media Consortium 10]. Nonetheless, there are still some obstacles to overcome and enablers to exploit in order to achieve a widespread adoption of DGBL and AR.

For example, there is a strong opportunity to apply the abovementioned technologies and theories for achieving an Inclusive Learning. In our opinion, Digital Games and AR are technologies that can and should be used to address the principles of the Universal Design for Learning [Rose et al. 02] since they present properties that can foster learning in children with different needs.

Given that Attention Deficit Hyperactivity Disorder (ADHD) is a behavioral condition that makes focusing on everyday requests and routines challenging and affects as far as 10% of elementary school kids [American Psychiatric Association 13], we considered specially ADHD implications for learning in our user-centered design. We observed ADHD as it is considered particularly special in kids because of the lack of the right executive functions that control attention and hyperactivity [Doyle 06]. Note we have taken into account special requirements of ADHD for the game design; however, we consider that addressing the special needs of this population benefits all students as well.

In this paper, we explain an inclusive AR-enriched videogame for Logical Math Skills Learning named *Gremlings in my mirror*. We chose logical mathematical skills as they are fundamental in math understanding in early childhood [Canals 09]. This game is based on a set of design principles proposed on the basis of ADHD treatment considerations and AR affordances.

In section 2, we present some of the work related to the subject (AR and DGBL) and the input we had from pedagogy and psychology experts. In section 3, we show the design and development of the videogame, the decisions we took, the observations we made and the proposals we came up with. Finally, in section 4, we show highlights and conclusions of an observation scenario we carried on using the videogame with 20 children with different ages and needs

2. Related Work

Our work is based on several aspects: the considerations for applying AR to education, the considerations for designing and building games for learning, and the implications of considering the needs of all students.

For that, our work started by completing a literature review in order to recognize the current opportunities for Technology Enhanced Learning (TEL) when applying AR and Digital Games. With that, we came up with a set of conclusions and theoretical foundations for our work.

On the one hand, we reviewed the literature to find out the main characteristics of AR and the current hardware and software tools for the development of AR applications. On the other hand, we explored the pedagogical, and philosophical foundations of DGBL basing our most basic findings in the studies of Prensky [Prensky 01a, Prensky 04, Prensky 07] and James Paul Gee [Gee 03, Gee 07, Gee 09, Gee 08]. We also conducted two interviews to get deeper insight into the implications of the work with ADHD children and the instructions of Mathematics skills. These interviews and the literature review findings fed up the game design. In this section we show these findings separated in three topics AR, DGBL and ADHD.

2.1 Augmented Reality

An Augmented Reality (AR) system is that which overlays computer-presented material over the real world [Azuma 01].

There is global increasing interest in applying Augmented Reality to different contexts, like Architecture, Entertainment, Journalism, Traveling, Military and, of course, Education [Yuen et al. 11]. Because of this, some platforms in the worlds like Layar, Vuforia and Metaio, offer tools to create applications of AR to non-programmers, making it more accessible to the general population.

From a hardware perspective, some classifications of AR systems have been proposed including Hand-held, Headworn and Spatial devices with Projective, Video and Optical See-through displays [Tobar-Muñoz et al. 13, Azuma et al. 01, Krevelen et al. 10].

From a software perspective, we explored the most relevant and useful API's and frameworks in the market, including ARToolkit, UnityAR, Vuforia, NyARToolkit, ARToolkit for Unity and FLARToolkit. For this development we chose the Spatial Video Displayed type of AR application, thus these tools were observed because they are more focused in Image-based recognition techniques, rather than other types of AR like Location-based AR.

Since we had experience with the Unity3D game engine, our choices narrowed to UnityAR and NyARToolkit. After some tests, we chose the latter since it seemed very stable and easy to use when integrated with Unity3D (Utilities, C# language scripts, simple API, etc.).

At the end of the review stage we found AR as a very interesting-to-apply tool nowadays given the easiness of its adoption in a society full of powerful devices (such as smartphones and laptops).

AR has been labeled as a good tool for learning since it has unique affordances that can affect the learning experience like real-world annotation, contextual visualization and vision-haptic visualization [Santos et al. 14]. AR has been found to have a strong potential to provide both powerful and contextual "in situ" learning experiences [New Media Consortium 10], it allows Experimental learning without displacing the learner [Adelsberger et al. 08], and it fosters participation of the observer [Woods et al. 04]. This is proven by a lot of AR Learning Experiences (ARLEs) that have been found to be effective and positive for the learning performance of students as found by Santos et al. in their latest meta-analysis [Santos et al. 14].

Furthermore, we found some previous experiences on the application of AR to learning; specially some efforts applied to ADHD, like [Aziz et al. 12] where authors show the usage of AR courseware for ADHD students using cloud-computing and [Mohd Azmidi Bin Abdullah 12], a study that showed the use of AR in the classroom with a software using conventional assets like a computer and a projector. Those efforts gave us an empirical background for our study.

2.2 Digital Game Based Learning

Regarding Digital Game Based Learning (DGBL), we mainly used theoretical referents to support the game design. For that, we used Prensky's work [Prensky 01b, Prensky 01a, Prensky 07, Prensky 04] to orient the game with the DGBL philosophy of learning by doing and fun as the greatest motivator.

Later, we applied Gee's properties in our Game Design as described in [Gee 05, Gee 09]. Gee claims that a good learning game:

- Allows the player to take advantage of the game system to obtain their goals.
- Offers microcontrol mechanics to enhance the intimacy feeling of the player.
- Offers Experiences to the learner for good learning
- Uses models to model the situations in game or those from the real world.
- Allows the player to enact their own trajectory through the game.

Also, the same author claims that Digital Games are good for learning by mentioning the most important characteristics of a game for learning in [Gee 05]. Those characteristics helped to design our own principles.

Although scarce, DGBL has seen applications using AR technologies in the last decade. Classical examples include the Location-based AR experiences conducted by Klopfer, Rosenbaum and Squire [Klopfer et al. 08, Rosenbaum et al. 07, Squire et al. 07] and more recently some authors have shown experiences applying new devices and new approaches to Image-Based AR, like [Lee 08, Carmen Juan et al. 11, Barreira et al. 12].

2.3 ADHD

Our literature review on ADHD led us to consider in the design the model of executive functions [Brown 06] which states that ADHD comes from a dysfunction on the "executive functions". These are functions of the mental apparatus that control other functions. These functions include: Inhibition Control, Working Memory, Planning, Cognitive Flexibility and Fluency.

Furthermore, we interviewed Dr. Ferrán Viñas, psychologist and UdG's professor who explained the most relevant aspects of the syndrome and taught us the most common techniques for intervention on ADHD kids. These techniques include:

- **Operant Conditioning:** According to McLeod [McLeod 07], Operant Conditioning means roughly changing of behavior by the use of reinforcement which is given after the desired response.
- **Token Economy:** According to [Flick 10], it consists in providing reinforcers such as points, tokens, cards, etc. associated to the realization of desired behavior.
- **Self-Instructions**: According to Banús [Banús Llort 13] 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.

3. Our Proposal

The theoretical and empirical support that the literature review gave to this project was used to build an inclusive AR-enriched videogame for Logical Math Skills Learning. For that, we proposed a set of Game Design Principles. With those in mind, we built a prototype with simple AR [Siltanen 12]. Our prototype is classified as a Spatial Video-Displayed game under the classification in [Azuma et al. 01, Krevelen et al. 10, Tobar-Muñoz et al. 13].

In this section we show the game design, the description of the development process and an overview of the final product in its current version.

3.1 Game Design

For the game design, besides getting advice on ADHD, we also asked for pedagogical advice. Thus, we consulted professor Maria Antonia Canals, UdG's professor emeritus and former elementary Mathematics teacher.

Also, professor Canals helped us to understand what a kid should have to effectively understand and apply Mathematics and basic logical skills. She told us that math should come as a result of a self-reflection process next to the interaction with an object of learning. Canals' work and materials can be consulted in [Canals 09, Canals 10].

With the experts input and literature review we proposed the following Game Design Principles for designing Inclusive AR games:

- **Comply with Gee's properties:** The game should comply with James Paul Gee's properties [Gee 09] as shown previously.
- **Comply with "Universal Design for Learning" principles:** By offering to children different ways to acquire the information in the visual and auditory means.
- **Design Learner-Centered Interaction:** 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 microcontrol [Gee 09], and also, should let a time for reflection about the learning [Prensky 01a]. Content-centered games should be avoided. Instead, Player/Learner centered games are preferred.
- **Be Fun/Appealing:** The game should be as fun for the kid, as possible. Because fun is the best motivator DGBL experts recommend [Prensky 01a]. Also, the likes of the kid should be taken into account (i.e. games and games genres the kid likes from previous experiences).
- **Augment:** This game should augment some things from the real world, especially if they represent something important for the learning or if they allow a better control within the game.
- **Consider Executive Functions:** The designer should have in mind, the *lack of attention*, *problems in retention*, and *delay aversion* ADHD kids show frequently [Brown 06].
- **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.
- **Reward by "Token Economy":** The game allows the kid to exchange tokens (coins, points, stars)

into new items, prizes or scenes.

- **Promote Self-Learning:** The kid should be as autonomous as possible in the game session. 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.
- **Induce "Operant Conditioning":** The game should reward desired actions on the game that lead to learning. When the game detects the kid is learning the content or skill they should be rewarded.

Note that the last three principles are complying with the techniques suggested in the interview and abovementioned.

As these are design principles the "correct" application is hard to acknowledge and it relies highly on the designer's experience. For example for our game we defined a set of levels with progressive difficulty to promote Self-Learning. In each level the kid learns something new and later levels expect the kid to scaffold on the already learned abilities to continue. Also, as the kid completes an action that ultimately leads them to win the game, it rewards with coins. These are meant to be used to purchase items (this feature is still not developed).

3.2 Types of AR Games

With the principles in mind, we proceeded to identify the possible AR Games to be used. However, we could not find a classification of AR Games. So, we proposed the following four types of games using simple AR (detailed in [Tobar-Muñoz et al. 13]) as shown in Figure 1:

- **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. See Figure 1-1. An example of this is PBS' *Fetch Lunch Rush*[1]. A game that uses AR cards which players use to play math games.
- **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. See Figure 1-2. An example of this is the *Droid Shooting*[2] Android game. In this game, players shoot little androids "flying" around the user. The user uses the camera to see them.
- **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). See Figure 1-3. An example of this is *Zombies! Run*[3]. A game aimed for runners, it tracks the position of the player and plays audios of zombies "chasing" the player to motivate them to run,
- **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. See Figure 1-4. An example of this is the *Wonderbook: Book of Potions*[4]. This is a game set in the Harry Potter Universe, the book itself is a set of markers and players play using the PlayStation Move as a Magic Device.

[1] http://pbskids.org/apps/fetch-lunch-rush.html
[2] http://goo.gl/9Jvt34
[3] https://www.zombiesrungame.com/
[4] https://www.playstation.com/en-us/games/wonderbook-book-of-potions-ps3/

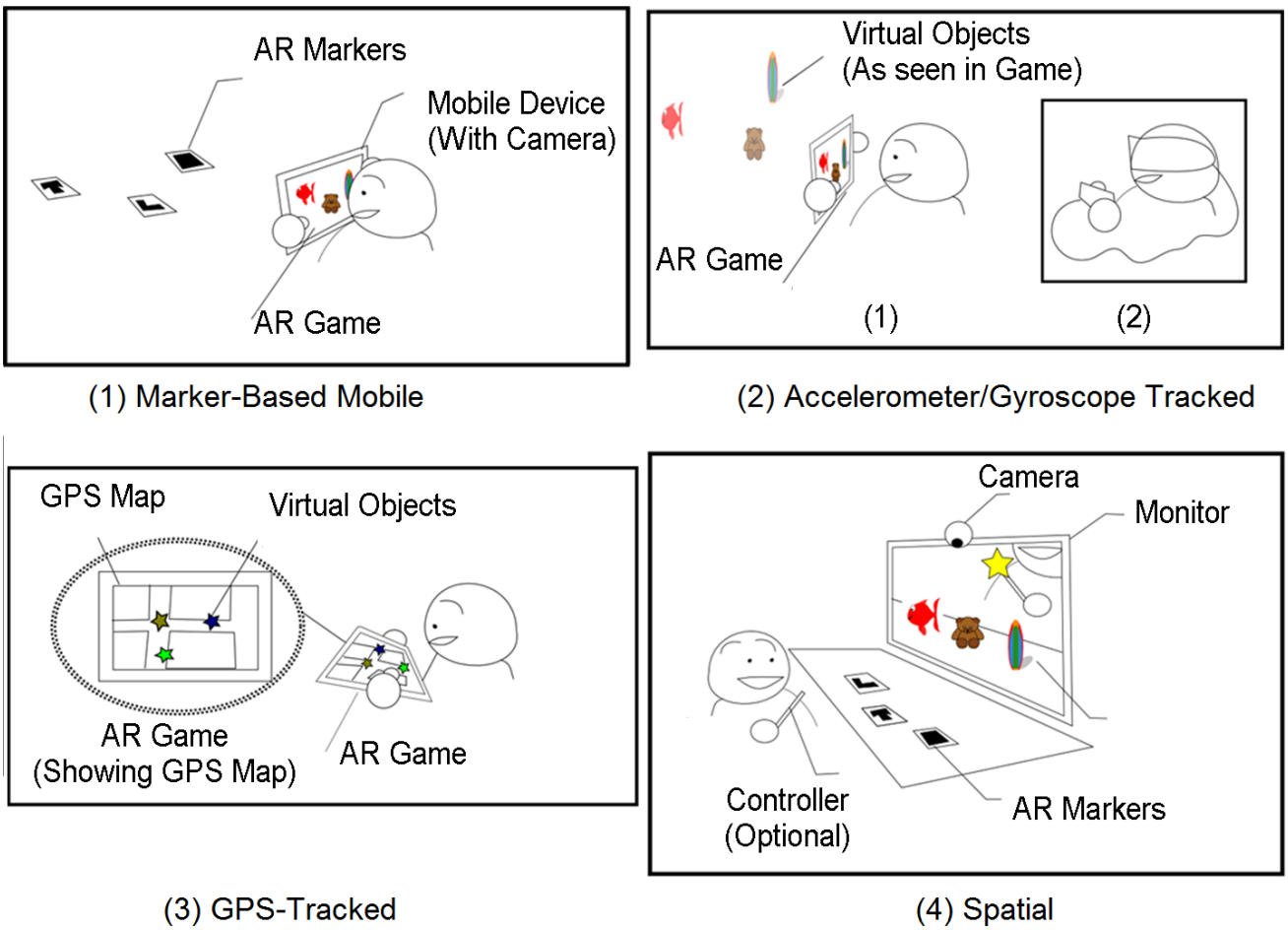

Figure 1. Types of AR Games

3.3 Types of Interaction in Marker-based Spatial Games

Since we decided to go for a set of spatial Marker-Based games, we then classified the different types of interaction we had available by using the type of application and platforms chosen. For that, we came up with the following three interaction types (our proposal is shown in detail in [Tobar-Muñoz et al. 13]) shown in Figure 2:

- **Marker for drag & dropping**: This type of interaction uses a marker as a mean to drag & drop virtual objects from one point to another. This happens by approaching the marker (in the virtual world) to the virtual object where it gets "attached". Later it can be placed in specific "placing" locations. See Figure 2-(1).
- **Marker for manipulating object's transform:** In this type of interaction the system tracks the marker and registers a virtual object with the transform of the marker respect to the camera. See Figure 2-(2).
- **Marker for placing objects:** In this type of interaction the augmented object shows over the marker always (unlike Drag & Dropping type in which user has to approach the marker). User has to bring near the marker to a real landing place. See Figure 2-(3).

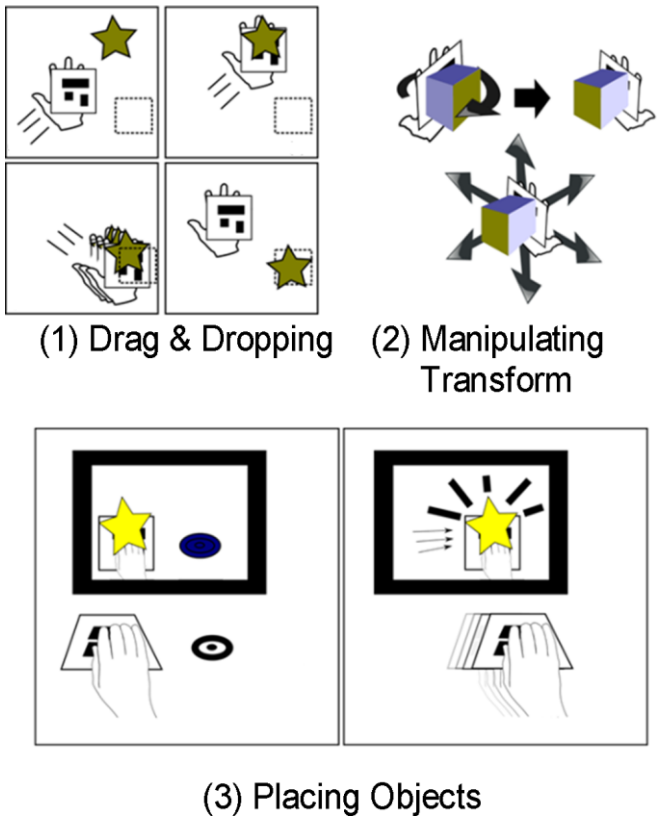

Figure 2. Interaction Types in Spatial – Marker-based AR games

3.4 Game Development

After the design phase we started the Game Development with the tools chosen. The design stated that the main form of interaction was the use of previously defined markers. However, even with NyARToolkit providing a great framework for detecting AR markers into Unity, we had to build and AR Interaction Framework over NyARToolkit and Unity3D for an easier implementation of our proposed interaction types.

With that in mind, our final software architecture looks as shown in Figure 3. Note that with the use Unity3D as the Game Engine and over the Interaction Framework we built a set of objects common to all the mini-games in order to ease the development of the game. The web version of the game is available at: http://bcds.udg.edu/Gremlings/.

In the game design phase, with the principles in mind and inspired by Canals' exercises, we proposed several game concepts.

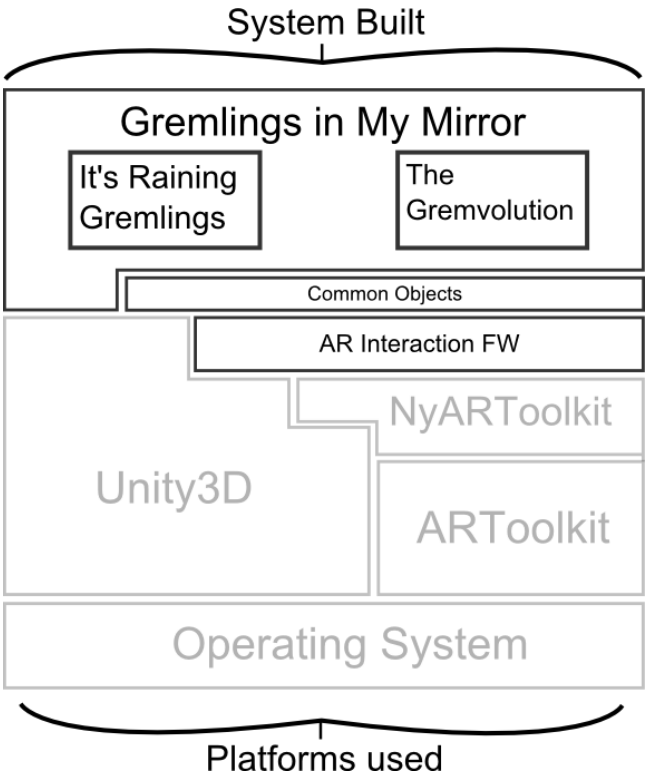

Figure 3. Game's Architecture

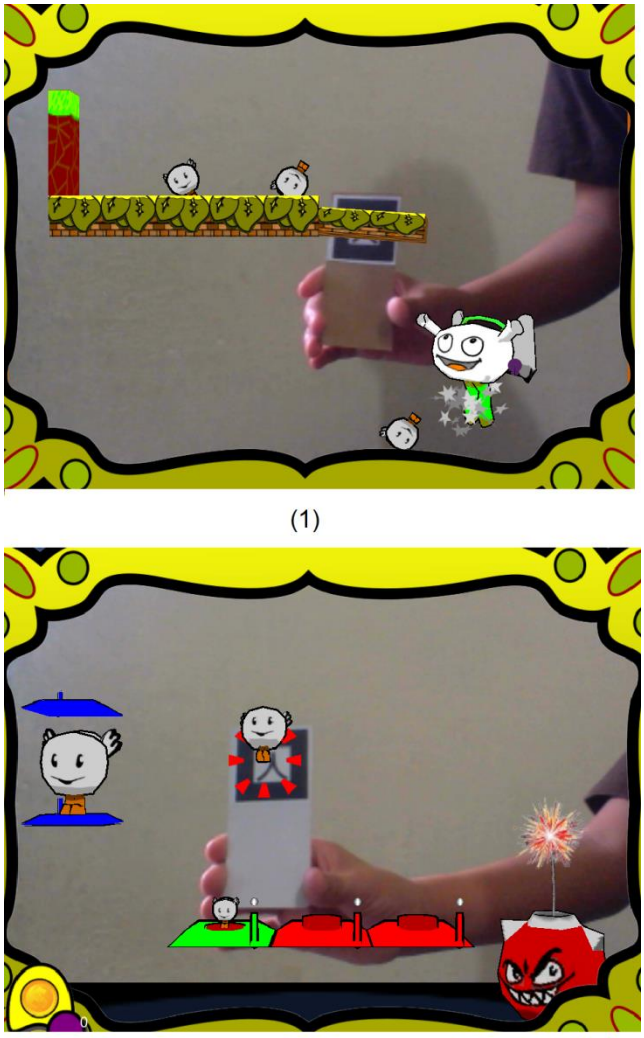

Figure 4. Snapshots of the mini-games in "Gremlings in my Mirror". (1) is called *"It's Raining Gremlings"* and (2) is called "*The Gremvolution"*

From these game concepts, we selected two mini-game game concepts: one for fostering pairing and one for ordering (called *Gremling Rain* and *The Gremvolution* respectively) both included inside one game called Gremlings in my Mirror.

In *It's Raining Gremlings* the kid uses the marker to guide the falling gremlings to the Big Gremling with the right color (Figure 4-(1)). The gremlings fall forever so the kid has plenty of time to think a strategy (Self-Learning). Following the techniques abovementioned the game rewards with coins when the kid advances or completes a scene (Token Economy and Operant Conditioning).
In *The Gremvolution* (Figure 4-(2)) the kid uses the marker to place the gremlings in the right switches (the kid has to realize that the gremlings should be ordered in size) or the bomb explodes. Unlike the previous mini-game, this game is lost when the bomb explodes, but the kid can try as many times as he or she wants. The same coin rewards are applied.

We also constructed a standalone version of the game with a system to record player's milestones which we used to carry-on the observation scenario we describe next.

4. Observation Scenario

We conducted an observation scenario where we observed children interacting with Gremlings in my Mirror.

4.1 Setting

We allowed 20 students from a school to play the game freely. This school integrates children with special-needs of access to learning. The scenario had the help of the school's psychologists and professors who helped aiding students when needed. However, they were instructed to not offer instructions when not needed, as we think every student is able to complete the game by mere playfulness and social interaction. From the group of 20 children, 16 were kids with some special need diagnosed, 3 with ADHD, 1 with Autism, 7 with Mental Retardation, 1 with Asperger syndrome, 1 with Microcephaly, 1 with Down syndrome and 2 with Deafness.

We offered the game to the students and provided each one with a printed AR-marker and let the game record the timestamp when they reached an important milestone within the game (See Figure 5 and Figure 6).

To observe and compare the students' performance, we divided the group in two: Kids with and without special needs. We averaged the timestamps to compare both. As this was a one-shot study, our observations are preliminary. That said, we were able to see that kids with special needs took slightly more time than the others and that their performance is similar.

4.2 Results

Considering that the game had a built-in system included to record the time each kid took to perform the in-game tasks, we were able to analyze and compare quantitatively their performances during the game. Also we conducted a structured interview with the school's headmaster to obtain her opinion in order to get a more qualitative view of the experience. Here we present the results.

4.2.1 Students performances while gaming

We divided the group in two: Kids with and without special needs. We averaged the timestamps to compare both (Figure 5 and Figure 6). We concluded that kids with special needs took slightly more time than the others and that their performance is similar.

It is noteworthy that all students clearly had problems at the beginning of the session because they were not familiar with the interaction method (the AR marker).

Thus, they tended to use the mouse or the keyboard to control the game which can be difficult and could turn the game hard to use in a non-controlled environment.

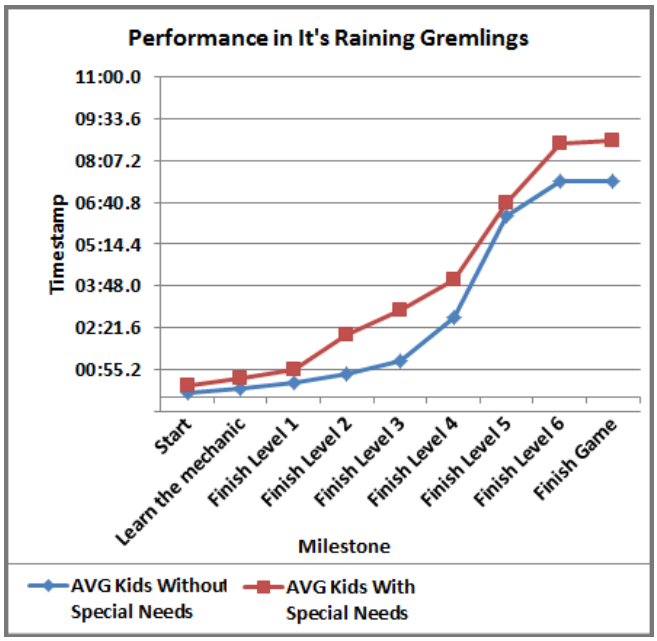

Figure 5. Performance Graph in "It's Raining Gremlings"

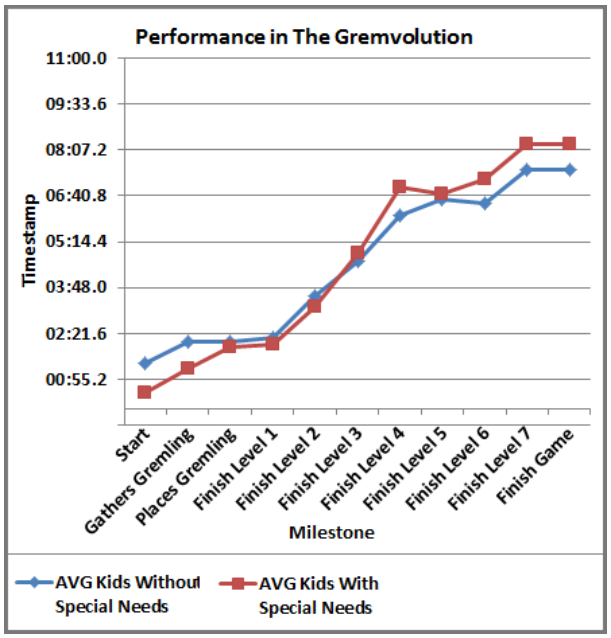

Figure 6. Performance Graph in "The Gremvolution"

Nonetheless, the students were not undermined by that, they showed persistent to achieve the goals in the game. Once they were able to use the game, they got acquainted with it. This situation evidences that designers have to take special considerations on User Experience and User Interface design for a successful interaction, gameplay and finally learning.

4.2.2 Teacher's Feedback

In order to obtain a more qualitative view of the results, we interviewed the headmaster of the school who participated in the experience.

When asked about the implications and importance of the game aimed to its purpose: The logical-mathematical thinking, she said: (*Comments here are translated from the transcript, the original interview was held in Spanish*):

"The motivation to use the game the kid shows helps them to be very concentrated in it"

About children motivation:

- *"I totally think they enjoyed the experience because I saw the kids joyful. First, when they were able to start the game, and after that, when they were able to play it. Most of them did not even want to leave the game. Just a few of the kids couldn't find a motivation to play*

the game, but the majority enjoyed it."

- *"I think the players who did not enjoy the experience could not do it because those were very particular cases (as a strong Mental Retardation, for example).*

About the mathematics learning:

- *"Kids like ours, like ADHD, for example, have a lot of difficult on cognitive processes, especially in mathematics. Although they have difficulties in several cognitive areas, they have the worst time on mathematics. But it was very surprising how they achieved the game's objective and that they did it in a very short time (no more than 10 – 20 minutes per kid), when they often have problems in solving problems taking more time than that."*

About the technology:

- *"Teachers nowadays have to use a lot of tools to maintain the attention and achieve learning on students. And technology has opened the possibility to achieve our learning goals. Technology allows teachers to rapidly reach more pertinent, timelier goals even with less effort. These tools are great tool for us, because they allow the teacher to have a role of counselor who presents the kid with goals and tools. The teacher won't be replaced ever, but technology is now our right-hand."*

About AR:

- *"I think that kind of technology allows the kids to recognize themselves which is one of the more important features of the game. Also, by seeing themselves [reflected] in the game they feel they are the protagonists in the game which is very important."*

When asked about the autonomy in learning:

- *"It is hard to define that. On one hand, the game allows the kid to make decisions which is a part of autonomy. On the other hand, since the game (and all games) has a closed set of goals and rules which can be counterproductive for the kid's autonomy."*

When asked about the inclusiveness of the game:

- *"I think the game is applicable in any context, in any student independently of their condition and with good results; in fact, we had a very diverse group with kids with different needs and the game showed good results."*

4.2 Discussion

Our observation scenario is indeed an interesting yet transversal and preliminary. However, our quantitative results suggest that students can and should be included in playful activities for learning, whether they have special needs or not. Note that in our measurements kids with special needs do compare to kids without special needs if we take into account the time they spent in advancing the levels. And they even can outsmart their classmates as shown in *The Gremvolution* (Figure 6 after the 3rd level).

Also, according to the impressions from the headmaster and teachers, they do think that AR benefits the overall flavor of the experience by letting students interact with something physic (The marker)

From this short experience we think that AR games are viable to be developed and deployed in classrooms for elementary school children with special needs. And this is an effort that witnesses the benefits of using games during activities in inclusive learning.

5. Conclusions and Future Work

We have shown a proposal including a set of Game Design principles for AR Learning Digital Games for all students and a videogame design, implementation and evaluation. Our proposal is based in documental and empirical research on which we base the game design principles for AR Learning Digital Games and considering some features of ADHD syndrome for supporting user-center design.

Using the proposed principles, we have presented "Gremlings in my mirror" an inclusive AR-enriched videogame for Logical Math Skills Learning. Also we show and as an empirical study on the application of digital games with AR from an inclusive vision.
Our observation scenario experience suggests that the Digital Game achieves the inclusion of all children into the learning process. All students achieved the goals of the game and felt strongly motivated in the

learning process which is convenient for children with special needs.

As a future work, our Game Design Principles are yet to be tested in other environments. Other environments can include other subjects like: Reading Comprehension, Biology, Physics and even the Social Sciences. Also, those principles have yet to be fine-tuned and proven in other experiences to validate their implications. We think some other observations on AR and DGBL have yet to be observed using the game, thus we plan to carry-on an experience to measure enjoyment, engagement and motivation in participant children.

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