Departament de Sistemes Informàtics i Computació
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# Gamification strategies as socialization tools in the context of pediatric hospitalization

PhD dissertation

**PhD program in Computer Science**

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# Resumen

En la presente tesis doctoral se aborda el problema de la socialización de los pacientes pediátricos en el contexto de su ingreso hospitalario, estudiando las posibilidades de mejorar este ámbito de la salud del paciente mediante diversas estrategias y herramientas tecnológicas teniendo en cuenta la problemática planteada y las dificultades propias del contexto.

En primer lugar, se realizará una evaluación del estado del arte, así como una justificación de la problemática existente, planteando claramente los objetivos e hipótesis del presente trabajo, así como la metodología seguida.

A continuación, se presentarán las diferentes herramientas implementadas y evaluadas, analizando los resultados obtenidos y situándolos en su contexto y marco tecnológico. Estas herramientas, que combinan actividades y aplicaciones presenciales, remotas o híbridas, implementan diferentes estrategias para poder valorar cuáles son las más adecuadas o que presentan un mayor impacto en el paciente.

Tras esto, se propone un modelo de diseño basado en los resultados obtenidos en estudios anteriores, así como su posible aplicación en diferentes ámbitos, discutiendo el mismo y justificando las decisiones de diseño adoptadas.

Finalmente, se establecerán las conclusiones obtenidas tras el análisis de los resultados y se plantearán cuáles son las posibles aplicaciones y trabajos futuros relacionados con el trabajo realizado en el marco de la tesis doctoral.

**Palabras clave:** Interacción Persona-Computador, Gamificación, Tecnologías hospitalarias, socialización.

# Resum

Aquesta tesi doctoral aborda el problema de la socialització dels pacients pediàtrics durant la seua estada hospitalària, i s'estudien les possibilitats de millorar aquest àmbit de la salut del pacient mitjançant diverses estratègies i eines tecnològiques, considerant la problemàtica plantejada i les dificultats pròpies de l'entorn.

En primer lloc, es realitzarà una avaluació de l'estat de l'art, així com una justificació de la problemàtica existent, i es plantejaran clarament els objectius i la hipòtesi del treball, així com la metodologia emprada.

Seguidament, es presentaran les diferents eines implementades i avaluades, analitzant els resultats obtinguts i situant-los al seu context i marc tecnològic. Aquestes eines, que combinen activitats i aplicacions presencials, remotes o híbrides, implementen diferents estratègies per a poder valorar quines són les més adients, o les que presenten un major impacte en el pacient.

A continuació, es proposa un model de disseny basat en els resultats obtinguts als estudis previs, així com la seua possible aplicació en diferents àmbits, discutint el model i justificant les decisions de disseny adoptades.

Finalment, s'establiran les conclusions obtingudes després d'analitzar els resultats i es plantejaran les possibles aplicacions i treballs futurs relacionats amb els continguts desenvolupats durant la tesi doctoral.

**Paraules clau:** Interacció Persona-Computador, Gamificació, Tecnologies hospitalàries, socialització.

# Abstract

In this document, the problems for socialization for pediatric patients in the context of their hospital internment are considered, analyzing the possibilities of improving this aspect of the patient's health through the use of different strategies and technological tools considering the difficulties posed by the environment and the context.

In the first place, an evaluation of the state of the literature and a justification of the existing problematic will be presented, clearly stating the objectives and hypothesis of this work, and also the methodology that has been followed.

Afterwards, the different tools that have been implemented and evaluated will be described, analyzing the obtained results and placing them in their context and technological frame. These tools, that combine physically placed activities and applications with remote or hybrid ones, implement different strategies in order to be able to analyze which are the most convenient or the ones that show a higher benefit for the patient.

In the following section, a design model, which is based on the results obtained in the previous studies, is proposed, with the justification of the design decisions made and a description of different applications and contexts in which the proposed model could be useful.

Finally, the conclusions obtained after the analysis of the results will be presented, and a short discussion about possible applications and future related works will be done.

**Keywords:** Human-Computer Interaction, Gamification, Hospital technologies, socialization.

# Content index

# 1. Introduction

This chapter will explain the motivation for this thesis, the goals and hypothesis that are proposed and the methodology followed while working on the thesis.

## 1.1. Motivation

During 2021, in Spain there were 278388 pediatric internments in the hospitals in the country [5], of which 272789 lasted for less than a month, 5507 were between one and six months and 93 lasted between six months and a year [4]. The average stay for patients who were in the hospital for less than a month was between 3 and 4 days, depending on the age group. For those who were in the hospital for more than a month, the average stay was between 50 and 55 days. Finally, for those who were in the hospital for more than six months, the difference between age groups is quite significant: under-1-year old children were in the hospital for an average of 230 days; children between 1 and 4 were interned for an average of 304 days, while children older than 5 were admitted for an average of 360 days [40]. It is important to note that under-1 children constitute a big percentage of the admitted patients and represent a group that has lower socialization needs with other peers than older children. However, the numbers of older children are still significant enough to do research to help them with their difficulties.

Specially, since hospital internment is usually a difficult and hard experience for those children admitted in the hospitals, as there are a lot of situations and factors that might cause fear or anxiety. Some examples of that are separation from their families and their homes, the changes to their daily routines and the interaction they have with other peers, besides the pain and suffering that the patient might experience during the hospitalization [59, 108, 155].

All this can be further exacerbated if the patient requires isolation measures. A study by Vall d'Hebron hospital in Barcelona in the year 2011 showed that a 5.4% of their pediatric internments required isolation measures [119], something that clearly adds more difficulties to those already mentioned for those children [27].

Another group that must be considered is the group of children with chronic diseases that require frequent visits to the hospital. While they are not in there for an undefined period without leaving, they still have to face a lot of difficulties that arise from those frequent visits and the treatments they receive, with an obvious social and psychological impact [59, 108, 155].

On the other hand, hospitals do not usually offer the necessary tools to help having a positive social experience in this context, as their main goal is (and must be so) helping recover from health issues. However, taking into account social necessities can make the patients feel calmer and have a better recovery process [142]. In fact, children would like hospital designs that offer more socialization opportunities with other people both from the inside and the outside of the hospital [97]

All this considered, it is an important area to do research in, and for this reason it was important to do the PhD in this context, in order to try to help mitigate all the difficulties explained before. Therefore, in the following chapters different studies will show the results obtained when using technological tools with the aim to provide a better social context for the patients while, at the same time, providing some new entertainment that makes their stay in the hospital a better experience. Social skills of children can be developed with the use of games and activities [167], and games and play constitute one of the fundamental pillars of culture [77]. Games with the goal of fostering collaboration between participants can create socialization opportunities [156], which is the main goal of this work. Finally, it is important to note that the education difficulties are also considered and some of the proposals include elements that can be used as an educational support tool in this context.

## 1.2. Objectives and hypothesis

Based on what has already been said in the previous paragraphs, the main hypothesis of this PhD dissertation will be:

- The use of collaborative technological solutions may have a positive impact on the social wellbeing of pediatric patients admitted into the hospital.

Besides, the following objectives have been addressed in the work done for this dissertation:

1. Analyze the requirements in collaboration with health and education specialists from the hospital itself as well as the families and children, and to integrate their proposals into the design of the technological infrastructure.
2. Consider the different approaches to social awareness in computer games and introduce them in the technological infrastructure.

3. Develop a theoretical model based on observational results regarding the most suitable strategies to foster social interaction between children.
4. Analyze the benefits and inconveniences of different software and hardware technologies regarding their use in the hospital and their accessibility to the families.

These objectives will help validate or reject the main hypothesis as they are the steps to follow in order to provide different technological tools that are appropriate for the context (objective 1), are focused on fostering social interaction (objectives 2 and 3) and that it is possible to use them in the hospital in an accessible way for the users, families and healthcare professionals (objective 4).

## 1.3. Research methodology

This thesis' work has been done following the Design Science research methodology [68], because it allows to identify the problem, set the objectives of the solution, design and develop that solution and finally, evaluate its outcomes, which suited the required work to do. Also, Wieringa's [175] methodological approach has also been taken into account, as it structures the research in a nested set of problems and tasks, something that has been helpful to achieve the proposed objectives.

Regarding the workflow used for the implementation of the different systems that were used during the development of the thesis' work, a spiral and incremental model according to the Rational Unified Process[95] has been used. This methodology is a standard for software development projects, and it allows to structure it around the "inception", "elaboration", "construction" and "transition" phases. In each phase, the required activities or disciplines are implemented iteratively. The methodology establishes that the analysis, design, implementation and evaluation activities for each technological element have to be performed iteratively and incrementally. In each iteration, a subset of the initial requirements identified for each specific objective defined in the previous section must be included, and intermediate prototypes, which might be early validated by the users, will be produced. These prototypes will be improved and enhanced between each iteration before finally becoming definitive once fully validated by all participant users.

Following these approaches combined allows linking the experimental perspective from the social science with action programs that provide a solution to the main problems by following an iterative approach which defines ever more detailed solutions to the initial problems in each iteration. It proposes a reflexive solution-seeking and learning process from the results obtained in the previous iterations, and the use of this methodologies sets two objectives: on one hand, to create a benefit for the final subjects of the research, and, on the other, to obtain new relevant knowledge. It is clearly a unifying proposal between the theoretical and practical aspects of the research, in which synergies are sought among the researchers and the professionals of the healthcare environment, as well as the users and families. Also, this approach permits a participative analysis in which all stakeholders are involved in the process of creating new knowledge and in the development of new proposals and solutions based on their feedback and their experience while using the implemented prototypes.

## 1.4. Outline of the thesis

This document will be divided into four parts in order to fully explain and develop the ideas that have already been introduced, and to describe all the work that has been done in the context of this PhD thesis.

The first part (that includes this chapter and the second chapter) will be focused on describing the motivation, the reasons for doing this work, establishing the hypothesis and the main objectives, and also describing the state of the literature regarding the question on technologies in the pediatric context with a focus on socialization fostering. The second part will explain all the work that has been done, describing the systems created and the motivation and decisions for each design and implementation, and the results obtained for each of them. The third one will focus on the proposed model obtained based on the previous research, while the fourth part will address the discussion, the conclusions, and the possibilities for future works.

The first part includes, besides the introduction, the publication "***A systematic review of game technologies for pediatric patients***" [85], which, as the title states, is a review of what research has been done in the field of the use of different game technologies in the hospital context for pediatric patients (defined in Spain as those with an age between 0 and 14, both included).

The second part is comprised by the work covered in the journal paper "***Tangibot: A collaborative multiplayer game for pediatric patients"*** [125], in which a co-located, multiplayer and collaborative game was proposed and its short-term impact on the children evaluated, the work presented in the conference INTERACCIÓN 2021, "***PicToMe: una actividad multijugador para pacientes pediátricos***." [127], which covers a remote, multiplayer activity and its evaluation. Also, the co-design work that leads to the model presented in part 3 and that was presented in the conference CHI Play 2019, "***Co-Designing Social Gaming Experiences for Hospitalized Children***" [128] and the doctoral consortium "***Gamification Strategies as Socialization Tools in the Context of Pediatric Hospitalization***" [126], which is a presentation at the same conference of the PhD work, will be referenced.

The third part will include the explanation of the proposed model, with a description of its key elements and its possible applications. Here, the use of the model in other contexts will be presented too, with the references of the paper published at the conference MobileHCI 2021, "***Designing a mobile AR application for improving pediatric psychological wellbeing***" [129], which explains the application of the model to the pediatric mental health field.

The final part will discuss the model proposed in part 3 and the justification for the design decisions based on the previously available research. After that, the conclusions will be presented as will the possibility for further development of the research in the same or other fields. Finally, the bibliography and the additional elements will be presented.

This work is therefore comprised of 6 research publications, 2 of which are journal papers and 4 are conference papers or presentations.

# 2. State of the research

## 2.1. Introduction

A hospital stay or visit is usually an unwelcome event in the life of any person, especially if the person is still a child. It may hinder a child's play time, which is an essential part of childhood development [77] or cause a breach in the child's usual social interactions (especially in the case of long hospital stays). Further, the child may have to deal with boring and repetitive therapeutic procedures, or even be submitted to painful medical procedures. One way of dealing with these situations is adding an element of play to the hospital visit. With the help of technology, games can be created to help in a number of ways, be it to boost motivation during therapy, distract from a painful procedure, provide a window for social interactions, and so on. In this sense, an introduced game can serve several purposes, including that of allowing a child's play time to remain undisrupted.

The emergence of new technologies provides a wide variety of tools to be used as medium for creating patient-centric games. In some cases, certain technologies can even serve to offer a companionship role for hospitalized children (e.g., [109, 111]). New technologies can also offer a higher degree of immersion, enhancing the effectiveness of the game and helping it serve its purpose. Furthermore, technology can be used to make the game itself become a measurement instrument serving both the patient as well as the medical staff (e.g., [10, 149]).

Several previous authors have provided systematic reviews to study the relationship between games and health for children. However, not all of them have focused on technological approaches (e.g., [93]), and the ones who have usually targeted adults (e.g., [89, 114]) or children outside hospitals (e.g., [100]). Therefore, there is a lack of information about how technology can be used to design games for pediatric patients in a hospital setting. In this respect, this work contributes with a systematic review of the literature, in which the different age ranges that are usually addressed, the circumstances surrounding the administration of the game (namely, during which procedures and/or to children with which pathologies), the technologies (i.e., devices and interactions) used, the type of company considered (i.e., whether the games are designed to be mono-user or multiuser, collaborative or competitive), the general purpose of the works, as well as their impact on the children, are presented. The results indicate that the most common age range considered is 6–12 years old; the most popular treatments, venipuncture procedures and chronic, neurological, or traumatic diseases/injures; the most used technologies, traditional computers or monitor-based video consoles; and that the games are usually designed with the purpose of serving as distractors or motivators for physical rehabilitation, and that they are normally played individually. The results also show that such technologies seem to have a positive impact on pediatric patients in terms of improving enjoyment, socialization, and motor functions; increasing emotional expressions; and reducing pain, anxiety, distress, and stress. However, there is not enough evidence supporting these benefits, and more research would be needed to confirm them.

## 2.2. Related research

Several previous efforts have been made to provide a general view of technological games in healthcare, however, to our knowledge, no systematic review has specifically addressed games for children in hospitals.

Most of the reviews conducted to date on technology and healthcare have not focused on the effect of the technology on the patients. Yao et al. [179], for instance, explored the use of RFID technology in healthcare. They identified applications of this technology (e.g., tracking, identification and verification, and sensing) in different areas (e.g., equipment, administering procedures, and surgery). They also highlighted the barriers to adopting this technology in healthcare (e.g., interference, ineffectiveness, cost, and privacy), and its benefits (e.g., improved patient safety and reduced medical errors, real-time data access, and improved medical processes).

Similarly, Fosso Wamba et al. [48] reviewed the literature to find applications and RFID issues in healthcare. They identified three main areas in which this technology could present benefits (namely, asset management, patient management, and staff management). Nevertheless, these two studies focus mainly on technical and business-related aspects of the implantation of RFID technology, and do not consider the potential of RFID to create game platforms for children (e.g., [2, 54]). Others have reviewed the literature to study the effect of serious games in the learning or practice of healthcare. In this respect, Ricciardi and De Paolis [154]conducted a review to assess whether games can be useful to health training, and whether they present benefits with respect to other approaches. Similarly, Lynch et al. [114] explored the MEDLINE database (accessible via PubMed) to study how videogames improve surgeons' performance. Kato [89] reported on several studies about the impact of video games on health, focusing on the pathologies treated or the medical unit in which the game is used. She included both games used to train medical practitioners as well as others aimed at improving the patients' health. However, her review is not systematic, which does not provide a complete picture of the work conducted in the area.

Other works have focused on patients, but not necessarily on children, as in the case of Costa et al. [29]who conducted a systematic review to identify different technological games for healthcare and their benefits, with focus on recent studies (published from 2009 onwards).

Their review classified the studies by game types (commercial, tailor-made, and adapted), by platform (console, desktop, and mobile), by interface (movement sensors, measurement sensors, controls, balance platforms, mouse and keyboard, microphone, and touchscreens), and by health areas (rehabilitation, self-care, treatment/therapy, clinical detection, monitoring, and health and wellness). However, they left out important databases in information technology such as the ACM Digital Library.

Other authors have focused on children, but not specifically on technology. For instance, Koller and Goldman [93] conducted a review on distraction techniques to alleviate pain and anxiety in children undergoing medical procedures. Even though they mentioned several technological approaches such as the use of interactive toys and virtual reality, the main scope of their work is not technological. Considering technology, LeBlanc et al. [100] reviewed fifty-one studies published up to 2012 on the effect of Active Video Games on physical activity in children and teenagers. However, these kinds of games are not suitable for some hospitalized children who are required to be bed-bound.

## 2.3. Research questions

With the aim of analyzing previous research focused on developing technological games in hospital settings for children, six different research questions were defined, revolving around three main axes: the patients targeted, the technological game itself, and the study conducted.

The ones concerning the patients are the following:

- RQ1: What age groups are considered?
- RQ2: In which procedures and/or with children of which pathologies are the technological games applied?

With respect to the technological game approach, the following research questions were considered:

- RQ3: What specific technologies are used and how are they related to RQ1 and RQ2?
- RQ4: What is the general purpose of each work? In addition, what purposes are addressed with each technology?
- RQ5: Do the proposed games involve more than one user in a collaborative or competitive activity, or do they focus on individual (mono-user) gameplay? In addition, what type of games (i.e., collaborative, competitive, or individual) are most used with each procedure/pathology and with each technology?

Finally, the following research question was defined with respect to the study conducted:

- RQ6: Have previous works studied the impact of technological games on patients? If so, what are the objects of study and the outcome of each work?

## 2.4. Methodology

The following describes the procedure followed to conduct the systematic review, i.e., where and how was the literature explored, which studies were considered fitting, and how were they analyzed to answer the above research questions.

### 2.4.1. Data collection

#### 2.4.1.1. Databases searched

For the purpose of identifying studies for this review that are relevant to information technology, health, and social sciences, the following online databases were consulted: ACM Digital Library, IEEE Explore, Science Direct, and Scopus. The latter is in fact an abstract and citation database which in turn directs to other online databases including Springer, PubMed, Taylor & Francis, Wiley Online Library, Hindawi, IOS Press, SAGE Journals, JSTOR, Bentham Science, and The BMJ, as well as the previously mentioned databases.

#### 2.4.1.2. Search terms

The search terms that were used were made up of a combination of different keywords that included the main object under review (i.e., games, gamification approaches, etc.), the subjects considered (i.e., children visiting the hospital, hospitalized, or in the pediatrics unit), and the approach taken (i.e., technological). More specific terms were added for the approach to include videogames, or digital and computer-based solutions. The resulting search string was the following: gam* ^; ((hospital* ^; children) ∨; pediatric) ^; (technol* ∨; video* ∨; digital ∨; comput*).

The search string was introduced into each database where the title, abstract, and keywords fields were searched. More specifically, in the ACM Digital Library and IEEE Explore it was entered as provided (replacing ∨ and ^ symbols by “OR” and “AND” keywords, respectively), whereas the other two databases required the use of their corresponding advanced search forms, which resulted in the following queries: (TITLE-ABS-KEY (gam*) AND ((TITLE-ABS-KEY (hospital*) AND TITLE-ABS-KEY (children)) OR TITLE-ABS-KEY(pediatric)) AND (TITLEABS-KEY (technol*) OR TITLE-ABS-KEY (video) OR TITLE-ABS-KEY(digital) OR TITLE-ABS-KEY (comput*))) [Scopus].

((TITLE-ABSTR-KEY(gam*) AND ((TITLE-ABSTR-KEY(hospital*) AND TITLE-ABSTR-KEY(children)) OR TITLE-ABSTR-

KEY(pediatric)) AND (TITLE-ABSTR-KEY(technol*) OR TITLE-ABSTR-KEY(video*) OR TITLE-ABSTR-KEY(digital) OR TITLE-ABSTR-KEY(comput*))) [Science Direct].

#### 2.4.1.3. Inclusion and exclusion criteria

The main inclusion criterion was that the work had to refer to technological games used in a hospital setting with pediatric patients. The only exclusion criterion was that the papers had to be in the English language.

### 2.4.2. Data analysis

After obtaining an initial pool of papers by using the search terms described above, an initial screening of these papers was performed manually in which the title and abstract were read and the previously mentioned inclusion and exclusion criteria were used. The next step was to remove the repeated papers that were accessed through Scopus but are publications from one of the other three databases. Finally, an in-depth analysis of each remaining study was conducted with three purposes in mind. First, to identify and remove any work that may have seemed relevant from the title and abstract but was in fact not so (according to the defined inclusion and exclusion criteria). Second, to identify and remove duplicate works that are published as separate papers but present indeed the same technological game, purpose, and evaluation (or do not contain an evaluation with children). This situation usually consists of having a work describing the technology and another with an evaluation (in this case, the most complete work, i.e., the one with the evaluation, is the one that is kept). Finally, the third purpose is to extract all the information relevant to the research questions. The analysis procedure to answer them was also conducted manually as follows.

- RQ1 (age ranges). Each study was analyzed in order to obtain the age range that the authors recommended for their game. In the cases where no ages were mentioned, this question was simply ignored.
- RQ2 (procedures and pathologies). The situation of the patients in each work was taken into consideration. This refers to when, where, or to whom the technological-game interventions were applied, namely, children with specific pathologies or undergoing certain medical procedures. In the cases in which more than one situation was addressed, all were included and considered.
- RQ3 (technologies). All the technologies used in each publication were taken into consideration, with special emphasis on the hardware used as output peripheral and the interactions or input mechanisms supported.

- RQ4 (purpose). The purpose of each study was established as the improvement or intervention that each approach was after. In other words, it was established as the goal that was intended for a game to accomplish.
- RQ5 (number of users). Each study was analyzed to establish whether the authors' proposal takes into consideration any form of collaborative or competitive gaming instead of focusing on individual gameplay.
- RQ6 (study). If a study was conducted to evaluate the impact of a certain game technology on the patients, the measures evaluated were extracted as well as the results and conclusions obtained.

## 2.5. Results

After obtaining 1305 papers identified by the search term, 108 were selected after the initial screening of title and abstract using the inclusion and exclusion criteria. After removing repeated papers, 95 studies were left. Finally, after the in-depth analysis of each of the remaining studies, 20 more papers were removed, hence obtaining a total of 75 relevant studies. The most frequent reason for removing papers after the in-depth analysis despite their having passed previous screenings was that the proposed game was meant to be played outside the hospital setting (e.g., at home). Another reason was discovering that the technological intervention used was in fact simply a measurement tool without any gamification applied. Out of these removed papers, four were essentially previous versions of others (i.e., the description of the same technology for the same target group, with no evaluation of hospitalized children). Table 1 summarizes the number of papers collected from the databases and the ones remaining after each screening step. Further details of the individual studies can be found in Appendix A.

*Table 1: search results summary.*

| **Database** | **Papers found** | **Papers after screening** | **Papers after removing repetitions** | **Papers after in-depth analysis** |
|---|---|---|---|---|
| ACM Digital Library | 12 | 11 | 11 | 10 |
| IEEE Explore | 321 | 16 | 16 | 10 |
| Science Direct | 82 | 6 | 6 | 6 |
| Scopus | 890 | 75 | 62 | 49 |
| Total | 1305 | 108 | 95 | 75 |

Figure 1 shows the number of publications since 2001. As can be seen, the tendency of building videogames in the context at hand is increasing. The chart shows a leap in the number of publications since 2010. Up to this year, there are 1.56 (SD¼ 0.88) works/year on average, whereas from 2010 onwards the amount is 8.71 (SD¼ 3.15) works/year.

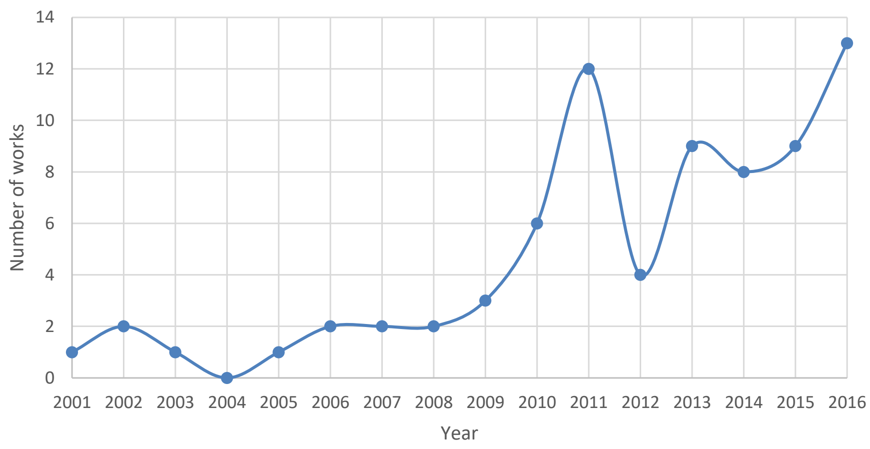



*Figure 1: number of publications over the years on the topic of interest.*

## 2.5.1. Patient-related results

### 2.5.1.1. Age ranges

Almost one third (32%) of the studies analyzed do not specify the age of the children they are aimed at. For the remaining 68%, Figure 2 depicts their distribution with respect to the age(s) considered, which are grouped into four stages of children's development: toddlers, preschoolers, school-age children, and adolescents [16]. The overall sum is greater than 100% because one work may target different age groups. As can be seen in the chart, most studies target children from 6 to 12 (i.e., schoolers, or children in primary school). Less attention has been paid to adolescents in middle- and high-school (between 27% and 48% of the papers), and to preschoolers (between 17% and 51%). Even fewer studies (4%) considered designing game technologies for nineteen-year-olds or for toddlers (only 1.96%).

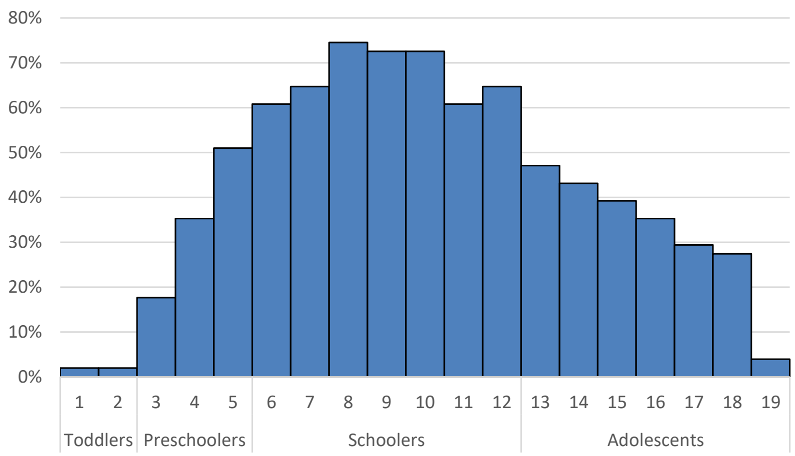



*Figure 2: percentage of publications considering children of each age.*

### 2.5.2. Procedures and pathologies

The analysis of the literature revealed that game technologies have been applied mainly to children suffering from different pathologies (69.33% of studies), followed by 17.33% that use them before, during, or after administering a certain medical procedure. 22.67% of the publications do not specify any procedure or pathology related to the intervention and only mention that the game is used in hospitals with children. The treatments considered to apply technological games are the following:

- Venipuncture: Refers to the process of puncturing a vein for surgical, therapeutic, or blood collecting purposes, in general. Venipuncture for hemodialysis or chemotherapy is also included in this category.
- Anesthesia: Refers to the process of administering anesthesia before a surgical procedure.
- Minor surgery: Refers to the moments before undergoing any type of surgery that does not require long periods of hospitalization before or afterwards.
- Cold pressor task: Refers to a procedure in which the patient's hand is immersed in ice water and used to measure changes in blood pressure and heart rate.
- Transplant: Refers to hospitalization after undergoing an organ transplant.

Figure 3 depicts the frequency of use of game technologies for each procedure identified. It reveals that the most common interventions are during venipuncture, followed by being administered anesthesia before surgery.

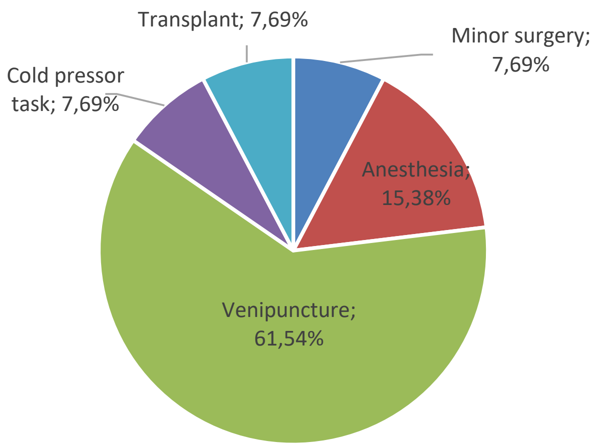



*Figure 3: frequency of use of technological games in each procedure.*

The pathologies addressed have been classified into seven groups, some of which are composed of more specific pathologies, as explained below:

- Chronic: Includes diseases lasting three months or more.
- General: Refers to any type of chronic illness, without specifying which one.
- Cancer: Refers to a group of diseases involving abnormal cell growth that have the potential to spread through the body. All types of cancer in any possible stage are included.
- Diabetes: A chronic disease in which the body lacks insulin to control the amount of sugar in the blood.
- Renal disease: Refers to the chronic kidney disease in which this organ progressively loses its function.
- Traumatology: Includes treatments of wounds and injuries.
- General physical disability: Any type of physical disability, temporary or otherwise. This could be a side effect of another illness, but in this case is taken into consideration individually.
- Neck: Neck-related issues that require keeping the neck straight.
- Burn: Refers to any type of burn injury that requires treatment, of any degree of severity.
- Neurological: Includes different diseases of the brain, spine, and the nerves connecting them.
- General: Refers to any neurological disorder, without specifying which one.
- Cerebral palsy: A specific neurological disorder that affects muscle movement and motor skills.
- Behavioral: A psychological disorder, sometimes also referred to as emotional disorder.
- Pulmonary: Includes any type of pulmonary disease (e.g., asthma).

- Ophthalmology: Refers to anything related to the anatomy, physiology, and diseases of the eye.
- Other severe illnesses: Refers to any type of critical or life-threatening illness in general, with no further specification.

Figure 4 shows that the most common pathologies considered (and with similar frequency) are chronic diseases, neurological, and trauma. The most frequently considered are cancer (21.15%) and cerebral palsy (17.31%).

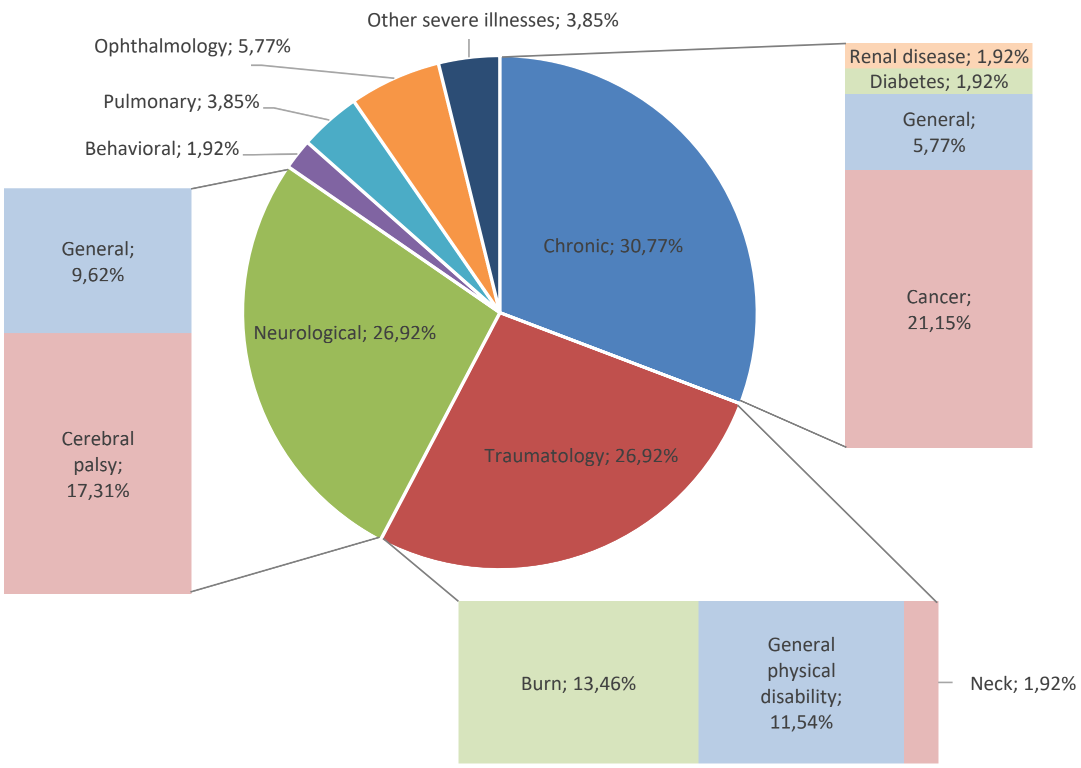



*Figure 4: details of each pathology considered with its frequency.*

## 2.5.3. Results related to game technologies

### 2.5.3.1. Technologies

The works analyzed were classified by the hardware they use as main output device (i.e., how users perceive the digital information in the game), and how children can interact with it (i.e., input mechanisms).

With respect to the former, the following alternatives were identified after processing the publications:

- Monitor: A medium-large screen that is usually used with computers or consoles (in the form of a TV) and is situated at a distance from the user. Only one work (1.33%) made use of a tabletop display and was also included in this category.

- Head-Mounted Display (HMD): Screen in the form of a helmet or goggles worn by the user. In combination with virtual reality, it provides a sense of immersion since the virtual scene occupies the user's whole field of view. However, it can also be used with augmented reality, in which the user views the real world augmented with digital objects.
- Handheld: A small screen the users hold in their hands while playing. It includes portable consoles (e.g., Nintendo Game Boy), phones, smartphones, and tablets.
- Robot: Refers to playing with a robot companion. It enables mixed reality experiences, in which the digital and physical worlds are combined in the same game activity. From the analysis, it was observed that one work (1.33%) used humanoid robots, and two (2.67%) relied on robots of indeterminate shape.
- Other: Includes other types of hardware such as projections on walls and floors, or tiles mounted on the floor.

Regarding the input mechanisms, the children can use to interact with the previous hardware in order to play the game, the following were extracted:

- n/a: Refers to when the children can only sense the outputs of the system.
- Controller: The output hardware is coupled with a specific controller, and interactions are based mainly on pressing buttons and/or pulling handles (e.g., mouse and keyboard for computers, or joysticks for consoles). Three studies (4%) made use of the Lokomat1 system, a commercial controller for physiological gait rehabilitation.
- Touch: The user enters input to the system by directly touching the output device.
- Tangible: Input comes in the form of physical objects the user can manipulate with a higher degree of freedom than is available with regular controllers. It includes both common and tailor-made objects and enables mixed reality situations.
- Gesture: Refers to making gestures with hands, arms, or the whole body, which are captured by any type of motion sensor. It includes those interactions in which the user holds a controller (e.g., Nintendo Wii) but interaction is not based on pressing buttons or pulling handles.
- Voice: The system reacts to the user's voice.
- Gaze: By moving their eyes, users point to specific parts of the output device (usually a monitor) to make a selection.

Figure 5 depicts the tendency of the analyzed works over time to consider the previous output/input approaches, using a 2-period moving average.

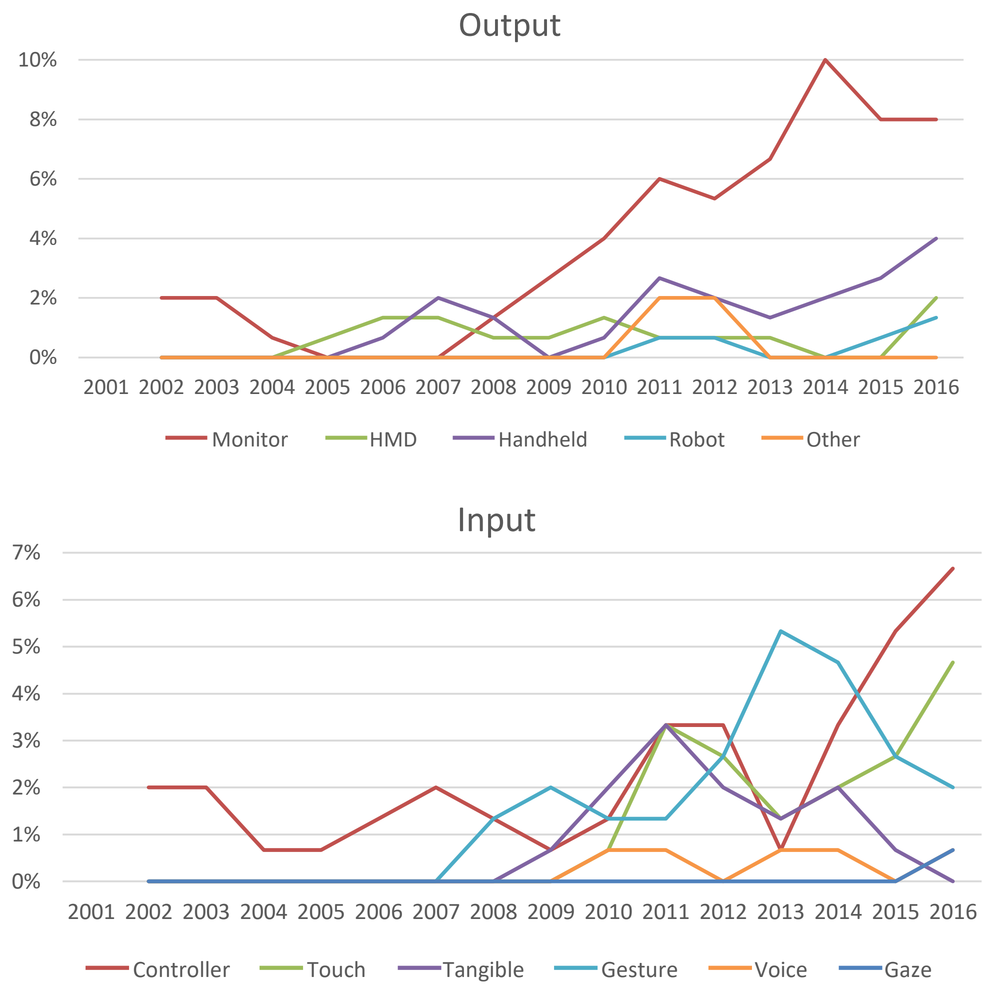



*Figure 5: tendency of works over time (2-period moving average) to rely on each output hardware (top) or input mechanism (bottom).*

Figure 6 shows the proportion of publications that consider each output device or rely on each input mechanism (for further details, see Appendix A). It can be seen that the monitor is by far the most common output device, and the controller the most popular input peripheral (followed by gesture interactions). In turn, Figure 7 depicts, for each combination of output and input technologies, the proportion of studies that make use of commercial or customized approaches. Only combinations with a frequency greater than 3% are shown in the chart, the rest are grouped in the two bars on the right. As can be seen in the figure, the most frequent combination is monitor and controller, which corresponds mostly to commercial consoles or PCs. 14.67% of the works also rely on commercial games, whereas 20% opt for designing their own. Another popular trend is to use gesture-based consoles, as 14.67% of the studies rely on commercial platforms such as Nintendo Wii or PlayStation Move, whereas only 4%

implement custom devices and games. The third most frequently used combination of output hardware and input mechanism is the use of touch-mediated handheld devices, in which customized solutions prevail with a proportion of 12%. Of these, 77.78% of the works implement games for Android tablets and iPads, whereas 22.22% take the customization process further and also design their own portable devices. It is worth mentioning that whenever tangible interactions are considered, regardless of whether the output device is a monitor, HMD, handheld, or robot, the approach is always customized, which might be due to a lack of generic tangible input hardware on the market. Going for commercial platforms is usually affordable, entails little development effort, and is interesting for studies that only want to assess the impact of videogames in general. However, the majority of the publications apply customization to some degree, making games tailored for the target children's age, pathology, or undergoing a certain procedure.

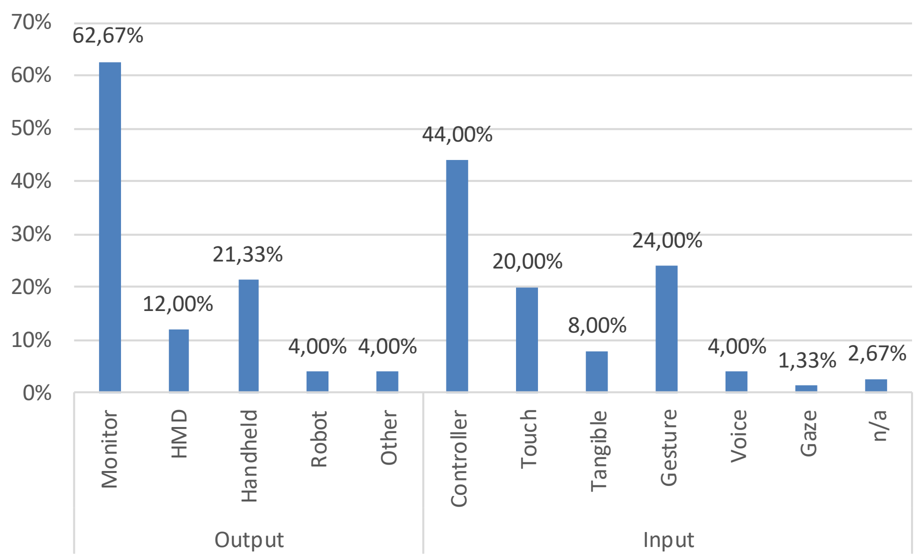



*Figure 6: proportion of publications that rely on each output device and input mechanism.*

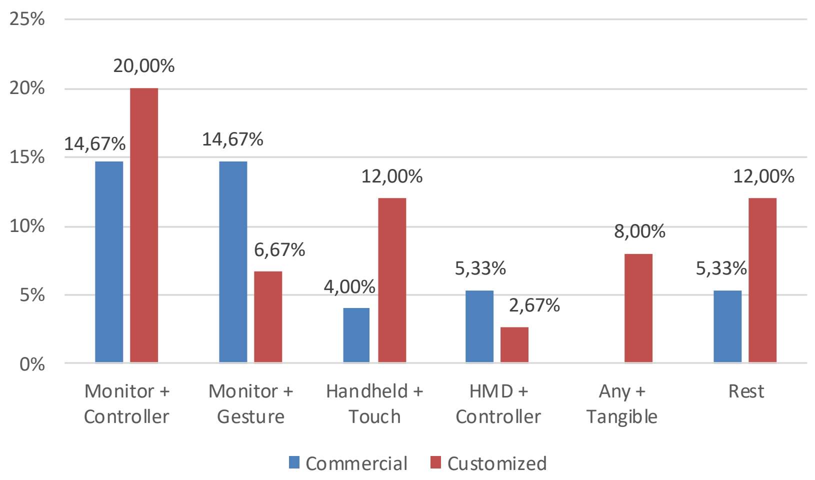



*Figure 7: proportion of publications that make use of commercial and customized combinations of output devices and input mechanisms.*

The relationship between the technologies used in each work and the patient's age was also analyzed. Figure 8 shows the proportion of studies that consider each output device and input interaction for the four age stages identified above. The distribution for schoolers is similar to the one in Figure 6 because it is the majority group, i.e. the monitor being the most common output hardware, followed by handhelds and HMD; and controllers being the most common input mechanisms, followed by gesture and touch interactions. For adolescents, the distribution is similar except for HMD being slightly more used than handhelds, although this difference is due to only one work. Some differences can be found for other age groups. The only work targeting toddlers relies on tactile tablets. For children in kindergarten or preschoolers, even though the most frequent combination is monitors plus controllers, there is less difference between these and handhelds and other types of interaction, although it is still infrequent.

The analysis of the literature also suggests that the target age group does not have a significant impact on the choice of specific output/input technologies. Although the works that create their own games do consider this factor and adapt the graphical user interface to children, commercial platforms are mainly chosen because they are appealing and well known to the subjects, and customized ones have other hidden motivations. Only five studies (6.67%) make an explicit reference to the children's age in their motivation. Krebs, Michmizos, and colleagues [94, 121] present the pediatric Anklebot, a custom controller specifically adapted to children aged 6–10; Akabane et al. [2] make use of toys for 5-to-10-year-olds as tangible manipulators; and Lu et al. [111] design a custom robot companion for children aged 3–7. Finally, Looije et al. [109] opt for using a friendly-looking commercial humanoid robot for bonding with children in primary school.

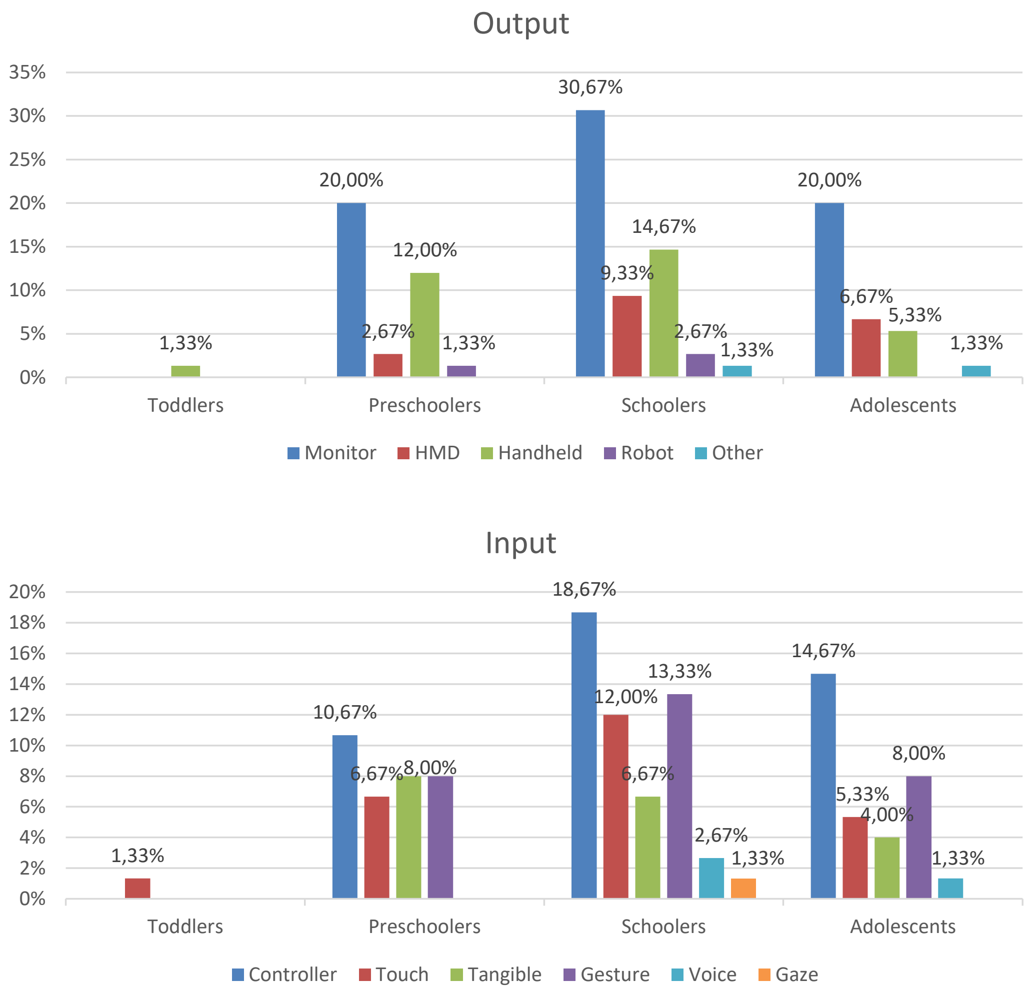



*Figure 8: proportion of works that consider the specified output (top) and input (bottom) approaches for each stage in childhood development.*

The technologies were also analyzed in relation to the different procedures and pathologies. The proportion of publications considering each output hardware and input mechanism for each type of procedure and pathology is shown in Figure 9 and Figure 10, respectively. Even though only 33.33% of the works analyzed explicitly report having a specific reason to use a certain technology because of the child's pathology or procedure undergone, this dimension does seem to influence the choice of input/output technologies more than the patients' age range. Gaming activities must not interfere with procedures like administering anesthesia, venipuncture, or minor surgery, and thus benefit from a portable handheld device [35, 45, 144] or from a gesture-based input [139], since they remove the need for wired controllers. Similarly, Law et al. [99] report on the need for hands-free input mechanisms like voice for cold press or tasks, since this procedure would keep the patient's hand busy.

With respect to the pathologies that can affect the choice of technology, two different groups with common requirements were identified. First, patients with either neurological problems or general physical disabilities (traumatology) that are subjected to physical rehabilitation require the ability to physically exercise a specific body part [74, 81, 94, 102, 107, 116, 121, 147, 148, 180], or to perform fine-grained movements [26, 55]. For this, they rely on commercial gesture-based consoles such as Nintendo Wii [74, 81, 102], which has been proven to improve movement abilities in people with motor impairments [36, 169]; the Lokomat system [116], which has been found successful at neurological movement rehabilitation [69]; or commercial tactile tablets, under the promise that direct touch capabilities will increase dexterity and muscle tone [55]; but most of the studies analyzed rely on tailor-made controllers, which can provide the most customization for the body part being rehabilitated. The second group corresponds to those patients with no specific pathology (pulmonary, chronic, burn-related, or other severe illness) but who must remain in hospital for long periods of time. The most frequently used technologies in this case are gesture-based commercial consoles that enable general physical exercise, such as Nintendo Wii [1, 141], PlayStation EyeToy [143], or PlayStation Move [19]; and commercial handheld tablets or smartphones the children can carry with them as they move around the hospital [11] and are also able to provide disease-specific game contents to each patient [166].

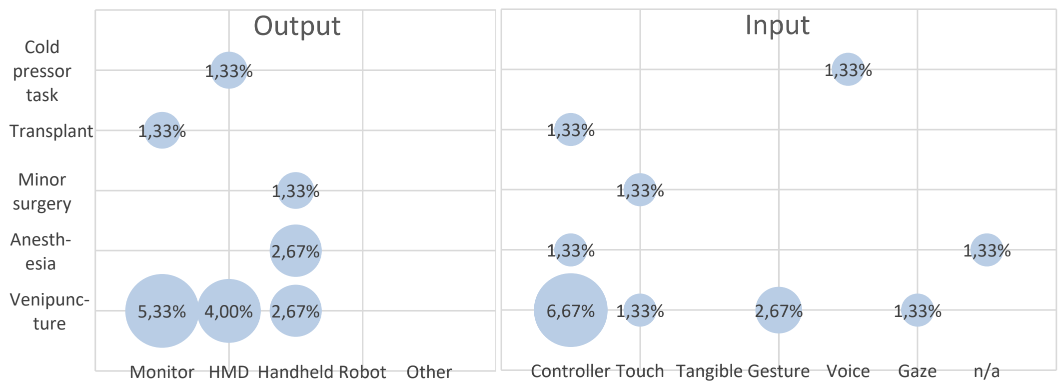



*Figure 9: Proportion of works that consider the different output (left) and input (right) approaches for each type of procedure.*


*Figure 10: Proportion of works that consider the different output (left) and input (right) approaches for each type of pathology.*

#### 2.5.3.2. Purpose

The purpose, or intention, of each identified work was also analyzed. After the in-depth analysis of each study, the following ones were identified:

- Distraction: Refers to the purpose of providing a way of entertaining the child while in hospital or while undergoing a specific procedure, with the aim of reducing the stress they might experience.

- Motivation: Includes the works that use the game as a motivator for the children to perform any kind of rehabilitation activity (e.g., physical, mental). At the same time, the game serves therapists to keep track of the patients' progress.
- Socialization: Considers works that provide a space for communication or socialization with either other patients, the hospital staff, or the outside world.
- Education: Refers to when the purpose is either to offer information about hospital procedures or the patient's illness, or to offer educational courses or a way of connecting with the patient's classroom in order to avoid falling behind in their studies.
- Emotion coping: Refers to when the work aims to provide a way for the patients to face and regulate the negative emotions they feel during their stay in hospital.

Figure 11 depicts the proportion of publications that propose games for each purpose identified, showing that the two most common trends are to use game technologies as motivators in rehabilitation activities and to distract the patients from the situation they are in. In turn, Figure 12 shows, for each purpose, the proportion of works that have considered each output device and input mechanism. The relation between technologies and purposes does not reveal any major differences from the general cases: monitors and controllers lead the technologies used. This is mostly due to their availability, because, although the custom solutions that implement their own games do so with a purpose in mind, the hardware and interaction modalities used seldom have a motivation underneath. As counterexamples, gesture interactions are used 8% more than regular controllers in motivation games. This has to do with these games being used mostly for physical rehabilitation, in which the game helps the patients perform certain body movements. In addition, HMDs are used to distract the children from painful medical procedures in 77.78% of the cases (the rest being used as motivators). The reason behind this is the immersive experience these devices provide, which cognitively abstracts the children from their situation as well as preventing them from physically seeing the procedure they are undergoing. For the treatment of burn injuries, in particular [91, 122, 123], it represents a non-pharmacological approach that has been shown to reduce pain and anxiety[70].

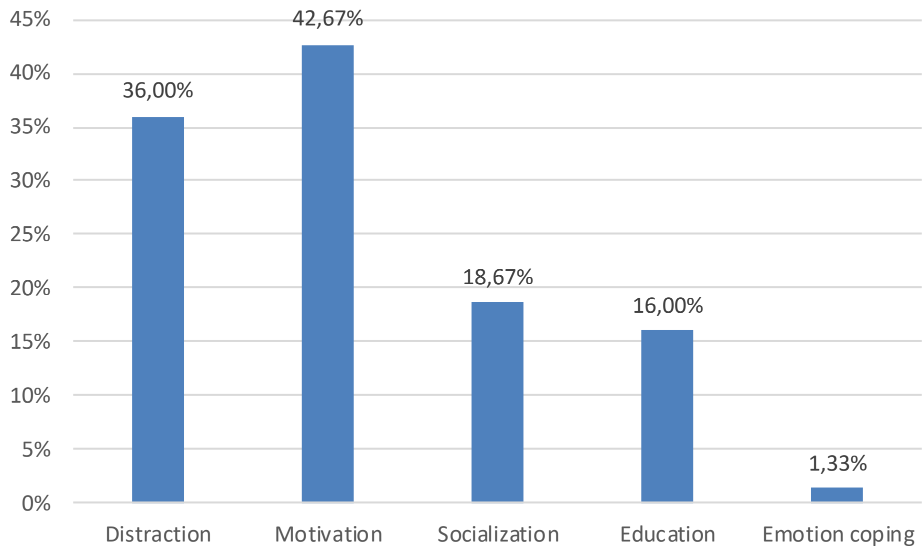



*Figure 11: proportion of works pursuing each identified purpose.*

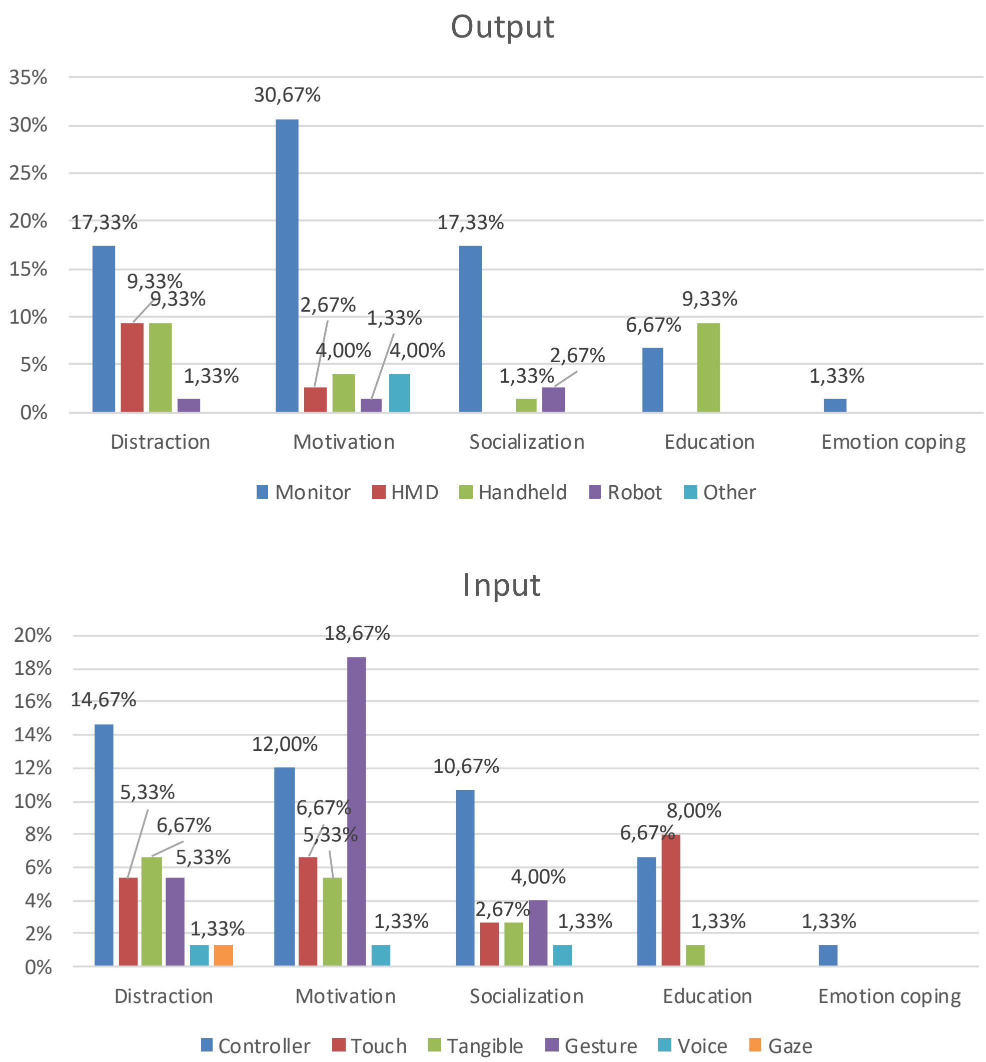



*Figure 12: proportion of works that consider the specified output (top) and input (bottom) approaches for each purpose identified.*

#### 2.5.3.3. Number of users

With respect to the number of users supported, the different technological games explored were classified into four categories:

- Individual: Refers to when a proposed game can be played individually by a single player or is not meant to be played in company at all.
- Collaborative (online): Refers to when the proposed gameplay includes collaborative activities that can be performed by players without requiring them to be in the same location at a given time.
- Collaborative (co-located): Refers to when the proposed gameplay by a study includes collaborative activities that a patient may perform with other patients, family members, or even hospital staff.
- Competitive (co-located): Refers to when gameplay may be competitive, where patients may play against other patients or family members or friends, in order to provide further incentive or create an environment in which the patient may feel more involved.

Figure 13 depicts the proportion of works that consider each user combination described above. It can be seen that individual games are used significantly more than multiplayer games. This can be related to the two main purposes pursued: using the games as simple distractors, or as motivators for different therapeutic tasks. With respect to the former, the game intervention is meant to be applied during a specific medical procedure, which is usually applied to each patient in private. As for the latter, different patients require different therapeutic routines, which would complicate any form of collaborative or competitive gameplay, especially if only one gaming device is available.

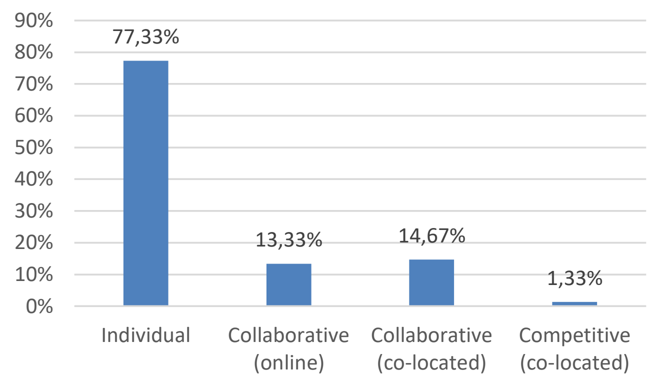



*Figure 13: proportion of works that consider each group of users during game play.*

Since the vast majority of studies target only a single user, the distribution of pathologies/procedures as well as of input/output technologies for individual games is similar to those shown in Figure 3, Figure 4, and Figure 6. Figure 14 provides more detail on which procedures or pathologies have been considered for each type of multiplayer games, i.e., collaborative (online), collaborative (co-located), and competitive (co-located). As can be seen in the chart, there is no predominant procedure or pathology in which multiplayer games are applied. In fact, in most cases none is specified. The only pathology that seems to stand out is cancer, as this is the most prevalent in any multiplayer modality. This may be due to pediatric oncologic patients being especially prone to psychosocial issues [115]and the fact that social support can help these patients cope with the stress of the disease [38]. Competitive play is seldom explored, which can be explained by these types of games having a potential effect on aggression [6, 63], which might not be desirable to foster in a hospital environment.

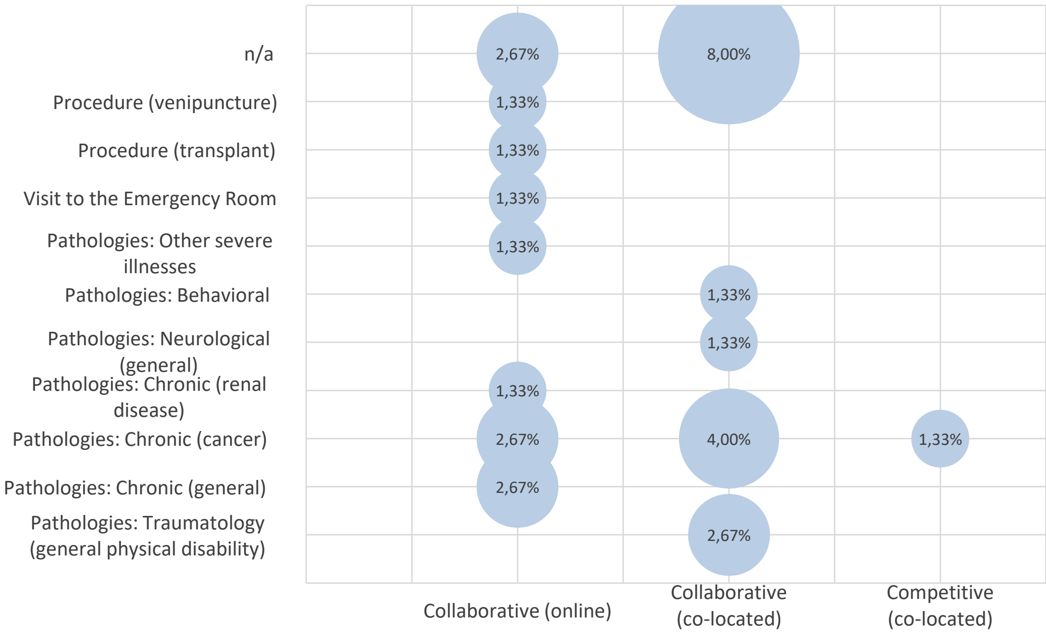



*Figure 14: proportion of each type of multiplayer game for each procedure or pathology considered.*

The relationship between the different multiplayer game types and output and input technologies can be seen in Figure 15. As for the technologies used, the tendency for individual games is the same as in the general case discussed above. For online collaborative games, the combination of output hardware and input mechanism that stands out the most is also controller-based monitors, i.e., computers and consoles, since the only requirement is to have a network connection. For co-located (collaborative and competitive) games, the most common interaction is through gestures. This is achieved by means of motion sensor consoles such as Nintendo Wii or Xbox Kinect, which enable multi-user interactions and having a shared workspace, which enhances awareness, a key factor in this type of activity [65, 66]. In addition, the fact that children can see each other moving around may provide a more fun experience, ensuring user acceptance. In contrast, handhelds are seldom used, even though they have been identified as potentially interesting for co-located activities through what has been called Multi-Display Environments, i.e., joining several devices together [53].

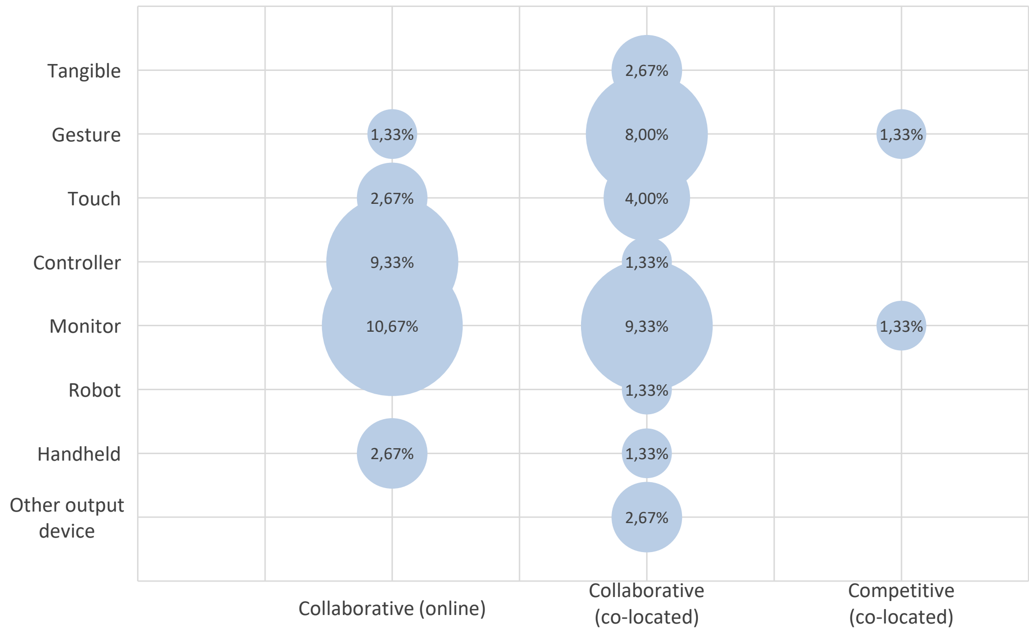



*Figure 15: proportion of each type of multiplayer game for each technology used (output hardware and input interaction mechanism).*

### 2.5.4. Study-related results

26.67% of the publications selected only describe a system design or implementation or discuss game requirements for pediatric settings. 6.67% of the total number of works analyzed study the feasibility of the approach in hospitals with children, 2.67% analyze how a specific game technology can help therapists create new activities and assess their patients, and only one work (1.33%) focuses on alleviating parents' anxiety. The remaining 64% of the publications selected present a study in which a game technology was evaluated with children in hospitals in order to measure one or many patient-related variables. Of this 64% of the studies, Figure 16 gives the proportion that considers each one of these variables. The most recurrent objects of study are enjoyment (39.58%), which consists mostly of informal assessments of users' acceptance and impressions, usually collected through observations or interviews; pain reduction (31.25%); improvement in motor functions (20.83%); and, to a lesser extent, reduction of anxiety, distress, or stress (14.58%), improvement in socialization (12.50%), and increased emotional expressions (8.33%). The rest, which can be consulted in Appendix A, were studied in less than 5% of the works.

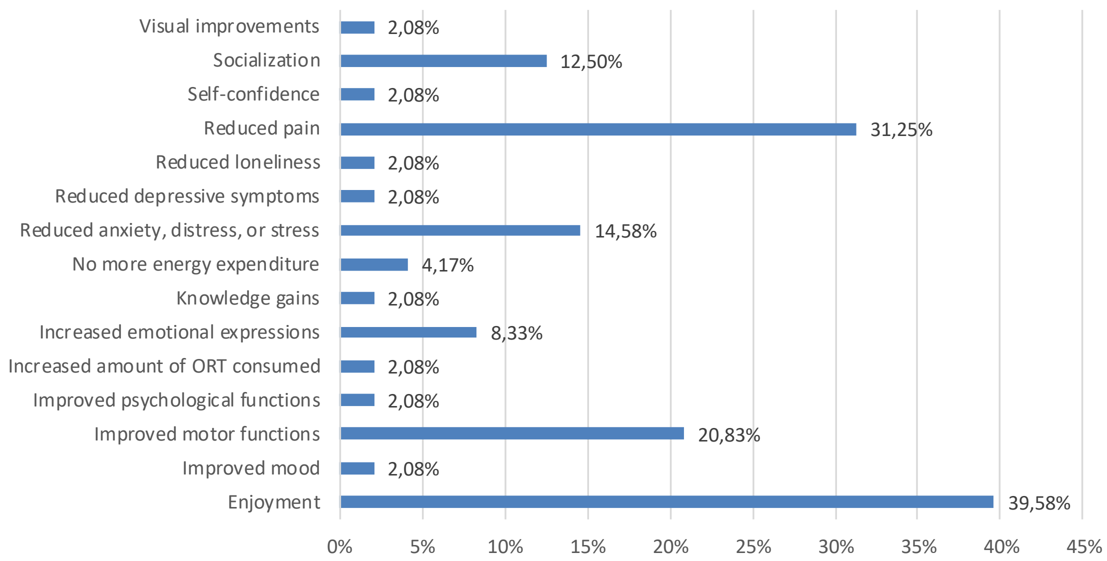



*Figure 16: proportion of works that evaluate each patient-related variable.*

In turn, Figure 17 depicts the success rate of each variable. Extreme values should be taken with caution due to the small sample of studies in which they were evaluated (see Figure 16). However, for those variables with more than 5 evaluations (which would represent 6.67% of the publications analyzed), it can be seen that game technologies for children in hospitals provide enjoyment, socialization, and increased emotional expressions in more than 90% of the cases; are able to improve motor functions in 80% of the studies; and reduce pain as well as anxiety, distress, or stress with a success rate greater than 70%.

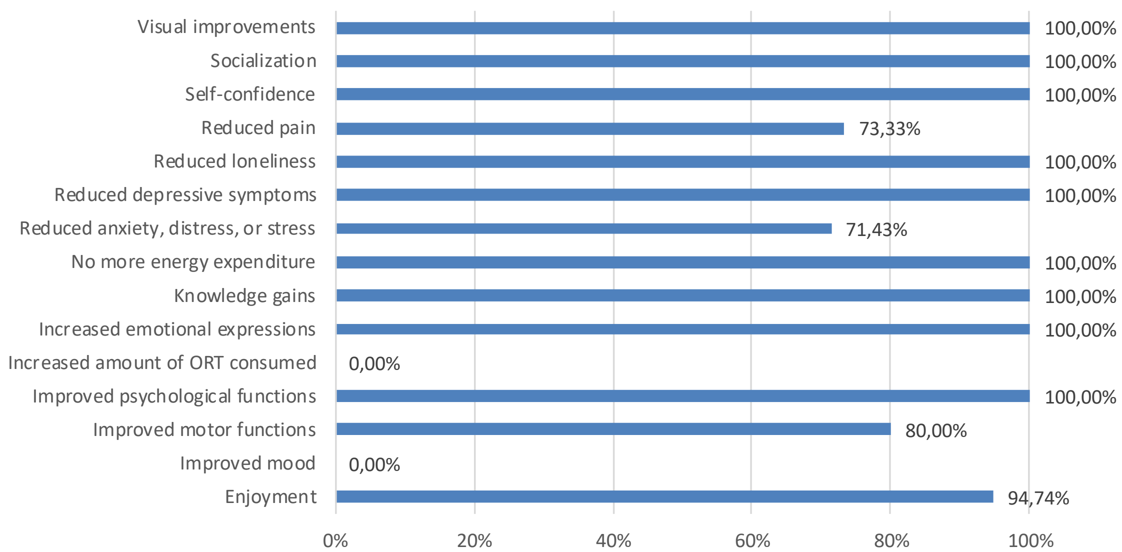



*Figure 17: success rate of the studies that consider each patient-related variable.*

## 2.6. Discussion

### 2.6.1. Target users

From the analysis of the literature, it was found that the most common target group is primary school children. This is probably due not only to their being more likely to accept a given game, but also to their capacity for understanding it. Younger children might encounter difficulties in understanding both the dynamics and interactions of videogames. This complicates their design, which, in turn, can discourage researchers from creating games for these patients. On the other hand, adolescents may be more easily bored with a game that is not in their usual style, and more mature approaches may simply work better, which would explain the fewer monotonic studies for this group of patients. In our opinion, these groups of users should not be disregarded, as they experience a huge number of hospitalizations per year. For example, in 2015, each country in the European Union experienced, on average, 11,120 and 7,688 hospitalizations of children aged 1-4 and adolescents aged 15-19, respectively, for each 100k inhabitants [41].

It was found that nearly 70% and nearly 20% of the studies consider using game technologies with children suffering from a specific pathology or undergoing a given medical procedure, respectively. With respect to the latter, the usual approach is to tackle potentially fearful treatments such as venipuncture. As for the former, the most common is cancer, a chronic disease that affects approximately 300,000 new children (less than 19 years old) each year, sometimes with fatal consequences [78]. General neurological and physical disabilities are also relatively common pathologies to be addressed, along with burn injuries and cerebral palsy. Most of these pathologies are very physical, observable pathologies. On the other hand, psychological disabilities, such as behavioral disorders, which include multiple diseases, are often neglected in this regard. This could be due to their harder-to-treat nature and the fact that they are often treated in specialized hospitals instead of general ones, but it presents an interesting topic that could be tackled though game technologies, as several studies with adults have pointed out. For example, a review by Horne-Moyer et al. [73] concludes that technological games often present the same benefits in psychotherapy as traditional methods, but they are in some cases more accepted, enjoyable, and engaging. Fernández-Aranda et al. [46] argue that some characteristics of videogames such as the capacity for immersion, low resistance to their use, and their demonstrated effects on brain activity make them very suitable for treating mental disorders.

Even though this review focuses on game technologies for pediatric patients, and therefore the publications analyzed focus on children, some of them [55, 113] reveal that they can also be useful for therapists, as they can serve as measurement tools and help to create therapeutic activities. Also, as Fernandes et al. [45] observe, games can help not only the patients but also their parents. This is particularly interesting as a hospitalized child causes high loads of stress to their parents. In fact, some researchers propose the need to include parental care in these situations [21, 160].

### 2.6.2. Technologies

It was observed that videogame consoles and traditional computers are the most commonly used technology. Input via controllers was practically the only mechanism considered up to 2008, and from this year on its use and the use of monitors present strong growth. This could be due to the wide variety of gaming consoles on the market, as well as their generally affordable prices. Using a gaming console or pre-made games also simplifies the work by removing any implementation aspect. Further, the variety of consoles also means a variety of gaming styles, which enables other interaction mechanisms such as gestures. For example, some come with motion sensor accessories like the PlayStation EyeToy, Xbox Kinect, or Nintendo Wii, which offer a more active play style, mostly for physical rehabilitation purposes, but also for co-located games, which enable socialization, as children can see each other moving around. Nevertheless, as previous studies have pointed out [53, 134], these kinds of technologies are fixed to a specific location, which would make them unsuitable for bed-bound patients. Neither would they be suitable for very young users, for whom they are known to present tracking problems. The use of handhelds seems to be more suitable in these situations because they are very easy to set up and adapt better to the user's posture. Their use is gaining momentum since 2010 along with touch interactions, which would correspond to the increasing popularization of smartphones and tablets, commonly used in other areas such as education [51, 134]. The interaction with these devices via direct touch is intuitive and well accepted and usable by children [132, 135]. According to Shneiderman et al. [162], it enables natural interactions for three reasons: a) the visibility of objects and actions of interest; b) the replacement of typed commands by pointing actions on the objects of interest; and c) the rapid, reversible, and incremental actions which help children to keep engaged and give them control over the technology, avoiding complex instructions that complicate the interaction. In spite of this, the potential of touch interactions with handheld devices has not yet been explored deeply in hospital settings. This would be interesting not only because good technology acceptance is key for the success of the game intervention, but because handhelds can be carried around with the patients, and are less obtrusive in certain procedures and situations as they are wireless. By joining several of these devices together one could devise co-located games to foster socialization [53, 84], which has been mostly unexplored in children in hospital.

HMD, on the other hand, have been around for many years, but not until very recently have they become popular and made available commercially. Devices such as HTC Vive, PlayStation VR, or Oculus Rift enable immersive virtual reality environments that, as explained above, cognitively abstract the children from their situation, making them especially interesting as pain distractors. However, they should be used with caution, as they are known to produce symptoms similar to motion sickness [98], and even though this can be reduced by playing seated instead of standing [120], they present too big of a risk to expose hospitalized children to them.

Other emerging technologies such as robots, tangible user interfaces, and voice interactions are still little used. Furthermore, tangible interactions seem to decrease year after year since 2011. This is surprising, as recent research tends to praise the benefits of tangible user interfaces over traditional devices or even tactile handhelds. These include increasing children's interest, engagement, and understanding of the activity [42], and having a positive effect on socialization [43]. In addition, incorporating interactions with the physical space in a technological game is perceived as easier and more fun than screen-based activities [84]. Tangibles can be represented as toys, which are already familiar to children (e.g., plush toys [61]). These, alongside robots, will enable new experiences in the near future with the recent advances in Artificial Intelligence and robotics. Robots are very interesting technologies to be used with children because, as argued by Li et al. [104], they capture their imagination. They hold special promise in situations in which parents are not always present [161], as in the case of hospitals. Robots could accompany the child physically during game play as a companion and be interacted via natural user interfaces such as voice and tangible objects. Breazeal et al. [17] proved that young children accept robots as interlocutors and informants, and others like Leite et al. [101] reveal that they can provide social support to a similar extent as other children.

### 2.6.3. Purpose

It was observed that most works focused on game technologies as motivators for rehabilitation activities or as distractors. One can assume that these two purposes are the most popular in game technology design for children in hospital because they are simpler to devise and implement. With respect to the latter, the topics of the game do not really matter, since the only goal is to abstract the child from his situation. As for the former, it is easier to build on therapeutic activities that already exist and simply provide extra aid instead of creating completely new activities for purposes that are not usually tackled in a hospital. This in turn leads to a lack of studies that have other interesting purposes as their main objective, such as fostering socialization, working on the children's emotional wellbeing, or promoting physical mobility.

Children who spend long stays in hospital or make frequent visits to it due to chronic diseases suffer large amounts of stress that can result in many social and emotional issues [16, 30, 136, 163]. These are caused not only by their physical symptoms but also by feelings of loneliness or isolation [173] that arise from being separated from their parents and friends. In fact, authors like Ceribelli et al. [24]

underline the importance of communication with the child in these environments. Building socializing experiences could benefit children's emotional intelligence [52], which could in turn help them regulate the negative emotions they feel, for emotional intelligence is mainly of social nature [158]. Collaborative gameplay can encourage a sense of camaraderie between patients and add to their social circle. Online collaborative games in particular open the window for socialization outside the hospital and can provide some sort of abstraction since the workspace is in a virtual world. On the other hand, collaborative co-located games can enable bonding between the patients and others in hospital, with whom they will have to spend a lot of time, namely caregivers, hospital staff, and fellow patients. This bonding is sometimes essential, as in the patient-nurse relationship, for the delivery of quality care [172].

Physical mobility is usually considered for patients in rehabilitation, but often neglected in game interventions for other children. Leaving aside those that are physically unable to move, physical exercise could be an interesting addition to game-based therapies, as it presents a plethora of health benefits, both physical and mental [145]. On the one hand, it helps prevent several chronic diseases like cardiovascular disease, diabetes, cancer, hypertension, obesity, and osteoporosis [174]. On the other, it can alleviate some depressive symptoms than can emerge during hospitalization, improve self-image, social skills, and cognitive functioning, as well as reduce the symptoms of anxiety [49, 171]. Exercise has also been found to reduce fatigue, somatic complaints, obsessive-compulsive traits, fear, interpersonal sensitivity, and phobic anxiety in cancer patients [37]. With respect to children in particular, the effects are similar: reduction of low density lipoproteins while increasing high density lipoprotein; improvement of glucose metabolism in patients with type II diabetes; improved strength, self-esteem, and body image; reduction in the occurrence of back injuries; and stress reduction, which may also improve the immune system [165]. However, it is worth mentioning that some research reveals that to achieve substantial health benefits, the exercise should be at least of moderate intensity [80], which some patients might not be able to perform. In any case, additional studies should be conducted to properly assess the impact of exercise-enabler games for pediatric hospitalization.

## 2.7. Limitations

As is the case with literature reviews in general, this review does not claim to be comprehensive or include every single existing relevant study. Here, the results obtained through the search terms from the databases mentioned previously are summarized. The research questions also leave out details that could also be extracted from the identified studies and which may contain information of interest, but it was decided to focus on general questions that could shed light on the current state of the literature in this matter and on missing areas of study.

## 2.8. Conclusions

A literature review was conducted with the goal of identifying the current state of works focusing on technological or video games for children in hospital settings and of finding areas of future study. 75 relevant studies were identified, which were analyzed to extract information about the patients they are directed at (their ages and whether the games are applied to children with specific pathologies or undergoing certain medical procedures), the approaches themselves (the technologies used, their purpose, and the number of users considered in a specific game), and the studies conducted to evaluate the solutions.

The results indicate that this topic is of increasing popularity (with more studies being published year after year). Also, that the most common trends in this area are focusing on primary-school children (aged 6-12) undergoing venipuncture treatments or suffering from chronic diseases (mostly cancer), neurological (especially cerebral palsy), or from physical injuries (mostly burns or physical disabilities). The purpose of the solutions designed is mainly to provide a means of distraction or to serve as a motivator to help with physical rehabilitation. The games proposed are usually devised to be played individually, and the most frequently used technologies are, by far, traditional computers or video consoles composed of monitors as output hardware and button-based controllers as input. Finally, it was observed that game technologies in pediatric hospital settings seem to improve enjoyment, socialization, and motor functions; increase emotional expressions; and reduce pain, anxiety, distress, and stress. However, there are not many evaluations available on these issues, and more should be carried out to confirm these benefits.

Several lines of future work can be derived from the results. First, designers could also focus on (pre-) kindergarten children (under 6) and teenagers (over 12) and try to find the most suitable game topics and technological devices and interactions for them when in hospital, since each age group presents entirely different needs. Second, psychological (behavioral) pathologies have been mostly neglected when designing games for pediatrics, and, as stated by Horne-Moyer et al. [73], more work is needed in order to know to what extent games can benefit these illnesses. Third, new studies could have purposes other than motivation or distraction, such as socialization, emotion coping, or fostering physical activity. Additionally, other stakeholders like parents/caregivers or hospital staff could benefit from being included in the games. Finally, recent but well-established technologies such as digital tablets should be further explored, and their capabilities (e.g., portability, direct touch) further exploited to better accommodate these goals. The same could be argued for emerging technologies such as companion robots, as well as other interaction mechanisms such as voice or tangible.

# 3. Experimental evaluation of socialization improvements through technology in the pediatric hospitalization context

## 3.1. Introduction

During the research associated with this PhD dissertation, and in order to create the gamification models and strategies that are the objective of the research, some experimental evaluations of different games, that serve as the foundation for the results that have been obtained, have been performed. More specifically, there were two games that were evaluated in the pediatric hospitalization context: Tangibot and PicToMe, both of which will be described, and their results will be reported in the following lines. Tangibot was the first of them to be evaluated, followed by PicToMe.

## 3.2. Tangibot

### 3.2.1. Introduction

As has already been said before, hospitalization is often a difficult experience for pediatric patients because it involves many elements which cause anxiety and fear, for example being in a strange environment, separated from their families, painful medical procedures or uncertainty about the future [59, 155]. These psychological consequences are not limited to the period of treatment inside the hospital but can continue afterwards [153]. Among the problems they have to deal with is not being able to communicate with other children [27].

In this respect, hospitals do not usually offer the necessary tools for children to have a positive social experience, which could be helpful to them for their recovery and peace of mind [142]. In fact, these patients require hospital designs in which there are more possibilities of social interactions with other patients and with people outside the hospital. They would also like to have more technology available to them as a play and distraction mechanism [97].

Children can develop their social skills with games and activities [167]. Some games can promote collaboration between peers in order to reach a common goal, which in turn promotes their interaction and provides opportunities to socialize [156].

However, although Computer Supported Collaborative Play (CSCP) techniques have been evaluated in schools [54], few studies have analyzed how these strategies can be implemented in a children's ward or how they could benefit socialization possibilities and the children's general wellbeing. This study describes a study on how CSCP can be applied in a pediatric context by implementing a prototype collaborative game and analyses its impact on children's communication strategies. It also examines the role of teachers in hospital context during CSCP and discusses the design guidelines that should be applied in future CSCP developments for hospitalized children.

### 3.2.2. Tangibot: a multi-tabled gamified quiz system

Tangibot was designed as a tablet-based multi-display environment to foster collaboration between peers by means of several general constraints that were considered during its design. First, the gamification dynamics would need the joint intervention of several patients simultaneously so that no single child could make progress without other peers. Second, the quiz would require the team to explore and discuss the different choices of action to take in the pursuit of a goal by means of communication, planning, and negotiation. Finally, it would require the continuous coordination of actions during the course of the activity in real time to reach the predefined goal.

The gameboard is formed by an undetermined number of cells with "items" placed on top, and the leading actor is a robot that can be moved by a set of movement commands (i.e., go forward, stop, turn left or turn right). The items on the cells are keys, walls, and bombs. The keys are the most important items on the board. When one is reached by the robot, the participants will be asked a question and answers will appear on the rest of the cells with keys. The goal is then to lead the robot to the correct answer cell to complete the quiz while avoiding the obstacles represented by the other two types of items: walls that impede the robot and bombs that explode on contact. This approach pursues two objectives: first, to support challenges and replays, two design elements that have been shown to improve engagement, enjoyment, and productive learning experiences [137]; and second, to include emotions and individual versus team responsibility for failed actions as factors that may hinder or empower collaboration, depending on how they are handled by the team.

In order to foster collaboration, Tangibot's main goal, the four movement commands to control the robot are split among the participants so that they are driven to cooperate and coordinate their efforts in order to plan and execute the robot's track on the board. The design rationale behind needing four users to control the robot is because working in small groups has been found effective in collaborative learning, since it "increases each student's opportunity to interact with materials and with other students while learning. Students have more chances to speak in a small group than in a class discussion; and in that setting some students are more comfortable speculating, questioning, and explaining concepts in order to clarify their thinking" [20].

With the aim of enabling a more dynamic approach in which physical mobility is encouraged and still provide high levels of workspace awareness, Tangibot was designed to be arranged on the floor, as can be seen in Figure 18.

*Figure 18: the playing area. The picture was not taken at the hospital, but the location of the elements remains the same.*

Each question/answer key cell is displayed on a different tablet to facilitate the dynamic reconfiguration of digital contents as the activity progresses. They are intended to remain fixed during the activity, so that the participants can view their contents at a glance even at a distance. Figure 19 pictures how questions are shown to the participants when the robot approaches the corresponding tablet, whereas Figure 20 and Figure 21 show the UI when the players get their answers right or wrong.

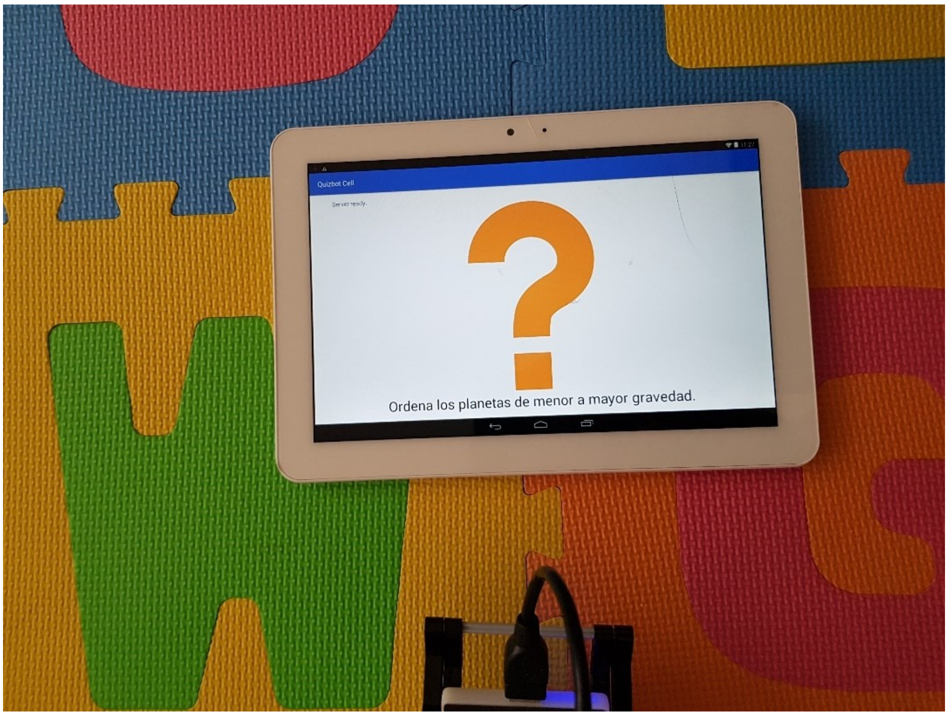



*Figure 19: how questions are displayed*

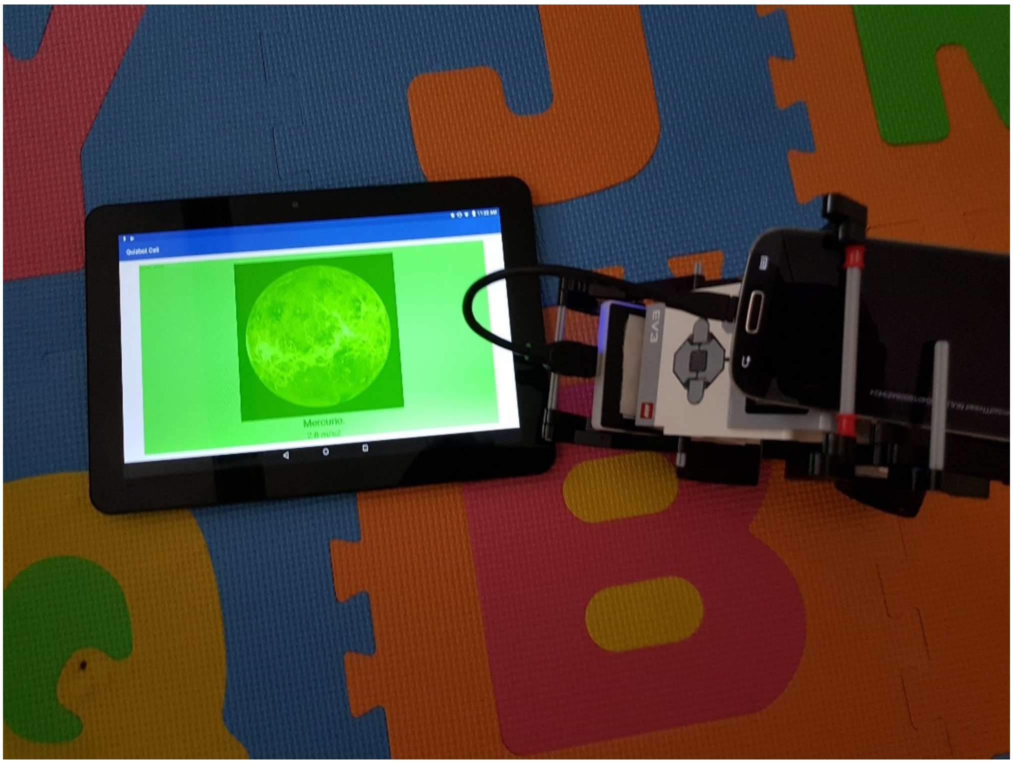



*Figure 20: display when the robot approaches the correct answer.*

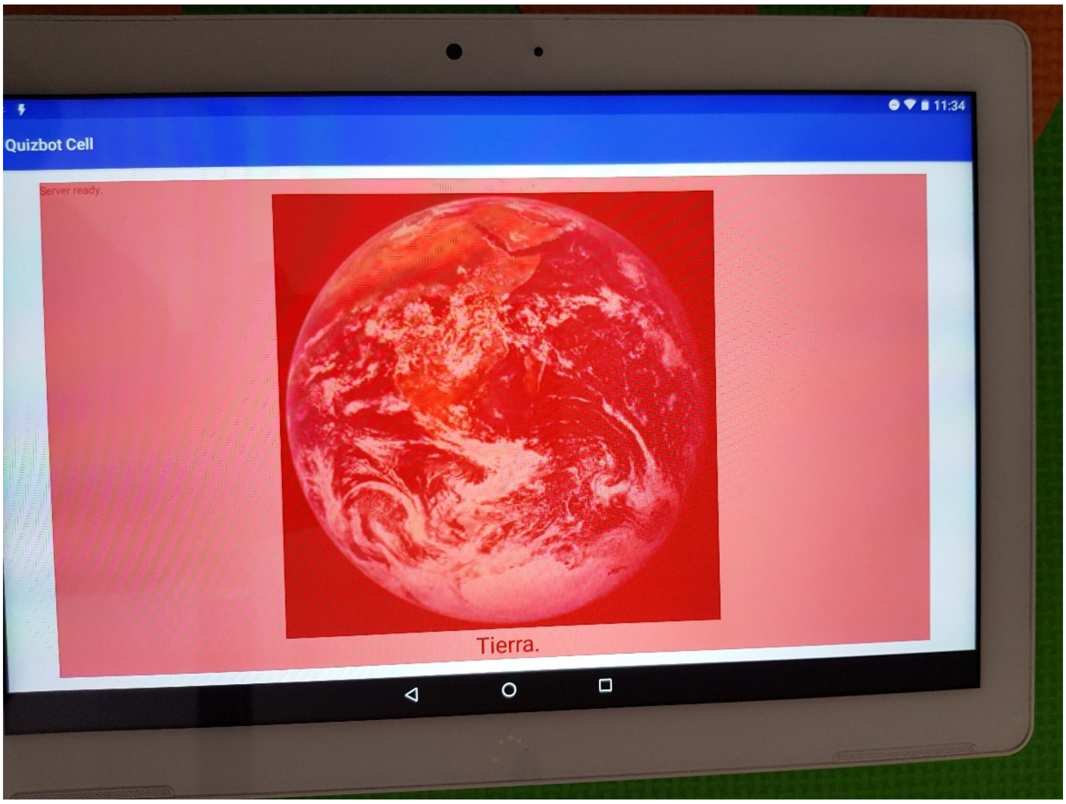



*Figure 21: this screen is shown to the players when the robot approaches an incorrect answer.*

The board, bombs, walls, and robot are physical artifacts the participants can physically interact with. A physical mobile robot and its paddle-based tangible control interface are used, as it has already been proven usable by children more than 3 years old in tasks that involve following paths [54, 133]. Each movement command is encoded in an RFID tag enclosed in an extensible paddle (see Figure 22), which triggers the corresponding movement of the robot when the users bring the paddle close to its RFID reader.

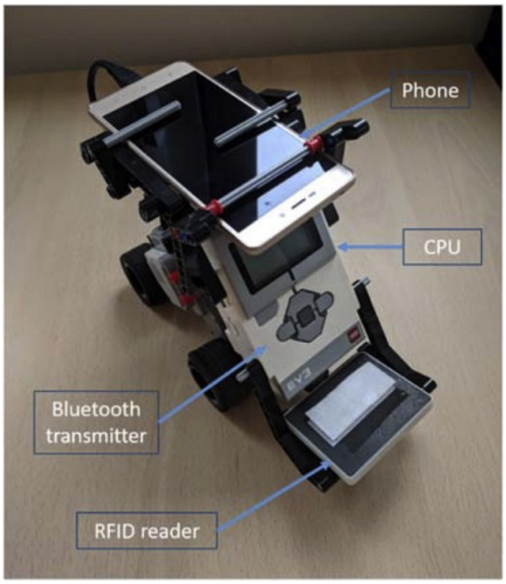



*Figure 22: the robot and the control paddles.*

Since the manipulation of the robot takes place in the real world, the elements that trigger digital events (i.e., bombs and tablets) also have RFID tags attached underneath that are read by Tangibot's RFID reader when it approaches (see Figure 23). The robot's movements are controlled by an application in the robot itself and written in graphical, block-based, Lego Mindstorms programming language. The phone on the robot sends the RFID tags read to a dedicated NodeJS server via an Android app using the Socket.io communication library. The same library is used by the server to send the events that trigger the proper video or audio feedback on the phone or the tablets.

*Figure 23: approach of the robot to the tablet and hidden RFID tags*

When the participants get all the answers right, they get positive feedback on the mobile phone above the robot (which is also used to connect the RFID reader with the server) as shown in Figure 24.

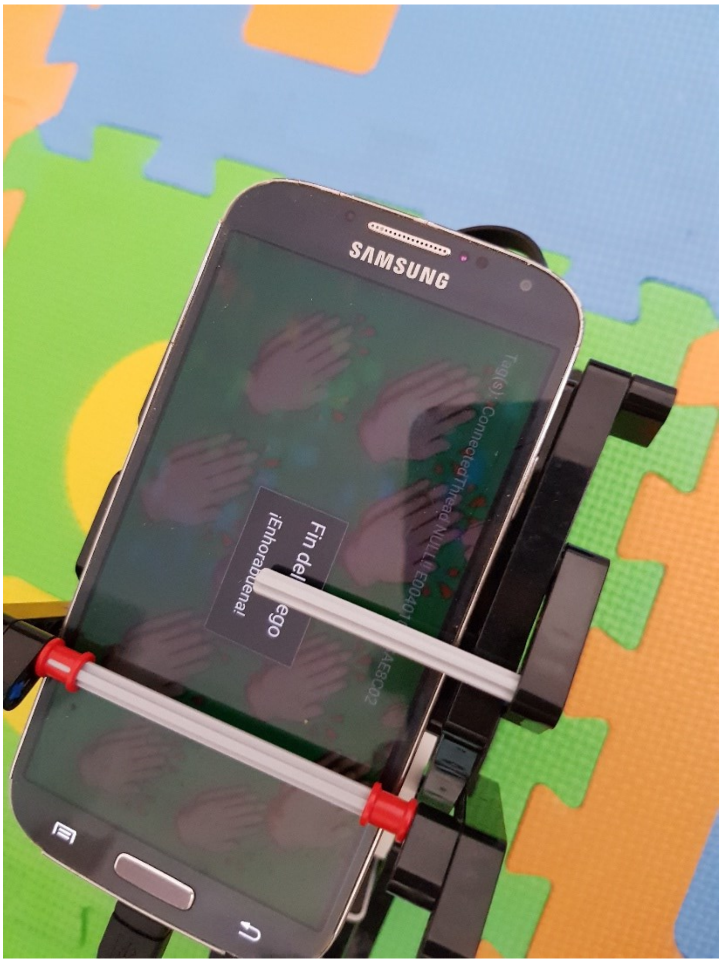



*Figure 24: positive feedback when all questions are answered correctly.*

### 3.2.3. Methods

The main goal of this experimental study was to enhance hospitalized children's collaboration and socialization through educational activities, and to assess the impact of the participation of a teacher in the collaboration and communication and in the psychosocial aspect of the gameplay. By using the Goal Question Metrics [164], it can be defined as follows: *analyze* the expressions and attitudes of children during the gameplay *for the purpose of* determining the impact of the game in their short-term psychosocial state and their perception of hospitalization, and the impact of the teacher on communication and coordination *from the point of view of* the interaction and collaboration between the children while using technology *in the context of* pediatric hospitalization.

Considering all this background, the research questions we formulate in this work are:

- RQ-A: What is the impact of the teacher on communications, joint information processing and interpersonal relationships among the children and with the teacher?

- RQ-B: What is the impact of the teacher on the technical coordination and motivation among the children and with the teacher?

- RQ-C: What is the impact of the teacher on the feelings and perception of the patients about the activity?

- RQ-D: What are the feelings and emotions shown by the participants during the activity?

From these research questions, the following null hypotheses are formulated to be statistically tested:

- $H_{0A}$: The participation of the teacher in the gameplay does not have an impact on the quality of the communications, joint information processing and interpersonal relationship of the participants, in answer to RQ-A.

- $H_{0B}$: The participation of the teacher in the gameplay does not have an impact on the quality of the coordination and motivation of the participants, in answer to RQ-B.

- $H_{0C}$: The participation of the teacher in the gameplay does not have an impact on the psychosocial state of the participants, in answer to RQ-C.

- $H_{0D}$: The game does not have an impact on the psychosocial aspect of the participants in the short-term, in answer to RQ-D.

#### 3.2.3.1. Participants

The children attending the hospital classroom were invited to participate in the game. However, given the nature of the game (which requires some physical activity), those with severe mobility restrictions could not take part.

For both types of session, 20 children with a variety of ailments took part in the experiment, with ages ranging from 4 to 12, with an average of 8.16 and a standard deviation of 2.93. 13 (65%) were males and 7 (35%) were females.

#### 3.2.3.2. Apparatus

For the experiment, six Android-based tablets were used with a Lego EV3 robot (see Figure 22) fitted with RFID readers that controlled the robot by orders from the palettes, plus an Android-based mobile phone (which communicated with the robot via Bluetooth) that provided feedback to the players regarding correct answers or exploding bombs and was also connected to the server to receive commands or information.

All the tablets ran a Java application which communicated with the central server by the Socket.IO library. The server was implemented with Javascript and was run as an instance of a NodeJS server.

#### 3.2.3.3. Procedure

The game was tested in the pediatric classroom of a hospital in Valencia (Spain) in May and June 2018. Each session was played in two parts, in a different order in different sessions: one included a teacher as part of the group, while the other was with children only. This was to test the impact of the teacher on the emotional, social and communicative aspects of the game. Initially, the children were introduced to the robot and given a brief explanation of how it worked. They were then invited to share out the roles and to start playing for 20 minutes or until the session was interrupted for any external reason. Sessions of less than 10 minutes were not considered in the results.

#### 3.2.3.4. Evaluation method

Three main evaluation methods were used to measure the three different aspects covered by the study: psychosocial effect, players' communication and coordination, and user experience.

An ad hoc measurement scale was used to measure the psychosocial effect. This scale analyzed seven dimensions and rated them with a score between 0 and 3, as detailed in Table 2:

*Table 2: analyzed psychosocial dimensions.*

| **Dimension** | **Description** | **Scoring system** |
|---|---|---|
| Affection | Facial or corporal expressions which denote some emotion | 0: serious expression. Seems sad, bored or in pain.<br>1: no emotion shown by the participant.<br>2: smiles or shows some enjoyment.<br>3: shows enthusiasm, laughs or is positively surprised. |

| | | |
|---|---|---|
| Somatic complaints | Verbal, facial or corporal expressions which denote some pain or discomfort. | 0: shows 2 or more expressions of pain.<br>1: shows 2 expressions of pain.<br>2: shows 1 expression of pain.<br>3: does not show any expression of pain. |
| Physical activity | Movements performed by the kid during gameplay, considering his medical possibilities. | 0: the child does not move during the activity.<br>1: the child does not move much during the activity.<br>2: the child moves moderately during the activity.<br>3: the child is very active, waving his arms, running or jumping. |
| Nervousness | Repetitive uncontrolled moves; verbal, facial or corporal expressions which denote fear or worries. | 0: shows 2 or more expressions or signs of nervousness.<br>1: shows 2 expressions or signs of nervousness.<br>2: shows 1 expression or sign of nervousness.<br>3: does not show any sign of nervousness. |

| | | |
|---|---|---|
| Social interaction | How the child interacts with the other participants. | 0: plays individually.<br>1: the child responds to the direction of a third person.<br>2: the child acts as a director of the activity.<br>3: the child collaborates with the other children on equal terms. |
| Interest | Pays attention to the tool and to its different functionalities. | 0: does not pay attention or does not want to play.<br>1: the child uses the tool but does not explore its full functionalities. Plays passively.<br>2: shows some interest and plays actively, exploring its functionalities.<br>3: gives suggestions to improve the tool, asks for more play time or shows interest in using it again at another time. |
| Satisfaction | Verbal expressions regarding the activity. | 0: makes a negative comment regarding the activity.<br>1: does not make any comment. |

| | | |
|---|---|---|
| | | 2: makes one positive comment regarding the activity.<br>3: makes two or more positive comments about the activity. |

All these dimensions were evaluated three times in each session: at the beginning, mid-session and at the end, by two independent observers.

The use of this ad-hoc scale was motivated because a lack of validated observational scales was observed for the evaluation of the behavior (physical, emotional and psychosocial) manifested by children aged 0 to 6 years and adults in difficult contexts, such as continuous interaction or a complex clinical state in the hospital's environment.

For this purpose, an initial non-systematic observation was made over one month, focused on hospital life, natural interaction between patient and caregiver, and the psychosocial factors involved. The work of Artilheiro [8] and Montoya-Castilla [130] was also used as an example in developing the observational scale. A reliability study was conducted. This study included 58 patients (M = 7.00 years; TD = 3.28 years; 33% girls) and 22 caregivers (M = 39.00 years; TD = 5.23 years; 73% women). The observation was carried out in the Pediatric and Hemato-oncological Unit of the Hospital Universitari i Politècnic La Fe in Valencia. For the analysis of the data, the Kappa interobserver concordance index was calculated. The results showed very good inter-judge concordance for the features Nervousness, Physical Activity and Somatic Complaints (K = 0.94; 0.87; 0.90); and good in the features Affection, Interaction and Interest (K = 0.65; 0.75; 0.77); In caregivers the concordance was very good for Nervousness and Emotional Reaction (K = 0.90; 0.86); good for the Interaction and Interest trait (K = 0.67; 0.68); and moderate for the Affect trait (K = 0.60).

A *Smileyometer* [151, 152] was used for the user experience. This is a 5-point Likert scale with values represented by smiley faces. This test was conducted twice: before and after the session.

The children's communication and coordination during the gameplay was assessed by the questionnaire designed by Meier et al. [118], with some minor adaptations for children. The questionnaire contains nine items related to five collaboration aspects, which are ranked on a Likert scale of 4 points from -2 (very bad) to +2 (very good). The assessment was performed by two independent observers. The nine items and their group aspects were the following:

1. Communication
    1. Sustaining mutual understanding
    2. Dialogue management
2. Joint information processing
    1. Information pooling
    2. Reaching consensus.
3. Coordination
    5. Task division
    6. Time management
    7. Technical coordination
- Interpersonal relationship
    8. Reciprocal interaction
- Motivation
    9. Joint task orientation

### 3.2.4. Results

To answer the research questions, a series of statistical tests were carried out with the data collected during the evaluation. Regarding the statistical tests performed on the data, t-tests and two-factor ANOVA tests were used, as the Likert scale data in this study represent a discretization of a continuous variable that represents a degree of agreement. These tests are valid and powerful and provide the same protection against false positives as non-parametric tests for this case, as discussed in [178].

First, with the aim of answering RQ-A and RQ-B, the data collected for the communication aspect of the experiment was analyzed using a two-part dependent t-test: first, communication and coordination between children playing alone was compared to that between children (excluding communications with the teacher) when the teacher was present. This data can be seen in Table 3.

*Table 3: comparison of communication and coordination between children when the teacher was present and absent.*

| | | Mean | N | Std. Deviation | Std. Error Mean | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| Sustaining mutual understanding | Without teacher | -1.35 | 20 | .844 | .189 | .309 | 19 | .761 |
| | With teacher | -1.40 | 20 | .852 | .191 | | | |
| Dialogue management | Without teacher | .65 | 20 | 1.137 | .254 | 1.143 | 19 | .267 |
| | With teacher | .35 | 20 | .875 | .196 | | | |
| Information pooling | Without teacher | -.35 | 20 | 1.387 | .310 | .705 | 19 | .490 |
| | With teacher | -.58 | 20 | 1.055 | .236 | | | |
| Reaching consensus | Without teacher | .40 | 20 | 1.210 | .270 | .391 | 19 | .700 |
| | With teacher | .30 | 20 | .657 | .147 | | | |
| Task division | Without teacher | .30 | 20 | 1.069 | .239 | .674 | 19 | .509 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | With teacher | .13 | 20 | .930 | .208 | | | |
| Time management | Without teacher | .93 | 20 | 1.029 | .230 | .677 | 19 | .507 |
| | With teacher | .65 | 20 | 1.226 | .274 | | | |
| Technical coordination | Without teacher | .65 | 20 | 1.309 | .293 | 1.22 | 19 | .238 |
| | With teacher | .23 | 20 | 1.141 | .255 | | | |
| Reciprocal interaction | Without teacher | .80 | 20 | 1.399 | .313 | .698 | 19 | .494 |
| | With teacher | .60 | 20 | 1.353 | .303 | | | |
| Conjoint task orientation | Without teacher | .93 | 20 | .693 | .155 | .767 | 19 | .453 |
| | With teacher | .78 | 20 | .910 | .204 | | | |

As these results show, there was no difference in the way children communicated and coordinated with each other when the teacher was either present or absent.

However, the communication and coordination among the children with the teacher and between each other (excluding the teacher) were compared when the teacher was part of the group (Table 4).

*Table 4: comparison between the communication between the children among themselves and between them and the teacher*

| | | Mean | N | Std. Deviation | Std. Error Mean | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| Sustaining mutual understanding | Between children and the teacher | -.95 | 20 | 1.087 | .243 | 1.989 | 19 | .061 |
| | Between the children | -1.40 | 20 | .852 | .191 | | | |
| Dialogue management | Between children and the teacher | .98 | 20 | 1.094 | .245 | 3.387 | 19 | .003 |
| | Between the children | .35 | 20 | .875 | .196 | | | |
| Information pooling | Between children and the teacher | .48 | 20 | .924 | .207 | 6.658 | 19 | .000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Between the children | -.58 | 20 | 1.055 | .236 | | | |
| Reaching consensus | Between children and the teacher | .63 | 20 | .483 | .108 | 2.221 | 19 | .039 |
| | Between the children | .30 | 20 | .657 | .147 | | | |
| Task division | Between children and the teacher | .08 | 20 | 1.370 | .306 | -.195 | 19 | .847 |
| | Between the children | .13 | 20 | .930 | .208 | | | |
| Time management | Between children and the teacher | .10 | 20 | 1.008 | .225 | -4.222 | 19 | .000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Between the children | .65 | 20 | 1.226 | .274 | | | |
| Technical coordination | Between children and the teacher | -.33 | 20 | 1.004 | .224 | -2.010 | 19 | .059 |
| | Between the children | .23 | 20 | 1.141 | .255 | | | |
| Reciprocal interaction | Between children and the teacher | .90 | 20 | .912 | .204 | 2.042 | 19 | .055 |
| | Between the children | .60 | 20 | 1.353 | .303 | | | |
| Conjoint task orientation | Between children and the teacher | .20 | 20 | .696 | .156 | -2.632 | 19 | .016 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Between the children | .78 | 20 | .910 | .204 | | | |

In this situation there is a significant difference between the way children interact with each other and the way they communicate and coordinate with the teacher. This time, there is an improvement in the communicational aspects of the interaction (dialogue management, information pooling and reaching consensus), which allows us to reject hypothesis H0A. However, there is also reduced performance in terms of technical coordination (time management and individual task orientation), also resulting in the rejection of hypothesis H0B.

To answer RQ-C, a two-factor ANOVA of repeated measures was conducted in which the factors were: the time (the three measures taken) and the presence or absence of the teacher. Given that all the children participated in both types of session, both were considered intra-subject variables. The statistical results can be seen in Table 5.

*Table 5: results of a two-factor ANOVA of repeated measures test regarding participant's psychosocial state during the game.*

| | **Quadratic Mean** | **F** | **df** | **Sig.** |
|---|---|---|---|---|
| time | 1.815 | 4.857 | 1.701 | .018 |
| teacher | .469 | 1.216 | 1 | .284 |
| time*teacher | .065 | .209 | 1.742 | .782 |

These results show that the only impact on the psychosocial state of the participants during the game was from the time, as detailed in Table 6 and Table 7, which invalidates H0D. This means that no impact was observed due to the presence of the teacher during the session, or derived from the interaction of both factors, which allowed us to accept hypothesis H0C. Full details of the teacher’s impact can be seen in Table 8.

*Table 6: results for each timeframe in sessions without the participation of the teacher.*

| | | **Mean** | **SD** | **N** | **p** | | | **F** | **df** | **$\eta^2$** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | $T_1$-$T_3$ | Global | | | |
| Affection | Beginning | 1.48 | .595 | 20 | .005 | .367 | .122 | 2.229 | 2 | .105 |
| | Mid-game | 1.83 | .693 | 20 | .358 | | | | | |
| | Ending | 1.65 | .905 | 20 | | | | | | |
| Complaints | Beginning | 3.00 | .000 | 20 | . | .330 | .377 | 1.000 | 2 | .050 |
| | Mid-game | 3.00 | .000 | 20 | .330 | | | | | |
| | Ending | 2.95 | .224 | 20 | | | | | | |
| Activity | Beginning | 1.35 | .651 | 20 | .028 | .074 | .053 | 3.408 | 1.668 | .152 |
| | Mid-game | 1.78 | .678 | 20 | 1.000 | | | | | |
| | Ending | 1.78 | .952 | 20 | | | | | | |
| Nervousness | Beginning | 2.85 | .671 | 20 | .330 | .541 | .508 | .689 | 2 | .035 |
| | Mid-game | 3.00 | .000 | 20 | .330 | | | | | |
| | Ending | 2.95 | .224 | 20 | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Social interaction | Beginning | .75 | 1.198 | 20 | .000 | .007 | .000 | 14.082 | 2 | .426 |
| | Mid-game | 2.25 | .953 | 20 | .023 | | | | | |
| | Ending | 1.83 | 1.092 | 20 | | | | | | |
| Interest | Beginning | 1.83 | .568 | 20 | .163 | .748 | .387 | .974 | 2 | .049 |
| | Mid-game | 2.07 | .674 | 20 | .217 | | | | | |
| | Ending | 1.90 | .852 | 20 | | | | | | |
| Satisfaction | Beginning | 1.13 | .559 | 20 | 1.000 | .878 | .978 | .022 | 2 | .001 |
| | Mid-game | 1.13 | .455 | 20 | .666 | | | | | |
| | Ending | 1.15 | .401 | 20 | | | | | | |

In this case, there are statistically significant differences for affection (between moments 1 and 2), activity (between moments 1 and 2) and social interaction (moments 1 and 2, 1 and 3 and 2 and 3). This reinforces the rejection of hypothesis H0D, as this data shows a short-term impact on the psychosocial state of the participants.

*Table 7: results for each timeframe in sessions with the participation of the teacher.*

| | | **Mean** | **SD** | **N** | **p** | | | **F** | **df** | **$\eta^2$** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | $T_1$-$T_3$ | Global | | | |
| Affection | Beginning | 1.35 | .564 | 20 | .023 | .640 | .054 | 3.164 | 1.663 | .143 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mid-game | 1.78 | .658 | 20 | .033 | | | | | |
| | Ending | 1.45 | .776 | 20 | | | | | | |
| Complaints | Beginning | 2.98 | .112 | 20 | .666 | .330 | .561 | .588 | 2 | .030 |
| | Mid-game | 2.95 | .224 | 20 | .330 | | | | | |
| | Ending | 3.00 | .000 | 20 | | | | | | |
| Activity | Beginning | 1.13 | .666 | 20 | .003 | .007 | .001 | 8.876 | 2 | .318 |
| | Mid-game | 1.68 | .712 | 20 | 1.000 | | | | | |
| | Ending | 1.68 | .783 | 20 | | | | | | |
| Nervousness | Beginning | 2.95 | .224 | 20 | .577 | .330 | .377 | 1.000 | 2 | .050 |
| | Mid-game | 2.90 | .308 | 20 | .163 | | | | | |
| | Ending | 3.00 | .000 | 20 | | | | | | |
| Social interaction | Beginning | .60 | .576 | 20 | .000 | .002 | .000 | 15.561 | 1.990 | .450 |
| | Mid-game | 1.83 | .832 | 20 | .080 | | | | | |
| | Ending | 1.43 | .783 | 20 | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Interest | Beginning | 1.60 | .476 | 20 | .024 | 1.000 | .105 | 2.496 | 1.721 | .116 |
| | Mid-game | 1.90 | .528 | 20 | .076 | | | | | |
| | Ending | 1.60 | .771 | 20 | | | | | | |
| Satisfaction | Beginning | 1.00 | .000 | 20 | .330 | .163 | .377 | 1.000 | 2 | .050 |
| | Mid-game | 1.03 | .112 | 20 | .577 | | | | | |
| | Ending | 1.05 | .154 | 20 | | | | | | |

These results show differences for affection (between moments 1 and 2 and moments 2 and 3), physical activity (moments 1 and 2 and 1 and 3), social interaction (moments 1 and 2 and 1 and 3) and interest (moments 1 and 2).

*Table 8: results of the ANOVA test to see the impact of the teacher in each of the psychosocial aspects evaluated in each timeframe.*

| | | | **Mean** | **N** | **Std. Deviation** | **F** | **df** | **Sig.** | **$\eta^2$** |
|---|---|---|---|---|---|---|---|---|---|
| Affection | Beginning | Without teacher | 1.48 | 20 | .595 | .629 | 1 | .437 | .032 |
| | | With teacher | 1.35 | 20 | .564 | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mid-game | Without teacher | 1.83 | 20 | .693 | .083 | 1 | .776 | .004 |
| | | With teacher | 1.78 | 20 | .658 | | | | |
| | Ending | Without teacher | 1.65 | 20 | 0.905 | 1.070 | 1 | .314 | .053 |
| | | With teacher | 1.45 | 20 | 0.776 | | | | |
| Complaints | Beginning | Without teacher | 3.00 | 20 | .000 | 1 | 1 | .330 | .050 |
| | | With teacher | 2.98 | 20 | .112 | | | | |
| | Mid-game | Without teacher | 3.00 | 20 | .000 | 1 | 1 | .330 | .050 |
| | | With teacher | 2.95 | 20 | .224 | | | | |
| | Ending | Without teacher | 2.95 | 20 | .224 | 1 | 1 | .330 | .050 |
| | | With teacher | 3.00 | 20 | .000 | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Activity | Beginning | Without teacher | 1.35 | 20 | .651 | 1.185 | 1 | .290 | .059 |
| | | With teacher | 1.13 | 20 | .666 | | | | |
| | Mid-game | Without teacher | 1.78 | 20 | .678 | .336 | 1 | .569 | .017 |
| | | With teacher | 1.68 | 20 | .712 | | | | |
| | Ending | Without teacher | 1.78 | 20 | .952 | .202 | 1 | .658 | .011 |
| | | With teacher | 1.68 | 20 | .783 | | | | |
| Nervousness | Beginning | Without teacher | 2.85 | 20 | .671 | .388 | 1 | .541 | .020 |
| | | With teacher | 2.95 | 20 | .224 | | | | |
| | Mid-game | Without teacher | 3.00 | 20 | .000 | 2.111 | 1 | .163 | .100 |
| | | With teacher | 2.90 | 20 | .308 | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Ending | Without teacher | 2.95 | 20 | .224 | 1.000 | 1 | .330 | .050 |
| | | With teacher | 3.00 | 20 | .000 | | | | |
| Social interaction | Beginning | Without teacher | .75 | 20 | 1.198 | .241 | 1 | .629 | .013 |
| | | With teacher | .60 | 20 | .576 | | | | |
| | Mid-game | Without teacher | 2.25 | 20 | .953 | 2.316 | 1 | .145 | .109 |
| | | With teacher | 1.83 | 20 | .832 | | | | |
| | Ending | Without teacher | 1.83 | 20 | 1.092 | 1.547 | 1 | .229 | .075 |
| | | With teacher | 1.43 | 20 | .783 | | | | |
| Interest | Beginning | Without teacher | 1.83 | 20 | .568 | 1.400 | 1 | .251 | .069 |
| | | With teacher | 1.60 | 20 | .476 | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mid-game | Without teacher | 2.08 | 20 | .674 | 1.347 | 1 | .260 | .066 |
| | | With teacher | 1.90 | 20 | .528 | | | | |
| | Ending | Without teacher | 1.90 | 20 | .852 | 2.591 | 1 | .124 | .120 |
| | | With teacher | 1.60 | 20 | .771 | | | | |
| Satisfaction | Beginning | Without teacher | 1.13 | 20 | .559 | 1.000 | 1 | .330 | .050 |
| | | With teacher | 1.00 | 20 | .000 | | | | |
| | Mid-game | Without teacher | 1.13 | 20 | .455 | .884 | 1 | .359 | .044 |
| | | With teacher | 1.03 | 20 | .112 | | | | |
| | Ending | Without teacher | 1.15 | 20 | .401 | 2.111 | 1 | .163 | .100 |
| | | With teacher | 1.05 | 20 | .154 | | | | |

The kappa index for the two observers that participated in the evaluation was computed to test their agreement rate. The result was a kappa index of 0.82, which translates to "almost perfect", according to Landis and Koch [24].

### 3.2.5. Conclusions

A study conducted in a hospital classroom with 20 participants revealed that the teacher has an impact on the children's communication and coordination procedures but has no impact on the psychosocial state of the participants. The teacher's impact was found to be positive about communications. Dialogue management significantly improves when the communication includes the teacher, which means speaking turns are observed more consistently. Information pooling also improves, and the participants ask the teacher more questions. Consensus is also reached more often and more easily, but this does not reflect on the performance, as the time management is evidently worse when the teacher is present, as is also the joint task orientation.

On the other hand, it was found that the teacher does not have an impact on the psychosocial state of the participants during the game, and that it is the game itself which changes their state over time. In the case of affection, which reflects the participants' emotions of joy or boredom, their state improved significantly after a few minutes of play. The same thing occurred for physical activity, interest in the activity and interaction between peers, which increased in value in the first part of the game, although physical activity and interaction were reduced towards the end. No changes were found throughout the game in the number of complaints, nervousness or satisfied comments, which remained very low for all these aspects, showing that the game distracted them from their various symptoms.

### 3.2.6. Threads to validity

Despite the contributions of this study, there are certain limitations. First, the number of participants in this research is reduced due to the available clinical population which could have an impact on the generalization of the results; and second, a comparison with other forms of measurement of known validity was not included to increase the validity and reliability of the observational scale measures.

## 3.3. PicToMe

### 3.3.1. Introduction

PicToMe was a study that was less extensive than the one done for Tangibot, due to time constraints caused by the academic calendar of the hospital's classroom. Nevertheless, the study aimed to improve some aspects of the results obtained in Tangibot and also to test and evaluate a different context, playing remotely with other people and with less participants in each session, in order to get more knowledge on how these differences impacted the social wellbeing of the participants.

### 3.3.2. The game

PicToMe was conceived to be a multiplayer, remote activity for pediatric patients in the hospital, with the aim of providing them tools to foster socialization with other peers in a situation similar to theirs. The main idea behind the activity was using a popular game like Pictionary adapted to technological devices, as drawing and guessing what the drawing is would require communication between the participants and could trigger spontaneous conversation about the topics and concepts that are required to be drawn.

With this in mind, each player had a personal account in which his/her name was stored, to allow the other players to see it and to know how to address their partners. Before the activity started, the researcher would set up a background Skype call in order to allow for communication between the participants. They would login into the system (Figure 25) and would be presented with an invitation system, whether it was for accepting or rejecting already sent invitations or sending a new one to another player, as can be seen in Figure 26 and Figure 27.

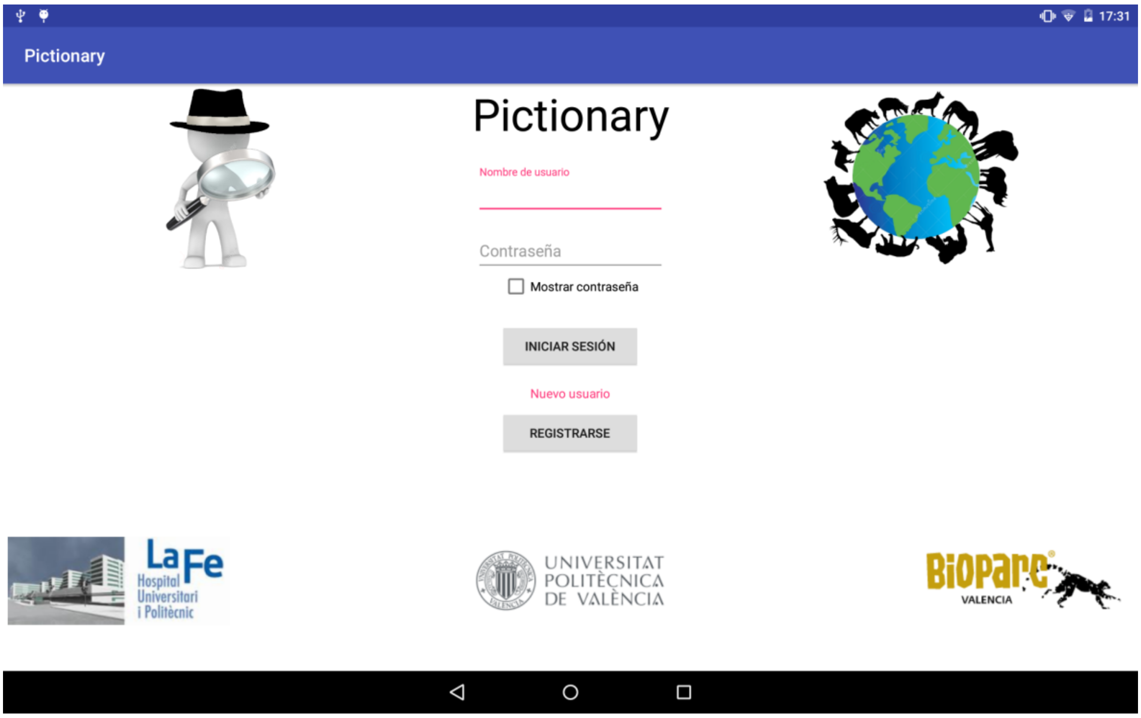



*Figure 25: login screen for PicToMe.*


*Figure 26: invitation management screen for PicToMe.*

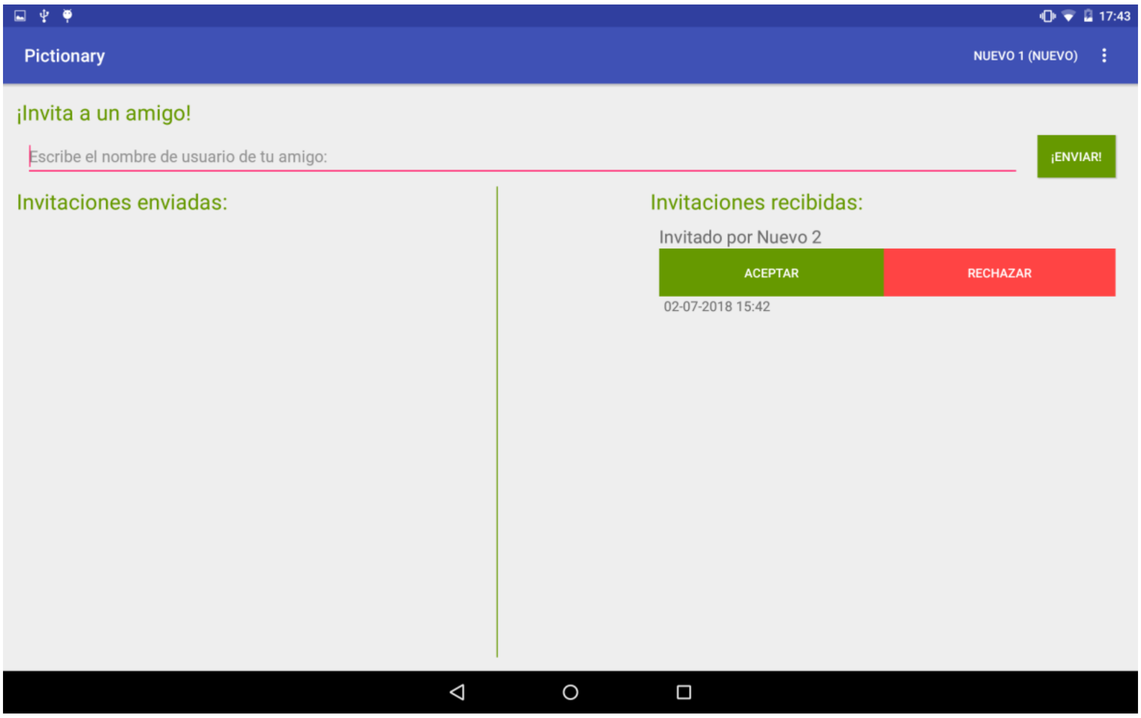



*Figure 27: an invitation has been received in PicToMe.*

When an invitation had been accepted, a new game would begin and the drawing participant would be presented with a white screen in which they could draw with their finger by touching the surface of the tablet. They could also change the color and the thickness of the lines they were drawing or delete some parts of the drawing. Also, an undo and a redo option were present too. All of this can be seen in Figure 28.

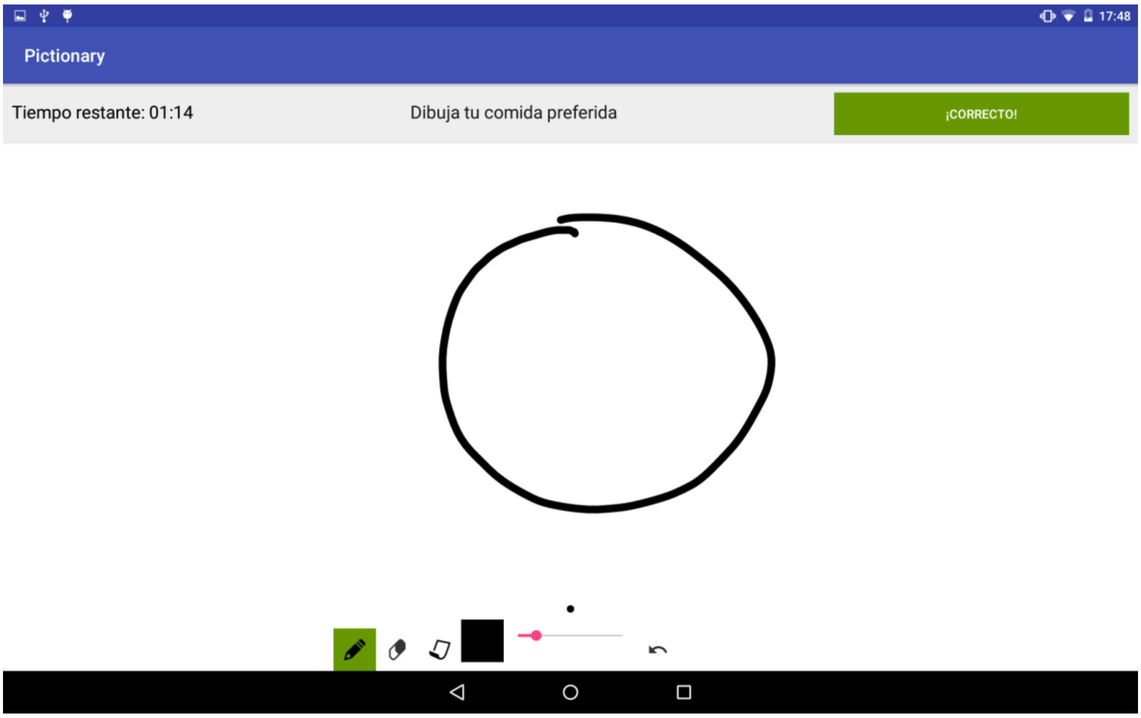



*Figure 28: drawing screen.*

On the other hand, the other player would be shown in near-real time what its peer was drawing and would be asked to guess what the drawing represented. When the correct answer was said, the player who was drawing would have to press the "Correct" button and points would be awarded based on the time remaining for that round. The screen that was shown to the player who was not drawing can be seen in Figure 29.

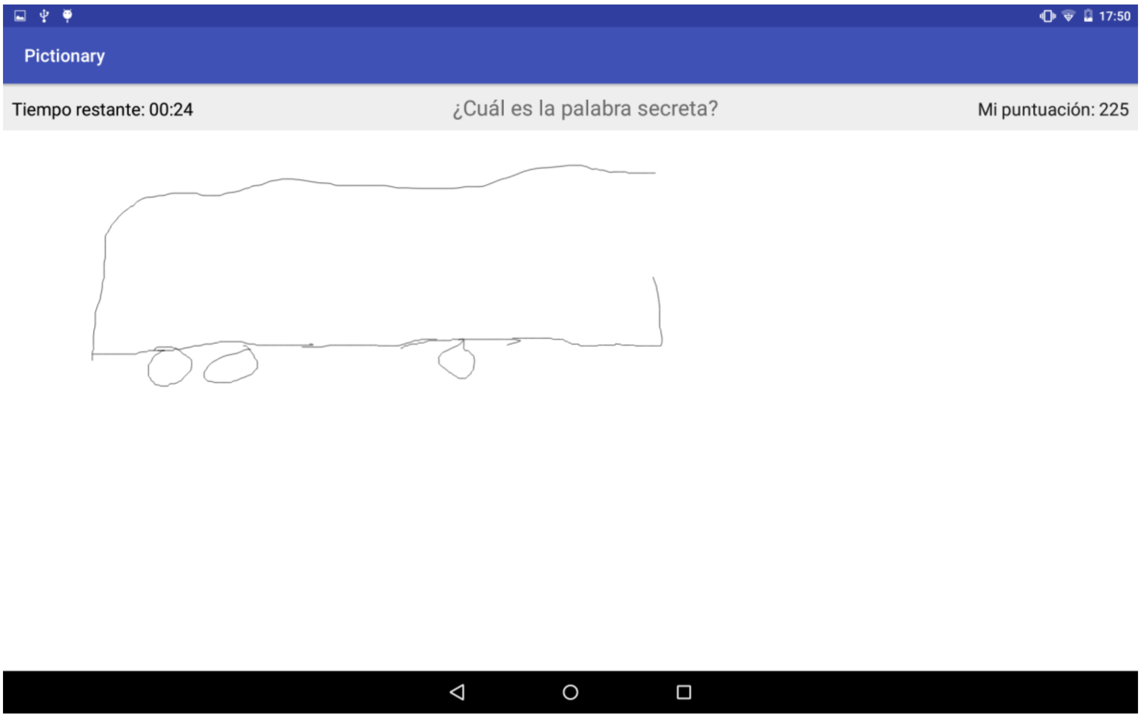



*Figure 29: drawing visualizer.*

Finally, some congratulation or consolation screen would be shown to the winning player and the one losing, respectively, and those screens can be seen in Figure 30 and Figure 31.

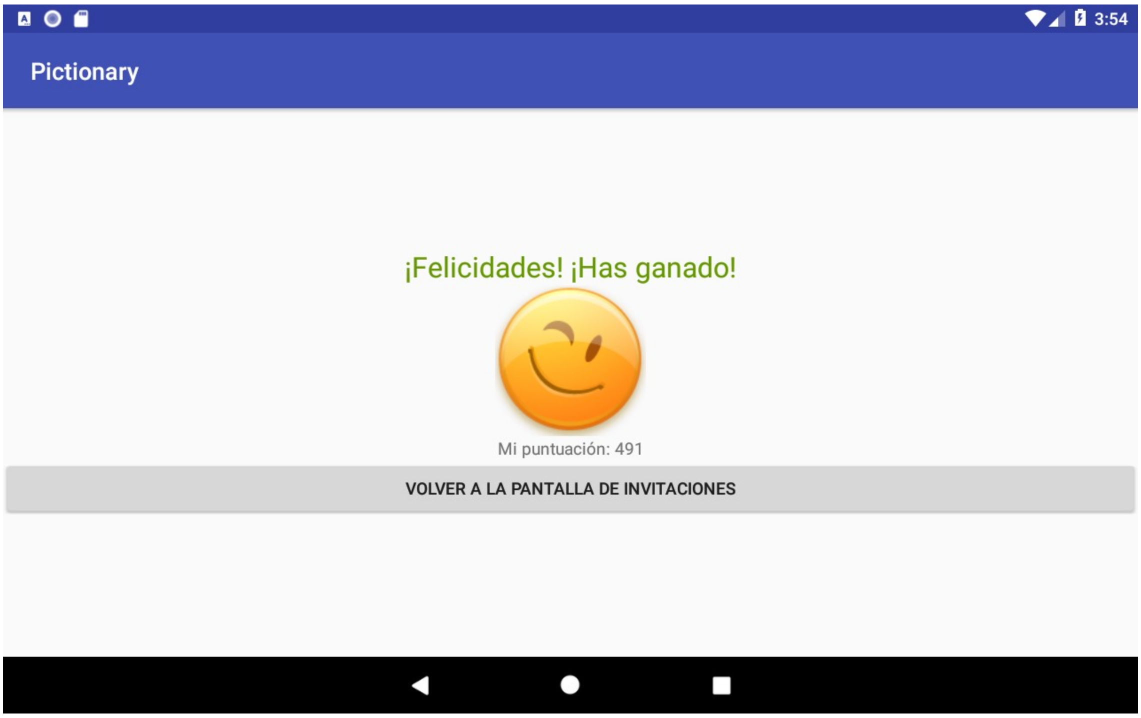



*Figure 30: congratulation screen*

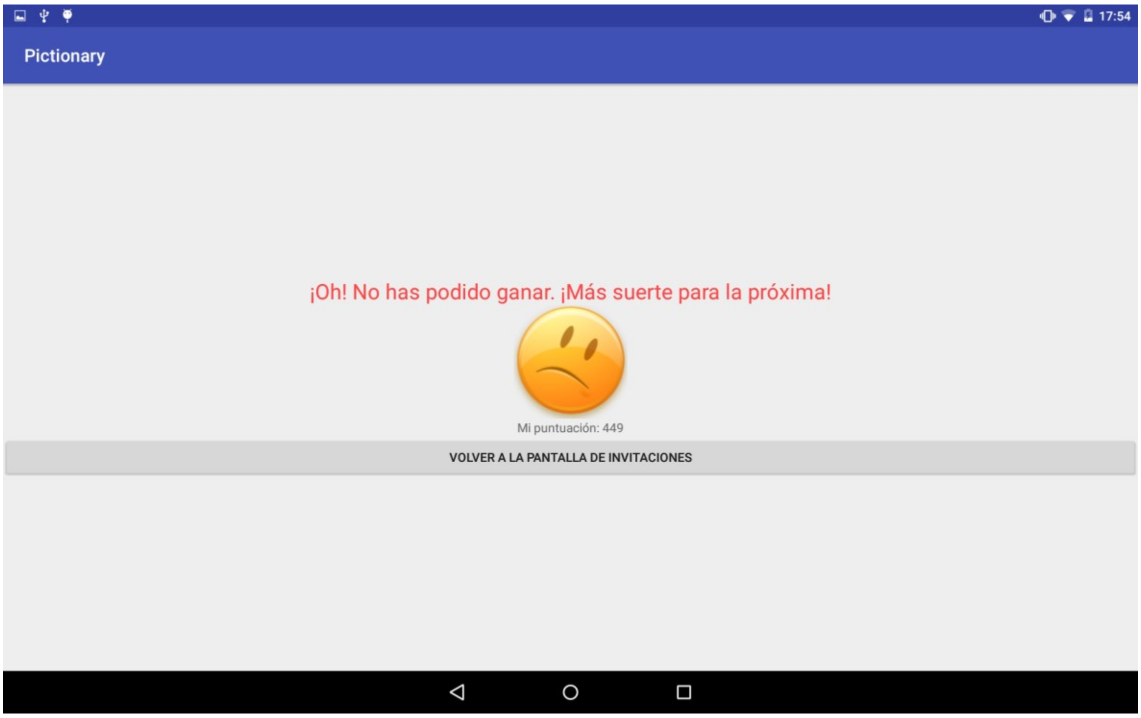



*Figure 31: consolation screen.*

### 3.3.3. Experimental study

In the evaluation, 16 game sessions took place, in which 38 participants from different areas and medical fields of the hospital were involved. 21 of them were males (55.3%) and the other 17 were females (44.74%). The average age was 13.03 (SD 1.241). Some of the participants played more than one time.

In order to perform the experimental study, the participants had to play in pairs that were previously formed by the researchers based on the availability of participants at the time. For each session, there was a researcher with each participant who was responsible of obtaining the observational results of the psychosocial state of the participant during the game, and also to prepare the devices that were going to be used by the participants before each session, by setting a Skype call to establish the communication. The researchers had to independently assess each participant at three points of the session: before starting to play (with the goal of knowing the base state of the participant), mid-game, and after the end of the game. Furthermore, the participants had to answer to a questionnaire based on a Likert scale using smileys [151, 152] after finishing the activity, in which they were asked both about their experience with the game and in the hospital with respect to socialization. The purpose of this was to have not only the observational values, but also the subjective perception of the patient.

The task that the patients had to complete was to draw, in turns, something that was asked by the app. The concepts were simple elements that could foster spontaneous expression of interests or similarities between the participants (for instance, players had to draw their favorite food). The other player had to guess what the picture was in the available time (two minutes). In order to solve the round, the player had to say what the drawing represented out loud. If the answer was correct, the drawer had to push a button to mark it as correct and the points would be awarded in an amount equal to the seconds remaining in the timer. After that, the turns would change, and the guesser would become the drawer and the other way around, and a new round would start. There was no round limit, but it was time based: the maximum amount was eight and a half minutes, and as many rounds as possible would be played in that time. The winner was the player with the highest number of points, and a congratulations message was shown to that player, while the other one would be shown a consolation one.

In order to evaluate the psychosocial aspects observed, an ad-hoc scale was used by the researchers, in which a scale between 0 and 3 was used for the affection (understood as those expressions that show emotions, with 0 codifying negative feelings and 3 the most positive ones, with 1 and 2 representing intermediate values), complaints (pain or distress expressions, with 0 representing the highest number of complaints and 3 that there were no complaints), socialization (spontaneous expressions that reveal something about the participant's interests), nervousness (expressions of fears or worries. 0 means 2 or more expressions, while 3 means none), interaction (related to the performance in game. If the participant had to be encouraged by other people in the room, 0 was marked, but if it was encouraged by the other player, 1 was the code used. 2 was used if the player had a leader attitude and 3 if it was an equally collaborative session), interest in the activity (with 0 being the least degree of interest and 3 the highest), satisfaction (0 means negative comments, 1 no comments made at all, 2 one positive comments and 3 more than one positive comments or gestures). In other studies with pediatric population, such Tangibot or HabitApp [23], the scale showed a good inter-judges confidence and a correction scale was presented.

### 3.3.4. Results

Therefore, considering the observational results obtained, and also the answers to the questionnaires provided by the participants, a statistical analysis was performed to see the impact that the activity had in the different aspects of the scale while it was taking place and right after its ending. The goal was to detect significant differences between the initial, pre-game observation (T1_Pre) and during the game (T2_Mid) or its finish (T3_End). The results obtained can be seen in Table 9:

*Table 9: statistical results of the study.*

| | **$T_1$_Pre** | **$T_2$_Mid** | **$T_3$_End** | | | | |
|---|---|---|---|---|---|---|---|
| | ***M (SD)*** | ***M (SD)*** | ***M (SD)*** | ***df*** | ***F*** | ***p*** | $\eta^2$ |
| Affection | 1.16 (0.64) | 1.76 (0.71) | 1.74 (0.6) | 2 | 20.02 | .000 | .35 |
| Interest | 1.55 (0.69) | 1.92 (0.75) | 1.87 (0.52) | 2 | 7.45 | .001 | .17 |
| Satisfaction | 0.97 (0.28) | 1.05 (0.32) | 1.05 (0.32) | 2 | 1.0 | .373 | .03 |
| Nervousness | 2.82 (0.61) | 2.66 (0.78) | 2.82 (0.56) | 1.67 | 1.94 | .159 | .05 |
| Complaints | 2.68 (0.81) | 2.84 (0.68) | 2.79 (0.70) | 2 | 1.49 | .231 | .04 |
| Socialization | 0.08 (0.27) | 0.11 (0.31) | 0.08 (0.36) | 1.66 | 0.12 | .848 | .00 |
| Interaction | 0.74 (1.03) | 1.95 (1.18) | 2.26 (1.18) | 2 | 22.08 | .000 | .37 |

As can be observed in Table 9, there are statistically significant variations for the affection, interest and interaction factors observed. This means that the activity has a positive impact for these variables between the initial moment and the other two evaluation moments. The other variables do not show significant differences between moments, but it can be seen that the satisfaction remains close to one at all times (which means that the participants do not make comments about the application), that the nervousness and complaints variables are also almost constant (and, given the values used in the scale, it means that practically no worries or complaints are expressed by the participants during the session) and that socialization values are close to 0 at all times, which means that the patients do not make spontaneous comments about themselves or their interests.

Regarding the questionnaire answered by the patients after playing, which was used to know their perception of the activity and their interest in some privacy questions, the questions were the following:

Q1: how are you doing in the hospital?

Q2: did you have fun with this game?

Q3: what do you think about the other children in the hospital?

Q4: could you learn something about the other person you were playing with?

Q5: did you find easy to communicate with the other player?

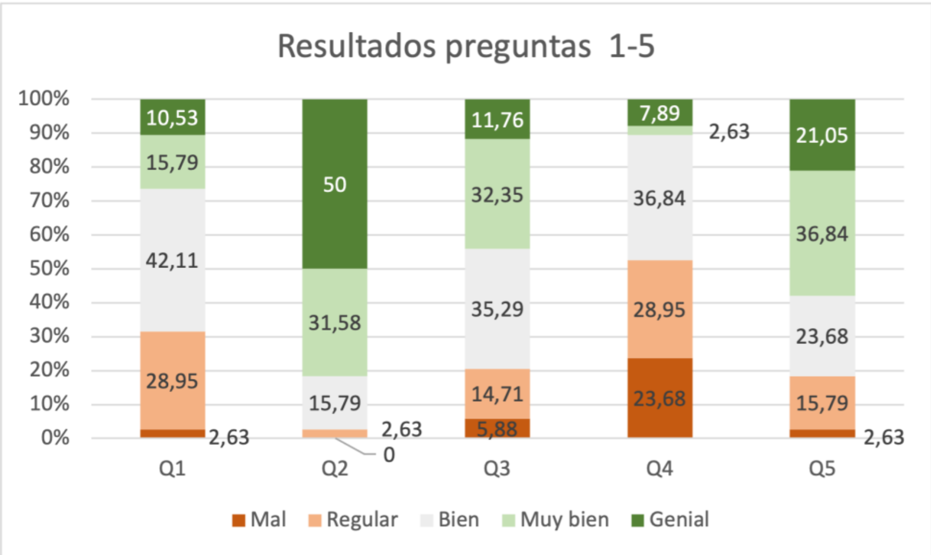



*Figure 32: results of the questionnaire (questions 1-5)*

The results of the questionnaire can be seen in Figure 32. It must be noted that, for Q4, the possible answers were “None”, “Few”, “Some”, “Quite a few” or “A lot” instead of the scale of the other questions, which was “Bad”, “Neither good nor bad”, “Good”, “Very good” or “Excellent”.

On the other hand, the second part of the questionnaire asked the following questions, whose possible answers were “Yes”, “No” or “I don’t care/I don’t know”.:

Q6: did you like the person you have played with?

Q7: would you like to see the other player’s face while playing?

Q8: would you agree to tell the other person the reason you are in the hospital?

Q9: would you agree with the other person knowing where you are in the hospital?

Q10: would you like to meet the other players in their bedrooms?

Q11: would you like to talk to the other players even if it was not in person?

Q12: are you interested in meeting with other people of your age in the hospital?

Q13: are you interested in meeting with other people in the hospital without considering the age?

Q14: do you think that talking and playing with other people in the hospital you will be happier and feel better?

As can be seen in Figure 32, the perception of the hospital stay is "Good", although the number of patients that qualify it as "bad" or "regular" is greater than the number of patients who consider it "very good" or "excellent".

With respect to the results related to the activity, it can be seen that it is considered as fun by the participants, but that it has not allowed them to learn many things about their game partners. There is a significant room for improvement too regarding the difficulty perception for the communication while using the tool, as there are many answers that are far from the most positive answers. Nevertheless, the perception of the participants regarding the application is, in general terms, good.

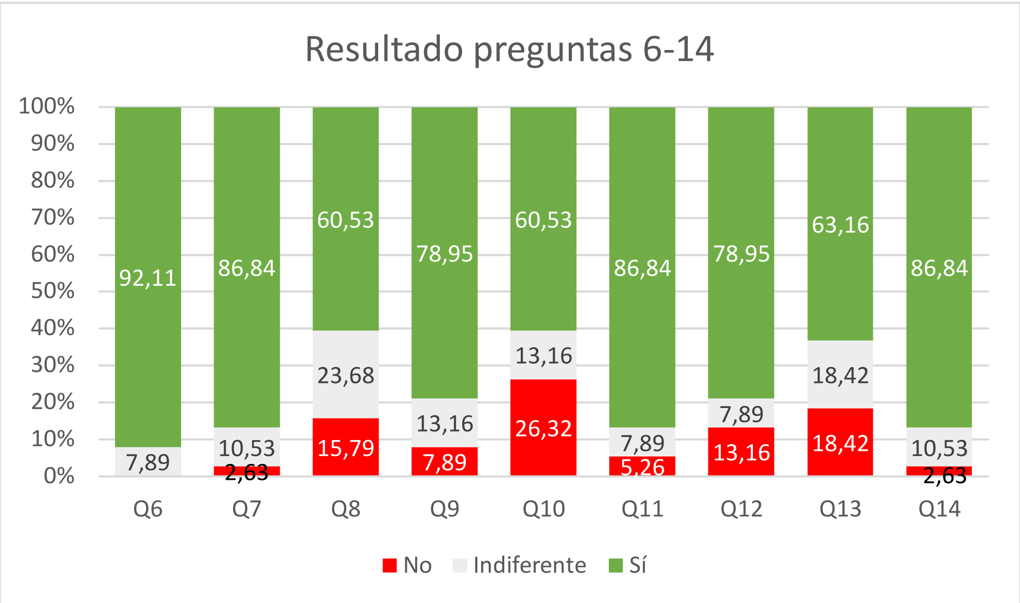



*Figure 33: questionnaire results (questions 6-14)*

With respect to the privacy questions (Figure 33), it can be seen that, in general terms, the patients are willing to provide more personal information to the other participants. However, it must be noted that the results obtained for question Q8 has a lower positive rate than the other questions, so they are slightly more concerned about revealing the reasons for their hospitalization.

Finally, regarding socialization questions (questions 10-14), the results show a preference for a remote interaction, although both options have a good level of support. Also, they also show the willingness of the participants to meet other patients (with a higher preference for people their ages, but with interest in other age groups too) and that they consider that talking or playing with other people will increase their wellbeing during the hospitalization.

With all this, it can be said that PicToMe has a positive short-term effect on the participants regarding their game experience, the interest they show and the interaction that they have with other participants. However, it was not possible to extend those interactions further away from the game and the task at hand (something that can be seen in the socialization value of the study).

### 3.3.5. Threads to validity

There are some threads to the validity of this study that must be considered.

On the one hand, the sample size is very small (given that it is a clinical sample with high difficulty to obtain for many reasons). This could be a significant factor given that the personality of each participant has an important impact on how they interact during the game and how extrovert and sociable they act during the game. As some participants have played more than one time, this could add some bias to the results. It must be noted that no pairs were repeated for the experiment, so no player has played twice with the same participant.

Another point is the presence of the researchers in the room of each participant while the game was being played, as it could have an impact on the player's attitude given that there is a stranger in their private space, and also, they are in front of their parents, so it is not a completely free and natural gaming situation.

Finally, the difficulties of the hospital environment must also be stated, as one of the goals of the experiment was to not interfere with the medical treatments and visits for the participants, which meant that some sessions had to be stopped before they could be completed and restarted after the procedure or visit had finished, something that might have had an impact on the participants.

### 3.3.6. Conclusions

The results obtained from this work are positive, even though one of the goals of the study, which was to get the participants to interact with each other in a spontaneous way and that the interaction could last longer than the game session.

However, it has been possible to see that the proposed activity has been fun and interesting for the participants (something that is shown in both the observational results and the answers to the questionnaires), and that it has a positive impact in the psychosocial state of the participant, even if it is only for the short term.

On the other hand, the answers of the patients show that there exists a desire in them to improve the conditions of their stay through socialization with other interned patients, something that presents a challenge to provide the tools and necessary situations to allow that to happen. Also, the results obtained with respect to the privacy concerns showed that the patients are not restrictive of their personal information, and that they are willing to share some of it with other participants while they are playing or talking to.

# 4. A Gamification Conceptual Model for Socialization Activities

## 4.1. Introduction

Gamification is, according to the Cambridge Dictionary, "the practice of making activities more like games in order to make them more interesting or enjoyable" [34]. However, research shows that the impact is not only making them more interesting or enjoyable: it has been shown that it has a positive impact on different kinds of skills. For instance, there are studies showing a positive impact on learning [146]. It is the case of [83], a study in which they measure the impact on learning Boolean Algebra through gamification strategies instead of traditional strategies, with a better learning result for the experimental group, or the study by Takbiri et al. [168], in which they used a gamified approach (specifically, the use of Easter Eggs) to foster learning. The results they achieved show an improvement with respect to the control group.

Furthermore, gamification can be a good strategy to help students with some disorders to achieve better results than with traditional approximations. An example of that is the use of games and videogames to help with the education of children with autism, like in the study by Najeeb et al. [138], or Carreno-Leon et al. [22], who use tangibles to support learning for this group of children.

Gamification also has an impact on the perception of learning, making it funnier and more attractive for participants. For instance, the works of [67] and [103], who used gamification in a collaborative-learning environment focused on Computer Science students, through the introduction of points, levels or ranks, which was positively accepted by the participants, or the study by Jiménez et al. [82], in which high school students use a scape-room-type of application in order to learn algebra, with positive results and a positive perception of learning.

Not only that, but gamification also has a positive impact when acquiring other important skills such as empathy or socialization. One example of this is [54], which found that a multi-tablet game to enhance collaborative learning in Primary Education obtained positive collaboration and socialization results from the participants. Another one is the study by Lopez-Faican and Jaen [110], in which they present an application oriented towards increasing the empathy of the participants. Also, collaboration, as outlined before, is an important effect of some gamification strategies. For instance, in this study by Gitarana et al. [57], the best results are achieved in cooperative-competitive, multiplayer games, over competitive-only activities.

Play is not only part of human nature but is also seen in animals' behavior and constitutes one of the fundamental cultural pillars [77], so making difficult situations more playful can provide a positive effect for those suffering those situations, while at the same time providing tools for personal growth and better connection to the rest of the society.

With all of this in mind, it is therefore an idea worth exploring to develop a conceptual model based on gamification to provide a set of tools to foster socialization for pediatric patients inside the hospital among other uses that will also be discussed in this thesis. This model, presented in the next lines, has been designed considering all elements of gamification outlined above, and taking into account that most of the examples defined previously are very specific to their application domain, so the proposed model also looks to provide a more general approach, with the possibility of expanding its uses to other areas of life or other target users.

## 4.2. The model

As can be seen in Figure 34, the model is quite complex and extensive, so in the following pages it will be explained in parts, with a special interest on the possibilities that each of the classes and relationships offer to the applications developed based on the model.

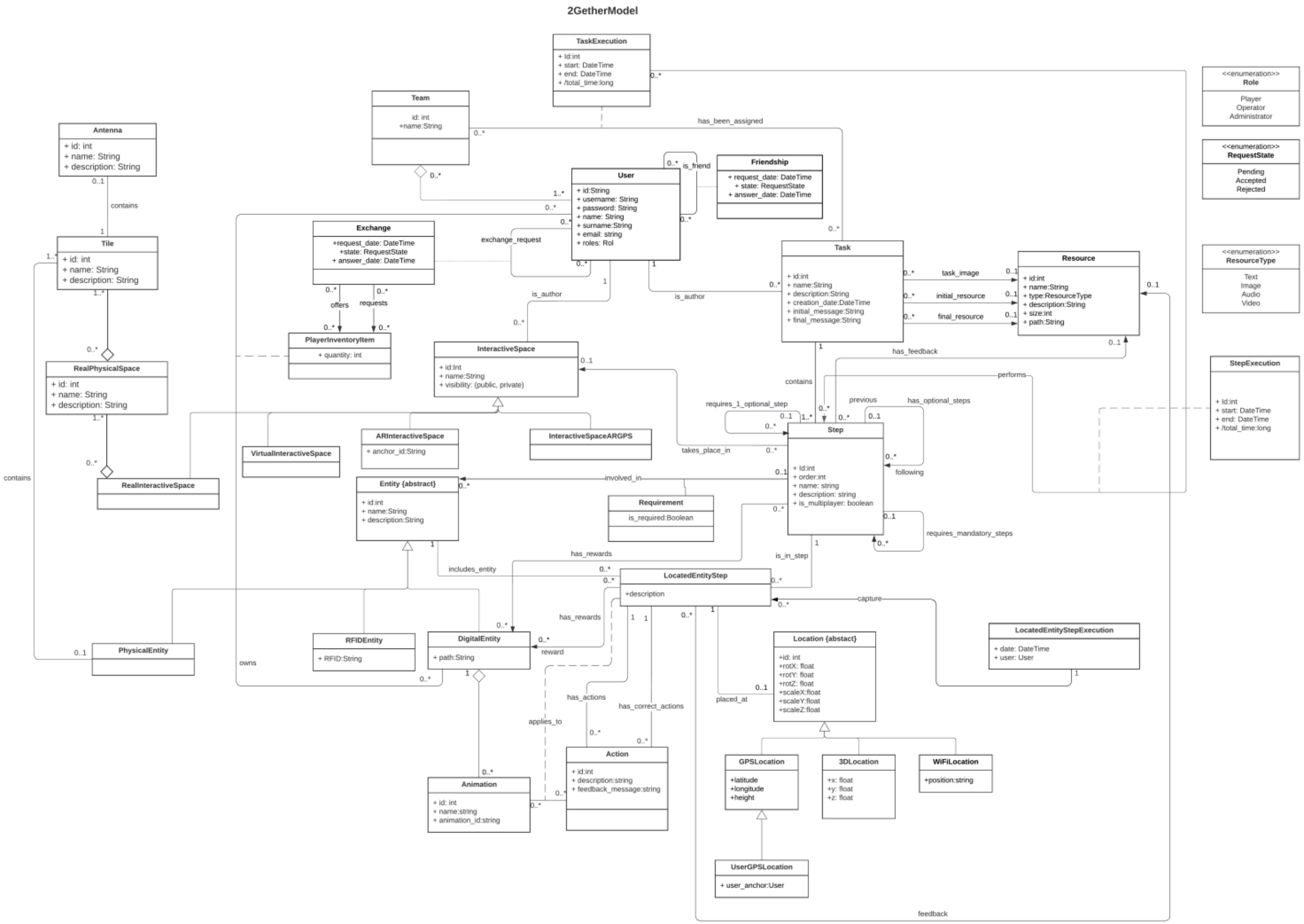



*Figure 34: the full proposed model.*

### 4.2.1. A model of Team Play

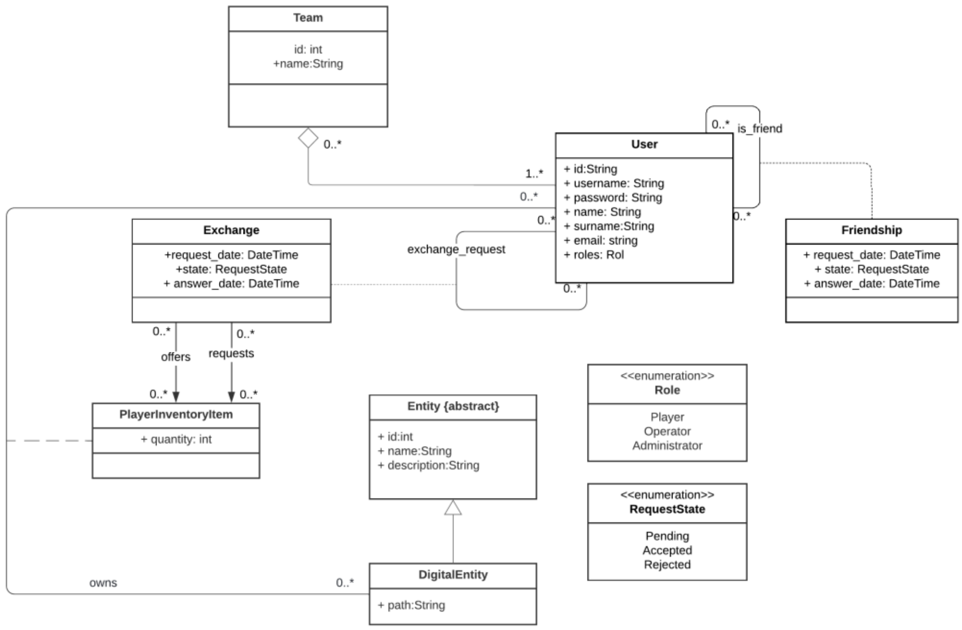



*Figure 35: the section of the model related to teams and users.*

Figure 35 above shows the relationships between the objects required for keeping the information about the users and how they interact with each other. The key element of this part is, of course, the class `User`, that represents everything that is needed to know for each user. One of its fields is `roles`, which is an enumeration of the possible existing roles:

- `Player`: a regular user, without mobility restrictions and that can perform any kind of activity.
- `Operator`: a user with some restrictions that require him/her to be only in one location. It is relevant only for physical or mixed spaces, as will be explained later on.
- `Administrator`: a special user with the permission to create new spaces or tasks.

The class `User` is related to itself in order to represent the friendship between different users, with an association class called `Amistad` that stores the status and information about the friendship request. This association class also relies on an enumeration class, `RequestState`, which, at the moment, has three possible values:

- `Accepted`: the request has been accepted and the users at each end of the relationship are friends in the system.
- `Pending`: the request has been made but no answer has been provided yet. The users are not friends for now.

- `Rejected`: the request has been rejected and the users are not friends in the system.

The same approach has been followed for the exchange of items between the users. An exchange request can be sent from one user to another one (self-relationship) and the information is stored in the association class `Exchange`, that again uses the same enumeration class (`RequestState`). This association class is related twice to the association class `PlayerInventoryItem`, which completes the relationship between `User` and `DigitalEntity` (which is a specialization from `Entity`). This class is the key to saving items in the user's inventory. Therefore, this relationship enables one important part of gamification: rewards (badges, progress trophies, etc). The class has the field quantity, so a given digital item can be obtained multiple times. This allows the user to exchange some of the items that have been won or obtained, creating an interaction between users to obtain the elements they are missing. The double relationship between `Exchange` and `PlayerInventoryItem` makes this possible: one player offers something and requests something else in exchange. The other player can accept or reject this offer. If it is accepted, the state of the exchange can be modified, together with the ownership of the `DigitalEntity`.

Finally, the class `User` is also related to `Team`, which acts as an aggregation class of users. This has the purpose of allowing multiplayer activities between users. A user can be part of multiple teams. This allows greater flexibility than restricting it to one, as the player can participate in different activities with different groups of people depending on its context. One example could be a pediatric patient who can attend activities in person and can play with other children in the same situation, but also has the possibility of playing with children with other conditions that do not allow them to leave their environment. That initial player, if it is part of both teams, can engage in the activities proposed to each of them instead of sticking to one.

## 4.2.2. A model of tasks

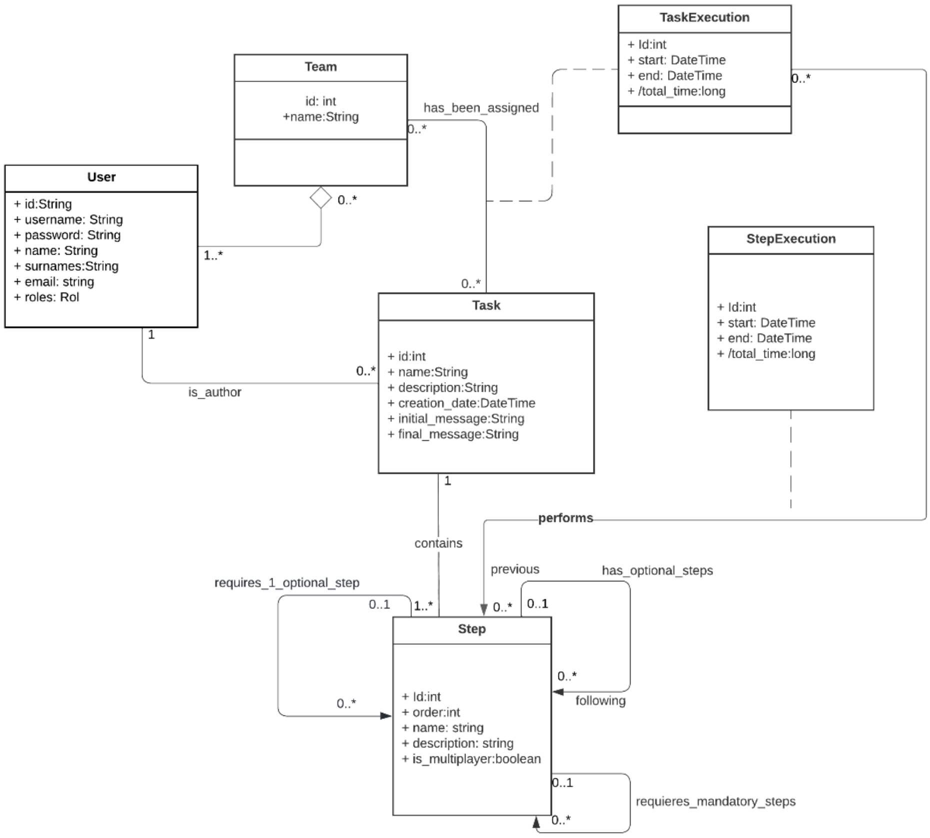



*Figure 36: the section of the model related to tasks.*

Figure 36 shows the foundations of the activities that the users will be able to perform. The model is based on tasks (class `Task`), which is a container for the whole activity. However, the activity might have subparts, so each `Tarea` is divided into `Steps` that offer great flexibility with respect to what can be done in each of them as will be explained later.

Teams are assigned tasks. It is important to note that a single user cannot be directly assigned a task. However, for single player activities, a team with just one member can be created, so it is effectively the same thing while reducing the number of relationships and the complexity of the system. There is a relationship between `User` and `Task`, which is used to identify which user created a given task.

There are two association classes, `TaskExecution` (between `Task` and `Team`) and `StepExecution` (between `TaskExecution` and `Step`) which are used to save the state of play when each step is finished so that the task can be completed later on, and therefore not forcing the design of tasks to adjust to a play time that can be acceptable in the given context, as the activity can be continued at another time, therefore giving more possibilities and putting the focus on the desired objective of the task in terms of wellbeing instead of introducing additional restrictions and compromises to be made.

`Step` is the most important class of the model. While `Task` acts as a container, `Step` is the key for it all to work. It defines what has to be done each time and can have sub-steps that make the complexity go as deep as needed. These sub steps are created through three self-relationships that make the class very flexible in terms of design. The first relationship, `requires_1_optional_step`, is used to define a set of sub steps of which at least one must be completed in order to be able to finish the parent step. The second one, `has_optional_steps`, defines a set of steps that can be completed before finishing the current one, but they are optional, and the task can be completed without doing them. The final one, `requires_mandatory_steps`, defines sub steps that are required in order to complete the parent step and, therefore, the task. Each sub step can have its own sub step too with the same conditions, so the activities that are designed when using this model can become very complex.

The difference between the first explained self-relationship and a combination of the other two is that it requires the user to complete one of the sub steps, whichever it is desired, while using the other relationships will make one of them mandatory in all cases, not giving the option to the user to choose which one of them. Therefore, this difference makes it necessary to have that additional relationship. An improvement could be made to this relationship, to allow the designer to require to complete more steps instead of just one while still allowing the user to choose the steps that will be completed, by adding an association class that has a minimum (integer) field that will reflect how many of those steps are necessary, with an additional restriction that the value of minimum must be lower than the length of the list (if it was equal, it would be better to use the list of required steps as all of them would be so).

### 4.2.3. A model of interactive spaces

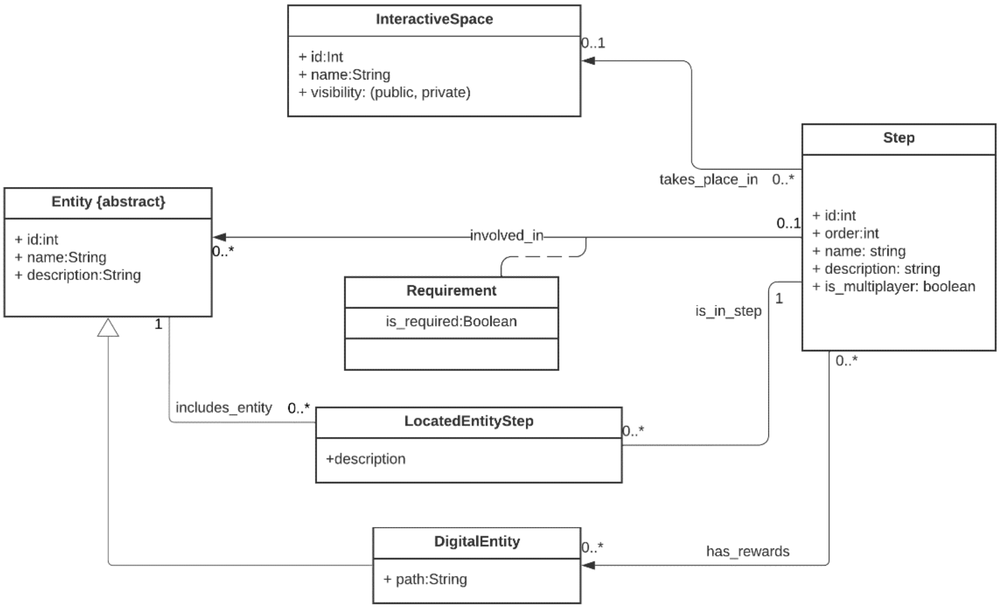



*Figure 37: the section of the model related to interactive spaces.*

Each step takes place in an interactive space (`InteractiveSpace`), which can be of many different types, as will be explained later. The same space can be reused for different steps, even in the same task or step (so two sub steps can use the same space). A step is also related to a digital entity (`DigitalEntity`), which represents the rewards obtained for completing the step. Also, there is a relationship to `Entity`, which is an abstract class that represent an element inside the application. As it happens with the spaces, there are different kinds of entities that will be introduced further down this chapter. This relationship has an association class, `Requirement`, which is used to represent that an entity is required to complete a step. For instance, if the step is opening a door that required a key obtained previously in the task (or in another task), the step will only be complete once the player (or one of the members of the team) has the required item. This is shown in Figure 37.

The relationship between `Step` and `LocatedEntityStep` is the most important of this part of the model. A `LocatedEntityStep` is the representation of an `Entity` in a step. It is the main interactive part of the step, as the entities are the elements with which the players can interact and play. There can be many entities placed in one step, and one entity can be used in multiple spaces, but each one will require its own `LocatedEntityStep` to represent it in the step.

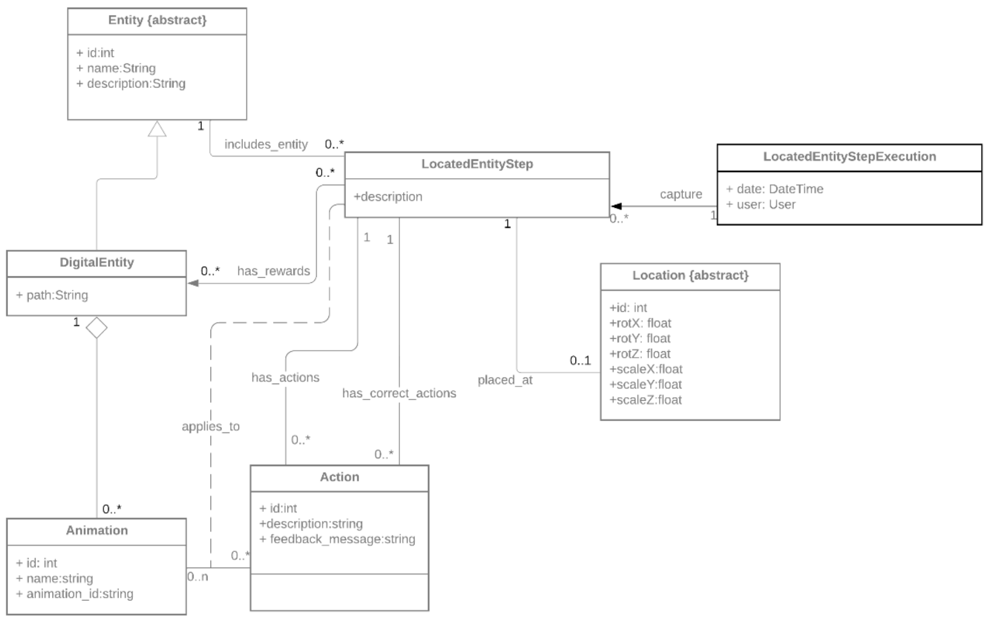



*Figure 38: section of the model showing the LocatedEntityStep key relationships.*

Each `LocatedEntityStep` inside a step is a representation of an `Entity` and has a set of possible actions (class `Action`) that can be performed on it. What each action does can be defined at implementation time, depending on what the intentions for each app developed following the model is aiming at. For instance, a "touch" action, a trivia form opening upon interaction, or a battle against a boss. There are two relations between `LocatedEntityStep` and `Action`: one for all the possible actions and another one for the correct or required ones. That way, some of the actions can be ineffective towards completing the step but still be present. Performing the correct actions to the entity can provide additional rewards to the player, through the relationship `has_rewards`. All of this can be seen in Figure 38.

Furthermore, when the `Entity` that is represented is of type `DigitalEntity`, it has the possibility of having animations to be played when the actions are performed, triggering them, as can be seen through the relationships between `Animation`, `DigitalEntity`, `Action` and the association relationship between `Animation` and `Action` that connects it with the `LocatedEntityStep`.

Also, each `LocatedEntityStep` has an instance of the class `Location`, that specializes in different classes depending on the context in which the application is being used, as can be seen in Figure 39. It will have a default set of coordinates for rotation and scale, in order to render the object correctly if it is a digital entity.

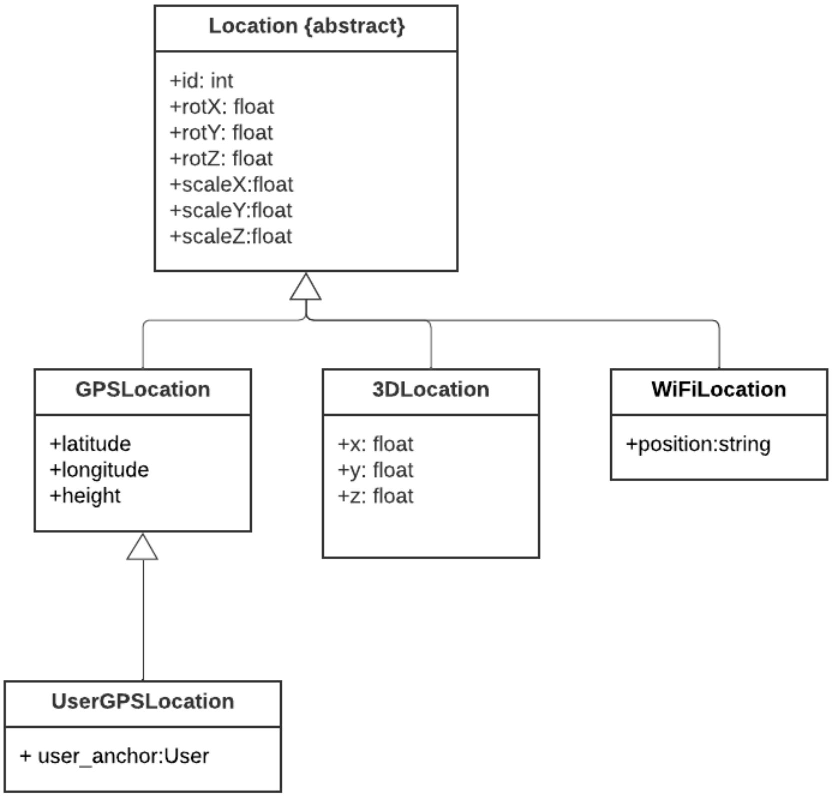



*Figure 39: the location part of the model.*

If the space is an augmented-reality, non-GPS based one (for instance, by using Google Cloud Anchors or similar technologies), the `3DLocation` class will be used, and the position will be stored based on a 3-axis coordinates with respect to the anchor point.

In the case of GPS being used, the class `GPSLocation` stores the latitude, longitude and height to know the position of the `DigitalEntity`. Finally, also positioning based on WiFi has also been considered (`WiFiLocation`), although it has not been implemented in any of the developments done with this model so far.

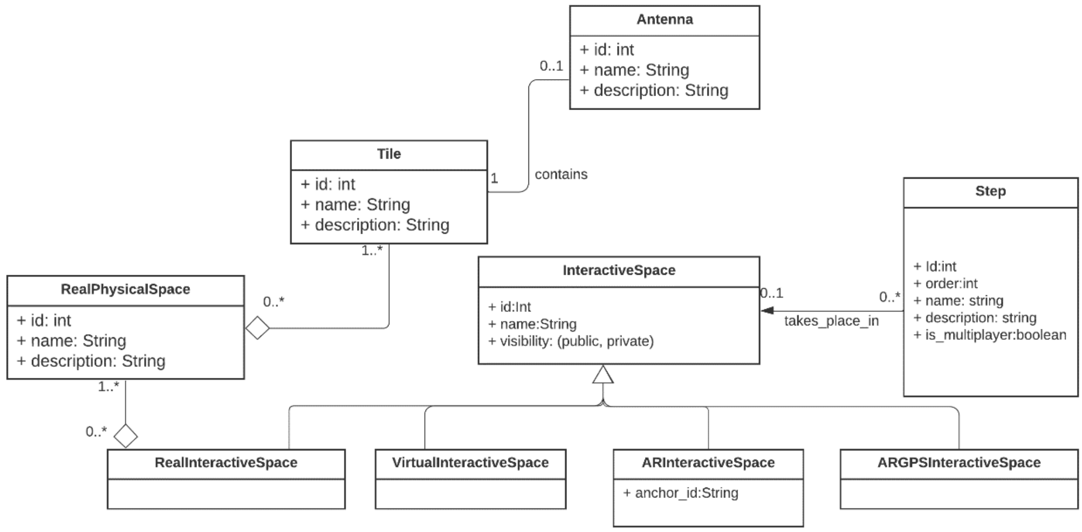



*Figure 40: the different kinds of Interactive Spaces.*

As has been said previously, each step or sub step takes place at an interactive space. This is represented in the class `InteractiveSpace`, which specializes into four different possible types of spaces (Figure 40):

- `ARGPSInteractiveSpace`: an augmented-reality space with GPS-based location.
- `ARInteractiveSpace`: an augmented-reality space based on anchoring.
- `VirtualInteractiveSpace`: a completely digital environment, which can be either a virtual reality environment or just an in-game scenario.
- `RealInteractiveSpace`: a real physical space which is not augmented through devices but has elements that make it interactable. It is connected to a definition of a physical space in which the activity takes place, based on `Tiles` with some connecting device (`Antenna`) to allow the interaction and communication with the digital system.

#### 4.2.3.1. Setting AR Spaces

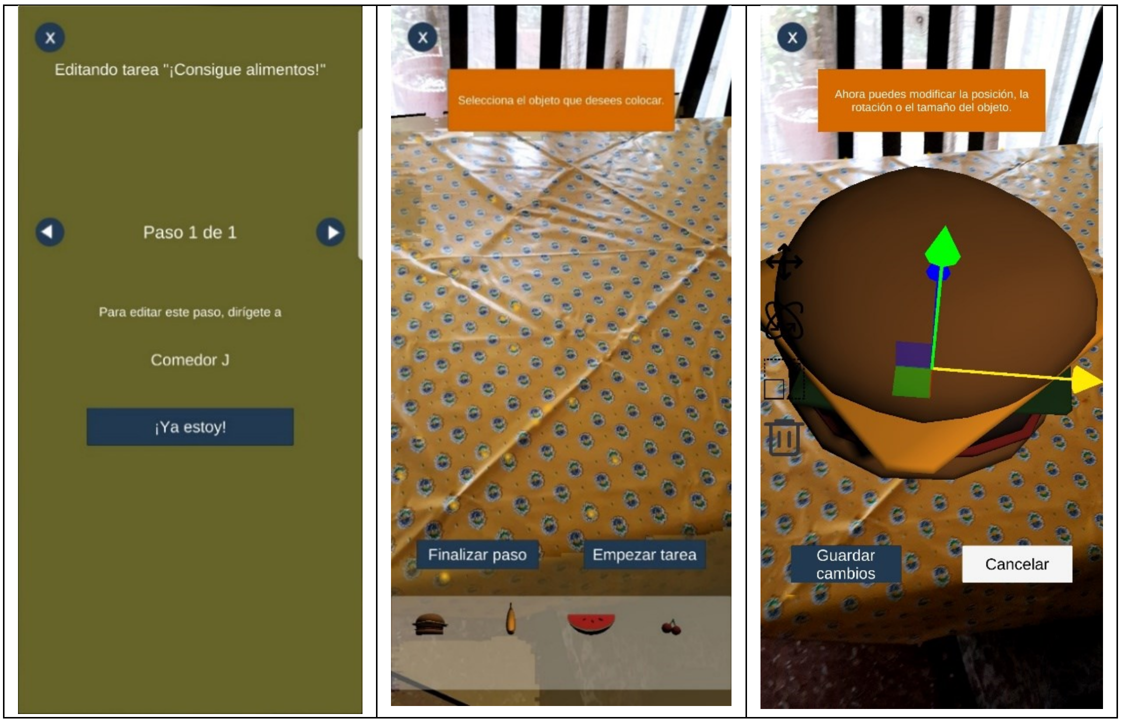
With this model of interactive spaces, it is possible to create an AR environment where the entities that will appear can be placed in that environment with total freedom. The use of the class `LocatedEntityStep` and its relations allows to set such elements with full integration in the context.

The use of the `Location` class, in any of its specializations, makes it possible to place the element in any size or rotation, in order to integrate it into the environment, trying to remove the possibility of having elements that look irreal in the context of the step or the activity. Also, with the specialized classes, the position can be adjusted, therefore having control over all three parameters: position, rotation and scale.

In order to achieve that, all implementations of the model so far have included a Task Editor which allows Administrators to place the elements for each step considering everything that has been mentioned in this section in a visual way, so they will know how the final users will see each entity in the step.

It is important to note that this only works for AR environments, as all implementations of the model so far have relied on the use of that technology to achieve their objectives. When the model is used for virtual environments with digital scenarios, a specific editor should be implemented based on the model.

As a sample of the editor that has been used in some of the implementations, Figure 41 shows some screenshots of it. The repositioning is done by placing the object by touching the spot where it is desired to be, and it can be adjusted by using the three arrows that represent the axis. Rotation can be done by interacting with the circles in the desired axis. Finally, scaling is done by doing a pinch gesture with an opening/closing action in order to increase or decrease the size of the digital element.



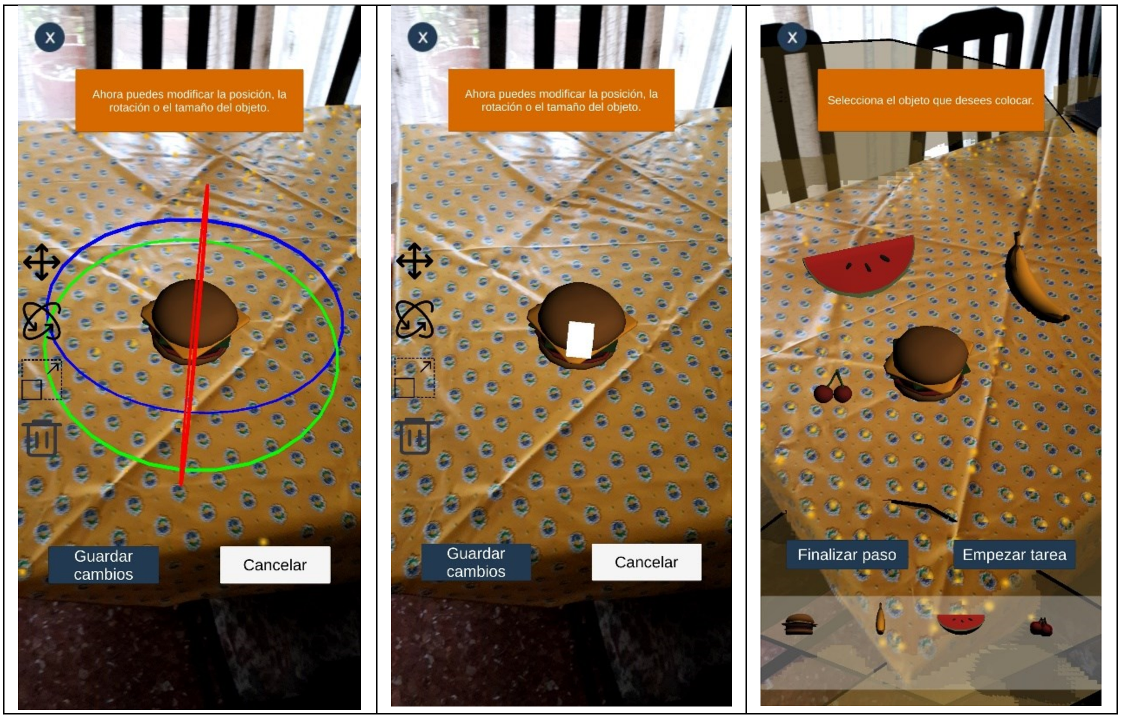



*Figure 41: the in-app AR space editor.*

### 4.2.4. A model of entities

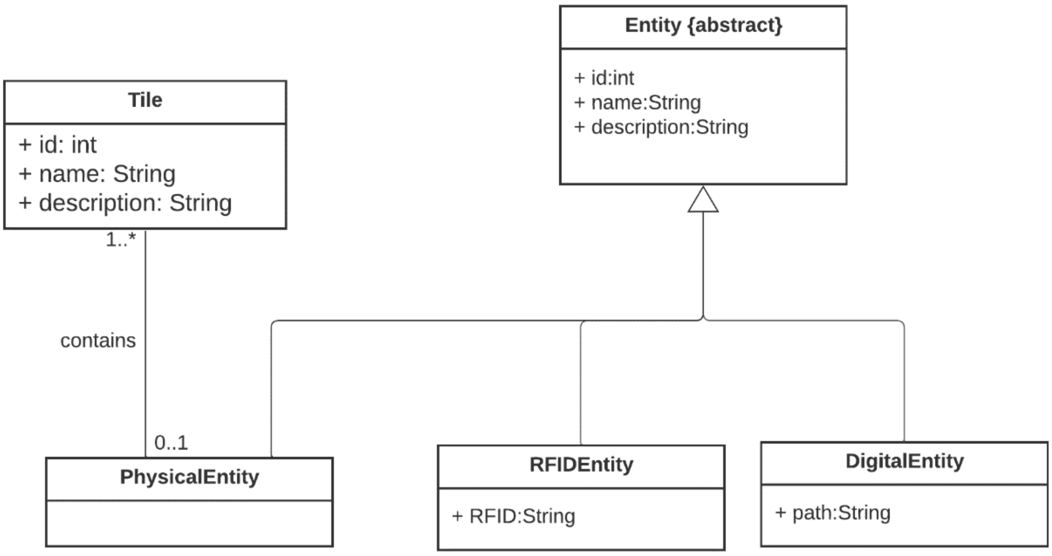



*Figure 42: the section of the model related to the entities.*

Finally, as can be seen in Figure 42, the entities can be of three different types: digital (`DigitalEntity`), which represents an object existing only in the system but not in the real world (and is what allows badging or trophies inside the application), RFID-based entities (`RFIDEntity`), which exist in the real world and are represented in the system through this class, or other kinds of physical world elements that are part of the activities but that do not have a way to connect to the system themselves and are therefore related to a `Tile` in order to provide that connection to the digital environment.

As has been described above, the proposed model offers a lot of flexibility when creating tasks and activities, which is something necessary in order to use it in different contexts, both inside the pediatric hospital and outside it. It allows different implementations and expansions to it through the actions and can be evolved to add new kind of interactions and technologies as required.

## 4.3. Practical applications of the proposed model

The model that has been described and presented in the previous sections has been implemented in different contexts to which it was suitable, as part of different research projects that were interested in testing and evaluating the model in specific areas of knowledge, making some adjustments to the proposal in order to suit their specific needs.

### 4.3.1. HCIHealth

HCIHealth was a research project participated by the Polytechnic University of València and the Instituto Tecnológico de Informática (from València too). The main goal was to provide technological support tools for pediatric patients with mental health issues that were to be used in combination with therapy provided by qualified psychologists, who were involved in the design process in order to define which kind of activities the tool would support and with which features, so that it was useful for the patients they were treating.

The application was defined as an Augmented Reality based one, as it could have a positive impact their performance in domestic tasks by enhancing their everyday spaces and gamifying the activities they would have to perform, as some studies in the literature suggest that gamification strategies can improve the children's performance while doing these tasks [67, 86].

Additional authoring tools would be provided to allow the parents and the therapists to set up the activities, by selecting the physical spaces in which the activity would take place and creating the different steps needed in order to complete the proposed task. This was done through a webpage in which they could also schedule the tasks for them to be available at specific times or to follow a regular pattern. Some screenshots of such webpage can be seen in Figure 43-Figure 46.

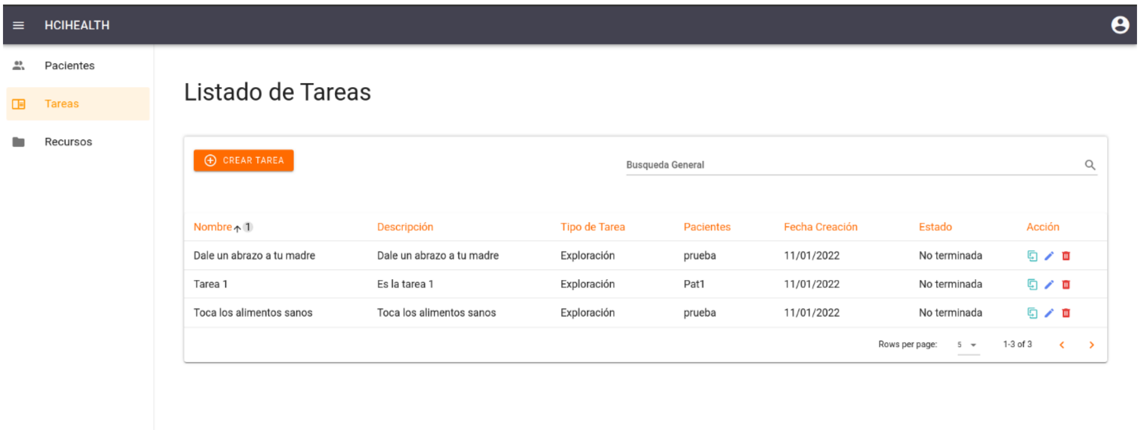



*Figure 43: list of the available tasks.*

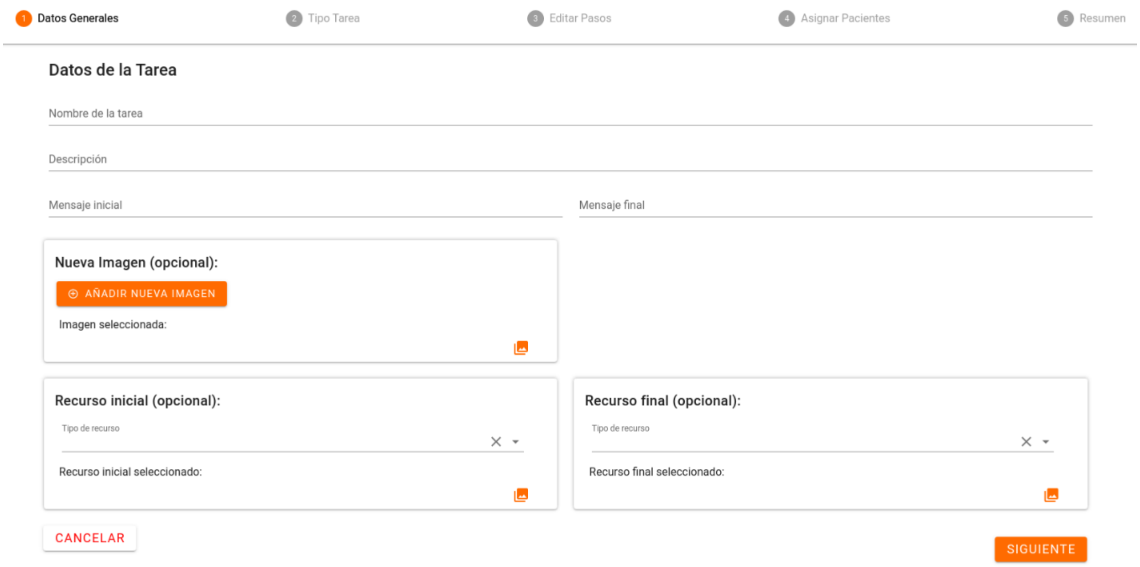



*Figure 44: initial task creation procedure*

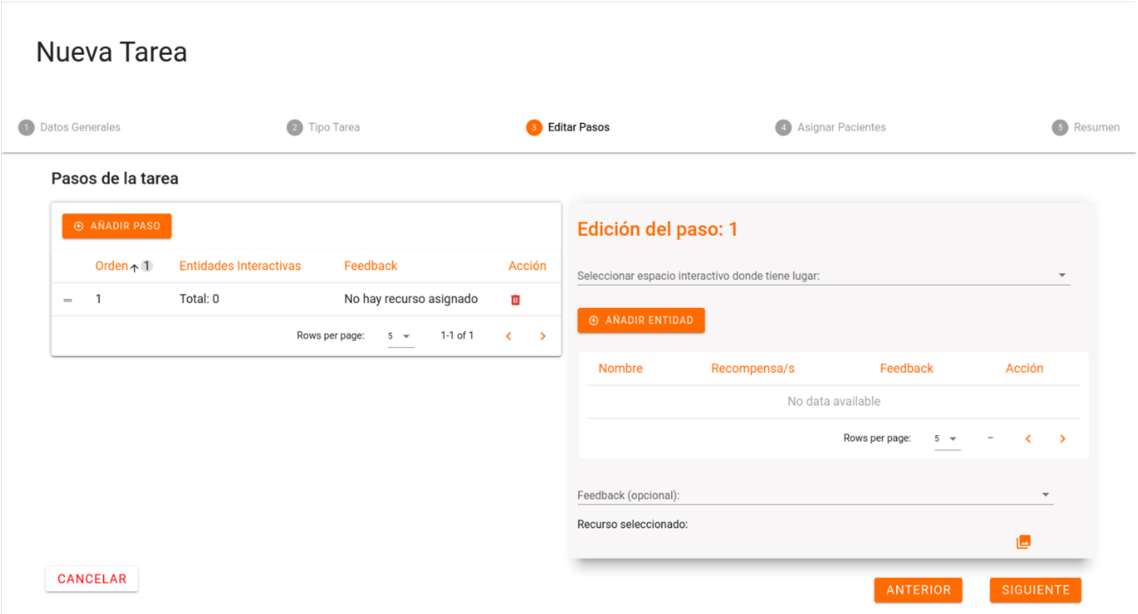



*Figure 45: step creation screen*

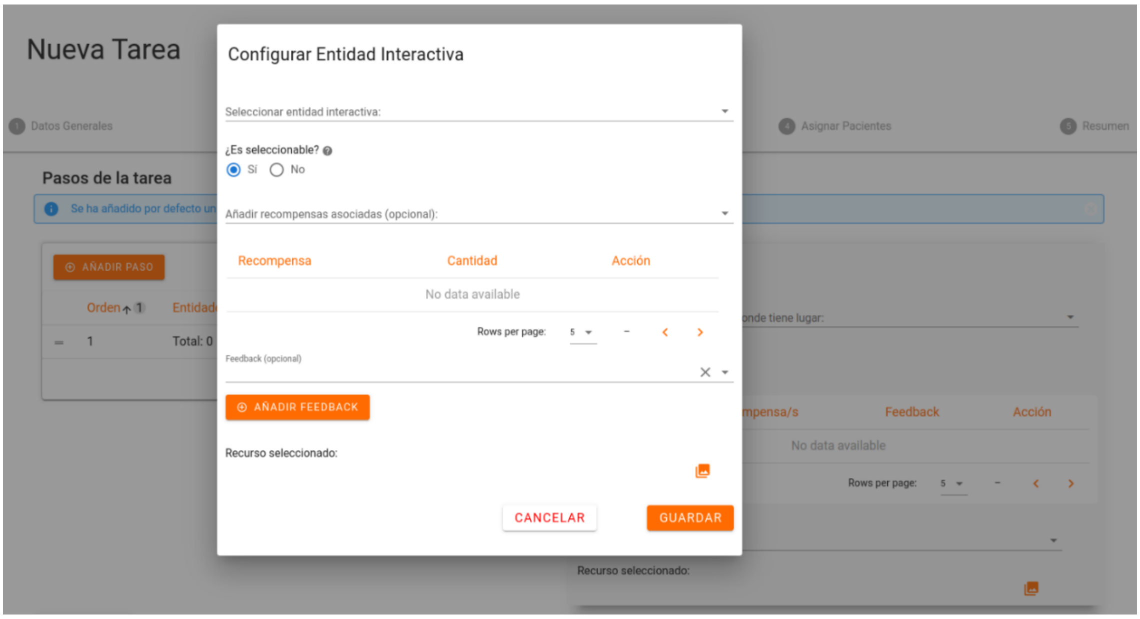



*Figure 46: interactive entity configuration screen.*

The final adjustments were done in the app, by using the editor shown in Figure 41 that allowed the parents of the patient to correctly set the object in the space (as many times it would be their home, their collaboration was required to perform this part of the setup) so that it did not feel so much unreal for the patient if, for instance, an object was flying around or being seen through a wall.

For this project, some additional changes were done to the model in order to fulfill the requirements and adapt it to its necessities. For instance, the class `Task` was specialized into two different types: exploration and exposure.

Exploration tasks were intended to be used as a therapeutic activity based on moving around and performing actions that would have a potential benefit for the patient, possibly to create habits for everyday tasks that the patients might be struggling with.

On the other hand, an exposure task was a planned (scheduled) task that would show a collection of virtual entities in the augmented space during a given time to produce a reaction in the participant. This can be useful for participants with specific phobias, as they would be exposed in a controlled manner to the entities that are appropriate for the therapy. This kind of treatment is used by therapists for some mental disorders, as [7] shows. Of course, this kind of tasks would be done under the control of the therapist to prevent undesired distress situations for the patients.

Also, and in order to provide motivation for the patients, a virtual pet was also introduced in the application. It allowed the player to feed it and play with it, although not in a very immersive way, as the player would simply press the piece of food to be given to the animal and an animation would be played (Figure 47).

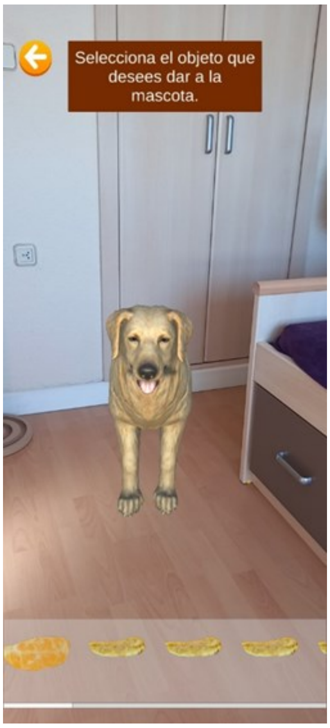



*Figure 47: the virtual pet.*

The evaluation of this implementation has not been completed yet, although some initial feedback from the participants was positive.

In Figure 48 it can be seen a simplified version of the model, with the changes required for the project.

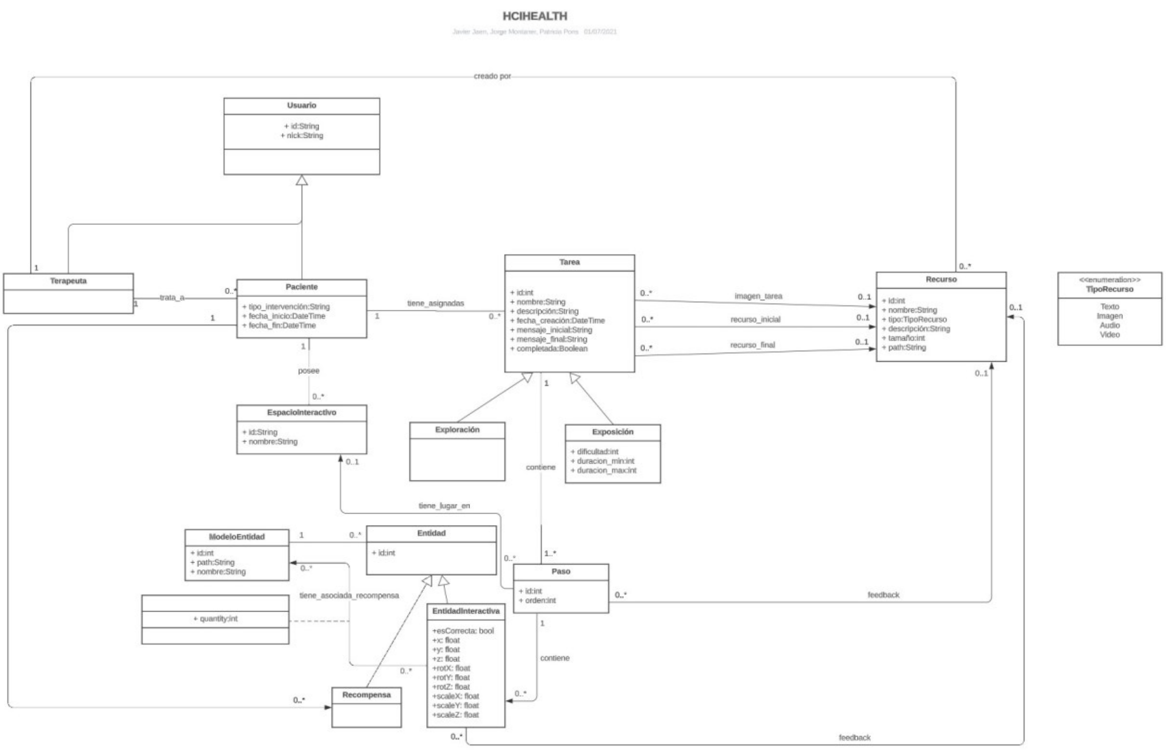



*Figure 48: HCIHealth model*

### 4.3.2. EmpathyAR

Another application that has used the model proposed in this thesis is EmpathyAR. In this case, the main goal was to evaluate the use of new technologies for new educational approaches when teaching empathetical skills and prosocial behavior for children and adolescents.

In this case, the full presented model was implemented in the application used for the evaluation. The system had an initial screen which allowed the users to log in or register a new account (Figure 49).

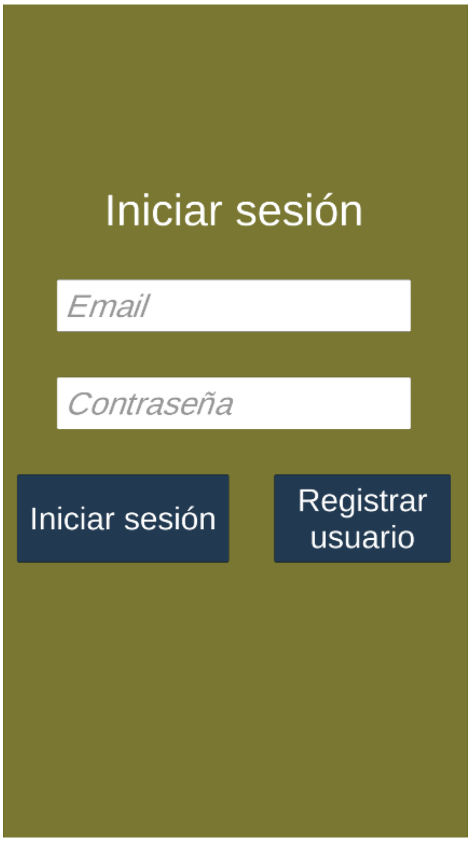



*Figure 49: login screen.*

When they logged in, they were presented with a list of available tasks, from which they could pick the one to play (Figure 50).


*Figure 50: application task list*

After the user selected the task, a new screen would show the total amount of steps that are required to complete the task and where to go in order to start with the first one (Figure 51).

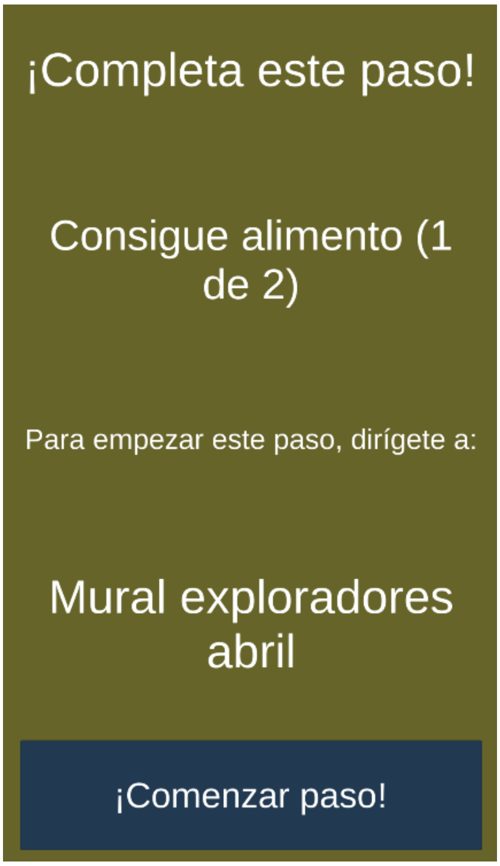



*Figure 51: initial step information.*

The full results of the evaluation in this area, as well as other screenshots of the application while performing the tasks can be seen in [110]. However, it can be said in this section that it has a statistically significant impact on two areas of the Interpersonal Reactivity Index (fantasy and empathic concern), and that the playing group achieved better results than the control group for the Prosocial Behavior questionnaire.

The main difference in terms of the application usage between this example and the one described in section 4.3.4 is that this one is single player only, whereas the other one was multiplayer, which was the cause for the problems described in that section. On the other hand, given that everything else was the same for both, the results achieved in terms of user experience and usability were positive, so even though the user interface is very simple, it is good enough for a research application.

### 4.3.3. 2GETHER

As part of the national project 2GETHER, the model will be used in order to implement cyber-physical social systems (CPSS) that will be used for patients with Autistic-Spectrum Disorders (ADS).

Cyber-physical systems are computational applications that aim to be embedded in the physical world, gathering information about the environment through sensors, and performing some actions in the physical world through actuators based on the information received through the sensors and the processing and calculations done with the data received, which will trigger that response delivered through the actuators. Some examples of use of these systems in the real world can be found on the railways or aviation.

When this methodological approach is applied to user-centered applications and contexts, they become CPSSs. These systems aim to put something as human as socialization in the computation processes of the systems, by talking into account interactions between individuals, the common environment in which a community of people live or their preferences, and providing an adequate response that maximizes the benefits for its users and their communities.

One of the goals of the project in the application domain of health is to research how the use of CPSS can help children with ASD, combining the concept of serious games with the CPSS approach, in order to prevent social isolation and lack of awareness of the environment (physical, social or temporal) when technological devices are used by them. This is because, in many cases, the approach with serious games for these children is focused on training them for some specific abilities instead of a broader, multi-context approach, something that could even increase the distance between the player's social environment and his/her perception and presence on it.

Besides, in the project it was felt that the use of other technologies such as virtual reality approaches could be expensive and difficult for the children and their families because, often, they require from specific devices that are not, at the moment, as widely used as simpler devices such as mobile phones.

Therefore, the model and the Augmented Reality approach could solve some of the problems that have been referred to before, as it integrates the technology into the real world of the patients by using a widely used device such as a mobile phone, that receives the information through its camera or GPS antenna (sensors) and offers an enhanced experience of the world through the screen that, being tactile, allows the interaction with the augmented environment.

No evaluation of this has been done yet, as the project has not finished and is still going on.

### 4.3.4. SocialAR

This application is also related to the 2GETHER project, but in this case, is oriented towards giving a solution to the Pediatric Isolation in the Hospital scenario that it also aims to do research in.

As has been said, pediatric hospitalization is a hard and difficult experience for the children who suffers it, and this is more evident for patients that require isolation as a consequence of their illnesses.

This was the main domain for this PhD work, and, while taking into account all other needs for the other scenarios, the model has been designed and iterated with the goal of providing the best fit for this scenario by combining different game strategies and technologies so that it can reach as many patients as possible and to provide them with technological systems that can help foster their socialization while being interned and also increase their wellbeing through those social interactions.

Whilst the model was also the main result of the PhD dissertation, some evaluations of it are planned, and an AR application that implements everything in the model (although as a research application and not a commercial one) has been designed and implemented.

Also, an initial evaluation of the application was planned for the months between February and May 2023, and some sessions were conducted. The activity planned for that evaluation included a task with three steps, in which the participants had to calm down a bear that had escaped into the hospital's classroom. In order to do that, they needed to retrieve some food that were stored in the corridor that led to the classroom. After that, they would move down the corridor and find help of a character that would give them a clue about what they needed to do when they found the bear. Finally, they would go into the classroom and would have to throw the food to the bear in order to calm it down so that its caretaker could take it back to its habitat. There were two kinds of participants: those with full mobility were the explorers that were moving around, and those with some restrictions or in isolation were the operators who had all the information of where the explorers had to go (they did not know, they had to seek that information from the operators). The participants would have had to fulfill a pre-session form with a pro-social behavior questionnaire and some control data, and a post-game one with the same questionnaire and also a user experience one.

However, there were significant difficulties during the evaluation sessions due to constraints imposed by the network of the hospital. Due to the game being designed as a real-time game, a Unity library was used in order to easily implement the networking required for the multiplayer feature.

The cybersecurity measures installed in the hospital's Wi-Fi network meant that the ports and IP addresses used by the library were blocked, making it impossible for the devices to communicate as designed (and as they were working outside the hospital). The researcher had to use alternative means to get connection in the devices and it was very poor, so network errors prevented the application from working correctly.

With all this considered, and with the process of requesting the opening of the ports being a lengthy one, the evaluation was halted with less than 15 different participants, that on their responses made many comments regarding the problems caused by the poor connection. Given the low number of unique participants, that many of them played in more than two sessions (and that it was always the same activity) and all the problems, no results were considered valid in that initial evaluation.

# 5. Discussion

The model proposed is the consequence of the results obtained in the different studies that have been described in this thesis. Based on them, the different design decisions have been made, or some necessities have been detected and are included as part of the model.

In the case of Tangibot, the results showed some impact of the teacher's presence in communication and coordination, but not in any other of the studied factors. The most important factor, and the one which had the most significant impact in the results obtained was the time since the beginning of the activity, with the highest differences between the measure before the beginning and the one mid-game.

The affection, physical activity and interest experienced the highest increase, and some other important values, such as nervousness or number of complaints (due to pain or feeling bad) remained at low values, which show that a physical activity like this one does not have a negative impact on the physical wellbeing of the participants. Besides, when playing alone the children had an interaction closer to being fully collaborative instead of hierarchical, and a significant increase in the interaction among peers both when playing alone or with the teacher.

On the other hand, the results between mid-game and end-game showed a decreasing tendency, being statistically significant for the interaction factor when the teacher was not playing with them, and also is visible in other factors even though it is not statistically significant. However, this does not apply to the level of physical activity, which remains more or less the same at both measures. Possibly, this is due to a too-long game session which led to the participants starting to be bored. This is related also to a possible lack of progress perception or knowledge of the goal, as there are a set of questions, but how many are left or what else they had to do was something the participants were not fully aware of. The difficulty of the questions could also have been a factor.

Considering absolute values instead of tendency, there seems to be a positive impact on the wellbeing of the participants, with participants showing some signs of having fun during the activity, with a lack of signs of pain, discomfort or nervousness, and with increased physical activity with respect to their normal routines in the hospital's classroom.

Regarding the interaction, there were differences between playing with or without the teacher: when playing with her, they asked more questions and asked for more information, which had a negative impact on time and technical coordination, but a positive one on information pooling as they look for the adult's confirmation about their actions.

All of this show very interesting information that could be used to design the physical part of the model. The technical details of how the environment worked (RFID tags, tiles, and interaction techniques) were included in the model so that this kind of physical, co-located activities could be played in the digital environment that the model provides. But also, the results regarding the decreasing tendency in many of the studied factors between the mid-game and end-game measurements showed that just asking questions with no sense of progress (this is not the same as lack of feedback) or a clear goal being provided was something that required a different approach, and a further step into that was done on the activity PicToMe.

In PicToMe, the same measurements were used with respect to the activity, but this time, due to the nature of the activity, the measurements for coordination and those relative to the presence of the teacher were removed, as well as physical activity evaluation.

The results show similar values for affection with respect to Tangibot for the mid-game measurement, but better results for end-game. The results for complaints were slightly worse but still close to no-complaints. This difference can be probably explained by the fact that the participants had conditions more severe than those who participated in Tangibot. In Tangibot it was children attending the hospital's classroom, whereas in PicToMe children with a wider range of diseases or health problems were part of the study, which mostly took place in their bedrooms.

For the interest, the results are also very similar mid-game, but better at the end-game in PicToMe, and the same can be seen for interaction results. In the case of nervousness or satisfaction, the results are very similar between both games.

As can be seen in the results of that second activity, the decreasing tendency for many of the factors between the second and third measurement disappears or is significantly reduced. A different approach was followed by showing a timer to both participants with the remaining time in each round, and they were told beforehand for how long the activity would run, so they could be aware of how each round progressed and how much it was left. This seemed to work, together with a shorter play time, which was something to consider when doing the design of the model. In this case, instead of using time, the progress was decided to be based on the number of steps, with the user knowing how many steps have been completed and how many there are left. A time limit was not considered because, in some PicToMe evaluations, the need for medical interventions or visits meant that the game had to be cancelled and played at another time from the beginning. Given the context, it was decided not to put time limits on the tasks so that they could be performed at the player's own pace and necessities. This could be a possible point for improvement, especially for use in other contexts other than the hospital's one.

However, even though many of the evaluation aspects were good, the socialization aspect of the game PicToMe was too low. Probably, this is due to the way it was evaluated: it was designed to measure the number of spontaneous or game-facilitated expressions of self-interests or questions about the interests of the other which were not a direct consequence of the actions required in the game. For instance, if one player had to draw the crest of their football team, what the researchers had expected was for the other player to say something like “this is also my favorite team!” or “my favorite team is this other one!”, which did not happen as often as was expected. Among the factors observed that could have caused this, the presence of the evaluators and maybe the parents while the game was taking place was one of them, as they were two strangers in their bedrooms taking notes while they were playing, something that can be considered invasive. Also, the personality and the context of each player did also have an impact. As pairings were random based on the availability of patients, differences of character were not taken into account. Finally, it was an observation of the evaluators that, in the hospital context, many children were quite shy not only during the activities, but even when they were offered the chance to participate, having the offer been turned down many times both for PicToMe and Tangibot, as well as for attending the hospital’s classroom activities that were unrelated to these studies. A possible solution to this kind of problems would be to use a different approach for groups/pairs formations, as proposed in [159], but always considering the special requirements and situations that arise in the hospital context.

With all the information obtained from these previous experiments, there were some considerations that had to be made when building the model. As has been said before, the requirements for activities similar to Tangibot had to be included, but that was only the technical part. It was observed that the results for physical activities in Tangibot had been good, and therefore it was decided to allow other forms of physical activities that required a lower grade of preparation and supervision. This is the reason for which Augmented Reality options were introduced in the model, as they allow for the participants to move around the hospital in a controlled way (given that the spaces are set in locations where the participants are allowed to go), but also could be useful in other contexts, as can be seen in the use of the model for the project HCIHEALTH or the positive results obtained in EmpathyAR.

The use of AR technologies, however, might exclude some of the patients which are in isolation or have a restricted mobility. Therefore, a new role, “Operator”, was introduced to allow this kind of patient to participate in a team activity with a physical component but only for the other participants, whilst at the same time offering socialization opportunities through coordination and collaboration, in a similar way as the participants had to coordinate in Tangibot. In the implementation that was done for SocialAR, only the operator had the information about the actions to be performed in each step and the location where it would take place and had to communicate this to the other participants.

On the other hand, PicToMe also showed that the participants could have fun with activities that did not imply movement, therefore the model was not restricted to AR or activities that required physical movement only. The introduction of virtual spaces allows that, with those spaces being digital environments such as scenarios inside the game engine, maybe with a character or an avatar that the player can move while playing in a collaborative game with other patients. It is to be noted that this has not been implemented in any of the projects that make use of the model yet, but no changes are expected to be required in the model when it is implemented, as the model accounts for the possible differences between virtual, physical and augmented spaces.

Another thing that had to be taken into account is the way to identify the augmented spaces depending on the characteristics. An indoor space requires a different method than an outdoors one. This can be due to poor GPS signal reception indoors, or also precision issues when two different spaces are very close to each other. Therefore, this approach works well for outdoors, but indoors it was decided to go with a relatively new technology as is Cloud Anchors. This technology, which uses the device's camera to get a set of feature points of the environment, allows the space to be identified by just using the image of the space, and allows close spaces to be differentiated from each other. However, this technology has a limitation that has to be taken into account when using it: as it is based on a scan of the space, any changes that happen to that space (a new piece of furniture is added, somethings are moved around, etc.) will mean that the space might not be recognized afterwards. This is something that actually happened when doing the initial evaluations for SocialAR: one of the spaces was a mural in which the children attached drawings of themselves depicted as explorers. As some were added and some removed, in the initial days, before the evaluator knew that the mural was actually changing and was not a fixed picture, the space was not recognized during some of the activities. Therefore, this is something to take into account when using this technology over GPS in order to avoid problems when setting and playing tasks and steps.

Another significant point for discussion is how the implementations of the model can be used. Based on the previous experiments, it was detected that more flexibility would be welcome as part of the model with respect to that available in Tangibot and PicToMe: when doing the evaluation for those activities, it depended on the availability of the researchers, but also, and more critically, on the presence of participants at the time which were not undergoing procedures, being visited by the doctors, or feeling unwell to participate. This led to a quite low number of results with respect to the number of attempts carried to complete activity sessions and days spent in the hospital by the researchers.

Therefore, the model was designed with the idea of not requiring the presence of the researchers or teachers at play time, only in order to set up the tasks, that could be then played at any time by the participants with the supervision of their parents. This is the reason behind the structure of teams and their connection to the tasks and the execution of them. With the obtained model, a task could be set by the teacher in the morning and the participants could agree to play it in the afternoon, when they usually have more free time as they do not have to attend school or receive the visit of the doctors. However, this requires the design and introduction of specific metrics to measure the impact of the tool when used as part of a research project, and that is the reason for which the initial evaluations of SocialAR were not done in this way, but in a similar way to the assessment of Tangibot and PicToMe, as there was no time left to design such metrics and obtain validation for them.

With all this in mind, it can be seen that the model is based on evidence obtained through previous research and experience, and that the work that has been done during the PhD program has allowed the design and implementation of the model in different contexts.

# 6. Conclusions and future work

As a result of the research work done in the context of the PhD studies, a proposal of a model based on gamification strategies and to be used in the context of pediatric hospitalization (among others) has been made. This model provides a design approach to implement applications with multiplayer capabilities in order to foster collaboration and socialization among the participants.

All four objectives that were proposed at the beginning of this documents have been achieved. Through the questionnaires that were given to users and professionals when doing the different activities (specially Tangibot and PicToMe), the analysis of the requirements was conducted and the results incorporated into the proposed model, considering the different approaches to socialization and technologies that were used in both studies. The proposed model, that has taken into consideration objectives 1, 2 and 4, completes the third objective.

The results obtained for both Tangibot and PicToMe show that there is a demand for social activities inside the hospital for pediatric patients (as was already detected in other studies referenced in the state-of-the-art chapter, such as [97]), and also that this kind of activities and games can have a positive impact in the short term in their wellbeing and hospital experience. Therefore, it is a research area in which it is worth doing more work and improving the results for a group of people who are going through very difficult times and experiences. These results also allow to confirm the main hypothesis of the PhD dissertation, as it is shown that there is an impact on the social wellbeing of the patients.

The obtained model is, therefore, a further step into that direction, which aims to expand the opportunities for new kind of activities that might combine different kinds of interactions while providing a firm ground where they can stand. Also, as it has been seen, the result is also adaptable to other contexts and objectives, and different gamification strategies can be applied for each environment with the use of the same model with small changes, making it an interesting framework to use and explore.

However, the reduced number of evaluations of its different implementations make it a necessity to design more studies with participants in order to further improve or refine both the implementations and the model if it was necessary.

With this in mind, the obvious initial future work includes the design and performance of those studies, by solving initially the implementation issues caused by the environment, and by having evaluation techniques that are adapted to the context and do not create constraints in the form of time or availability of participants while, at the same time, using measurement techniques that are validated in the literature that can provide a clear insight of the benefits and disadvantages of both the model and/or its implementations.

Other future works might include the use of the model in even more different contexts or with different goals in which participants could obtain a benefit by using it, such as its use in the educational contexts or in other areas of mental health. Also, an expansion to other age groups instead of only children could be evaluated as well, such as for the elderly, which could use gamified approaches to keep their minds sharp for daily activities.

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# Appendix A

| Work | Year | Age ranges | Procedures and pathologies | Number of users | Purpose | Output device | Input mechanism | Object of study | Outcome |
|---|---|---|---|---|---|---|---|---|---|
| [47] | 2001 | n/a | Pathologies: Traumatology (neck) | Individual | Motivation | Monitor | Controller | Increased self-confidence | The activity decreased the demand for individual interventions and provided opportunities for improving self-confidence. |
| [131] | 2002 | n/a | n/a | Collaborative (online) | Education, socialization | Monitor | Controller | System description and discussion about technology | The use of online collaborative games in e-learning in hospital can enable socialization, which would prevent the loss of humanization that would occur if teachers were replaced by technological devices. |
| [12] | 2002 | 8-19 | Pathologies: Other severe illness | Collaborative (online) | Education, socialization | Monitor | Controller | Reduced pain and loneliness, improved mood, and increased enjoyment | Children reported significantly less loneliness and were significantly more willing to return to the hospital for treatment. They were also marginally less worried and |

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| | | | | | | | | | experienced significantly less withdrawn behavior. |
| [15] | 2003 | n/a | Pathologies: Chronic (renal disease). Procedure: Venipuncture | Collaborative (online) | Socialization | Monitor | Controller | Feasibility | Results support the premise that computational environments may offer an opportunity for patients to participate in virtual communities that promote coping with chronic physical illnesses. |
| [33] | 2005 | 5-18 | Pathologies: Traumatology (burn) | Individual | Distraction | HMD | Controller | Reduced pain | Strong evidence supporting VR-based games in providing analgesia with minimal side effects and little impact on the physical hospital environment. |
| [144] | 2006 | 4-12 | Procedure: Anesthesia | Individual | Distraction | Handheld | n/a | Reduced anxiety | Patients demonstrated a decrease in anxiety in the preoperative area in the video game group compared to control group. |
| [58] | 2006 | 8-12 | Procedure: Venipuncture | Individual | Distraction | HMD | Controller | Reduced pain | Results show a decrease in affective pain for children in the VR group compared to children in the control group. |

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| [35] | 2007 | 3-9 | Procedure: Anesthesia | Individual | Distraction | Handheld | Controller | Feasibility | Most of the children evaluated were able to tolerate the PediSedate device and achieved an adequate degree of sedation. |
| [177] | 2007 | 5-18 | Pathologies: Chronic (cancer). Procedure: Venipuncture | Individual | Distraction | HMD, handheld | Controller | Reduced pain and distress | Fear and distress were reduced, but not pain. |
| [147] | 2008 | 5-18 | Pathologies: Neurological (general) | Individual | Motivation | Monitor | Gesture | Increased enjoyment | All participating patients accepted the system and trained in reaching and grasping tasks at a far higher rate than in conventional occupational therapy. |
| [13] | 2008 | 7-10 | Pathologies: Behavioral | Collaborative (co-located) | Motivation | Monitor | Gesture | Increased enjoyment | Analysis shows that patients were strongly motivated and that their behaviors and verbal expressions had rich psychodynamic content. |
| [148] | 2009 | n/a | Pathologies: Neurological (cerebral palsy) | Individual | Motivation | HMD | Tangible | Improved motor functions | Participants showed improvements in overall performance on the functional aspects, in upper extremity active range of motion, |

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| | | | | | | | | | and in kinematic measures of reaching movements. |
| [14] | 2009 | 11-15 | Procedure: Transplant | Collaborative (online) | Socialization | Monitor | Controller | Improved socialization | Results support the idea that innovative technologies can help adolescent patients to create a support network of peers when face-to-face interactions are impossible. |
| [139] | 2009 | 5-18 | Pathologies: Chronic (cancer). Procedure: Venipuncture | Individual | Distraction | Monitor | Gesture | Increased enjoyment, reduced pain and distress | Results failed to confirm a reduction of pain or distress but did show that non-immersive VR is a positive experience for children undergoing a minor procedure. |
| [102] | 2010 | 7-12 | Pathologies: Traumatology (general physical disability) | Individual | Motivation | Monitor | Gesture | Improved motor functions | The specific game being played had an impact on the quantity and quality of movements. Quantity of movement was significantly higher in experienced players, but there were no differences in movement quality between novice and experienced ones. Also, motivation |

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| | | | | | | | | | did not have an effect on movement characteristics. |
| [123] | 2010 | 3-10 | Pathologies: Traumatology (burn) | Individual | Education, distraction | Handheld | Touch | Reduced pain | Results show that multi-modal distraction offers superior pain reduction when compared to standard practices or handheld video games. |
| [99] | 2010 | 6-15 | Procedure: Cold pressor task | Individual | Distraction | HMD | Voice | Reduced pain | Children demonstrated significant improvement in pain tolerance during distraction relative to baseline. |
| [3] | 2010 | n/a | n/a | Collaborative (co-located) | Distraction, socialization | Monitor | Tangible | System description | Zootopia is an RFID-based tangible game to see animals in live streaming videos through collaborative play. |
| [92] | 2010 | 4-6 | n/a | Individual | Emotion coping | Monitor | Controller | System description | CPgame is a game to help children cope with their emotional reactions to medical treatments as well as to self-report their emotional status. |

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| [18] | 2010 | 4-18 | Pathologies: Traumatology (general physical disability), neurological (general) | Individual | Motivation | Monitor | Controller | Improved motor functions | The VR scenario induces an immediate effect on motor output to a similar degree as the effect resulting from verbal instructions by therapists. |
| [112] | 2011 | 3-5 | n/a | Individual | Education, distraction | Handheld | Tangible | Increased enjoyment and emotional expressions | Field observation found that children enjoyed naming and decorating the device, and they formed emotional bonds with it. Post-test interviews revealed that all the children felt emotionally attached to the device and expressed their desire to carry it with them next time. |
| [166] | 2011 | 12 | Pathologies: Chronic (general) | Individual | Education | Handheld | Touch | System description | $C^3$ is a game to provide disease-specific educational content to each patient in their own environment. |
| [26] | 2011 | n/a | Pathologies: Neurological (cerebral palsy) | Individual | Motivation | Monitor | Controller | System description | Description of a game for the rehabilitation of the pronation and supination movements. |

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| [50] | 2011 | n/a | Pathologies: Chronic (cancer) | Collaborative (online) | Distraction, socialization | Monitor | Controller | Increased enjoyment | Results suggest that referring to the pathology implicitly yields higher enjoyment than a game that refers to it explicitly. |
| [113] | 2011 | n/a | n/a | Individual | Motivation | Other | Touch | Help to therapists | Results suggest that the platform provides therapists an easy-to-use and flexible way of creating new activities for different patients. |
| [180] | 2011 | n/a | Pathologies: Traumatology (general physical disability) | Individual, collaborative (co-located) | Motivation | Other | Touch | System description | Presentation of a virtual reality game that uses a hybrid human motion tracking system for gait and dynamic balance, which is able to both track the lower limbs of the user and identify them. |
| [56] | 2011 | 7-19 | Pathologies: Chronic (cancer) | Individual | Education | Monitor | Controller | Increased enjoyment | Results suggest that participants generally enjoyed playing the game. |
| [105] | 2011 | 8-16 | Pathologies: Chronic (cancer) | Collaborative (co-located) | Motivation | Other | Gesture | Reduced depressive symptoms and anxiety | Results show that children in the experimental group reported statistically significant fewer depressive symptoms than children in the control group. However, there |

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| | | | | | | | | | were no differences in children's anxiety scores. |
| [111] | 2011 | 3-7 | n/a | Individual | Distraction | Robot | Tangible | System description | MediRobbi is a robot companion that aims to transform an intimidating medical situation into a joyful adventure game by accompanying the patient through their procedures. |
| [9] | 2011 | 4-14 | Pathologies: Ophthalmology | Individual | Motivation | Monitor | Controller | Feasibility | It is possible to develop a game-based system to measure fields in children in a noninvasive, affordable, and entertaining way. |
| [2] | 2011 | 5-10 | n/a | Collaborative (co-located) | Distraction, socialization | Monitor | Tangible | Increased enjoyment and improved socialization | Feasible way of encouraging children to communicate with others more while having fun in a hospital setting. |
| [123] | 2011 | 3-10 | Pathologies: Traumatology (burn) | Individual | Distraction | Handheld | Touch | Reduced pain and distress | A combined multi-modal distraction protocol reduced pain and distress experiences for young children during burn care procedures with respect to standard distraction |

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| [74] | 2012 | n/a | Pathologies: Neurological (cerebral palsy) | Individual | Motivation | Monitor | Gesture | No more energy expenditure, increased enjoyment, and improved motor functions | Moderate levels of activity achieved in half the games evaluated. Muscle activations did not exceed maximum voluntary exertions. Angular velocities and accelerations were significantly larger in the dominant arm than in the hemiplegic arm. A high level of enjoyment was reported. |
| [91] | 2012 | 11-17 | Pathologies: Traumatology (burn) | Individual | Distraction | HMD | Controller | Reduced pain | Statistically significant reduction in pain scores during dressing removal, and significantly less rescue doses of Entonox given. |
| [44] | 2012 | n/a | Pathologies: Chronic (general) | Collaborative (online) | Motivation, socialization | Monitor | Gesture | System description | The work explores the idea of improving communication between medical practitioners and patients using avatars in games to guide and encourage patients to comply with treatments, provide support, and |

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| | | | | | | | | | elicit information about their wellbeing. |
| [124] | 2012 | 4-10 | Procedure: Venipuncture | Individual | Distraction | Monitor | Gesture | Reduced pain | Active distraction did not reduce perceived pain more than an EMLA-cream analgesic during iv cannulation and venipuncture. |
| [19] | 2013 | 4-12 | Pathologies: Chronic (cancer) | Individual, collaborative (co-located), competitive (co-located) | Motivation | Monitor | Gesture | System description | Presentation of a game to enhance patients' resilience via mechanisms that stimulate coupling between the brain reward systems and physical actions. |
| [55] | 2013 | n/a | Pathologies: Neurological (cerebral palsy) | Individual | Motivation | Handheld | Touch | Help to therapists | The study demonstrates the ability to eliminate factors like distraction from the assessment of patients' motor abilities and progress over time. |
| [71] | 2013 | 1-3 | n/a | Collaborative (co-located) | Education | Handheld | Touch | System description and discussion about best practices | A discussion with experts yields several design guidelines around four categories: preparation of the child, motivation, distraction, and rewarding. |

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| [149] | 2013 | n/a | Pathologies: Neurological (cerebral palsy) | Individual | Motivation | Monitor | Gesture, voice | System description | Presentation of a multimedia game that can capture kinematic data from live gestures of a child and generate live analytical results. |
| [96] | 2013 | 5-18 | Pathologies: Neurological (general) | Individual | Motivation | Monitor | Controller | Improved motor functions | Children with neurological gait disorders were able to modify their activity to the demands of the VR-scenario, but cognitive function and motor impairment determined to which extent. |
| [76] | 2013 | n/a | n/a | Individual, collaborative (co-located) | Distraction | Monitor | Gesture | System discussion | The work proposes a set of themes for games that aim to reframe bodily perception to a more positive self-image full of creative potential. |
| [62] | 2013 | n/a | n/a | Individual | Distraction | Monitor | Tangible | Increased enjoyment | Positive reactions. |
| [81] | 2013 | n/a | Pathologies: Neurological (cerebral palsy) | Individual | Motivation | Monitor | Gesture | Increased enjoyment and improved motor functions | Most children preferred the game, and balance was significantly improved. However, results did not carry over to functional tasks, hence the need for further research. |

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| [1] | 2013 | 3-18 | Pathologies: Other severe illness | Individual | Motivation | Monitor | Gesture | Feasibility | VR exercise may be safely applied in a subset of critically ill children, but several threats to its feasibility in this population were observed. |
| [90] | 2014 | 8-18 | Pathologies: Chronic (cancer) | Individual | Socialization | Monitor | Controller | System description | Participatory design of a game to foster communication. |
| [150] | 2014 | n/a | Pathologies: Traumatology (general physical disability) | Individual | Motivation | Monitor | Gesture | System description | Presentation of a web-based 3D game that uses non-invasive methods to recognize body movements. |
| [141] | 2014 | n/a | Pathologies: Pulmonary | Individual | Motivation | Monitor | Gesture | No more energy expenditure | One game resulted in light intensity activity and another in moderate intensity activity. No significant difference was seen between patients and healthy control group in the energy cost of playing. |
| [60] | 2014 | 9-16 | n/a | Collaborative (online) | Socialization | Monitor | Controller | Improved socialization and increased emotional expressions | The game was reported to have high playability values, and high amount of interactions and positive emotions were observed during gameplay. |

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| [72] | 2014 | 12 | n/a | Collaborative (co-located) | Distraction | Monitor | Controller | Improved socialization and increased emotional expressions | Analysis shows how multiple human and non-human bodies become entangled in game place events and potentially generate affective atmospheres. |
| [116] | 2014 | 5-18 | Pathologies: Traumatology (general physical disability), neurological (general) | Individual | Motivation | Monitor | Controller | System description | Presentation of a project that connects rehabilitation games to various therapy devices for upper and lower extremities. |
| [25] | 2014 | 8 | Pathologies: Chronic (general) | Collaborative (online) | Education, socialization | Monitor | Controller | Improved socialization | Results support that multi-modal digital game-based learning provides social interactive processes and learning motivation. |
| [157] | 2014 | 10-14 | Pathologies: Chronic (cancer) | Individual | Motivation | Monitor | Controller | Improved psychological functions | Results show that 3D Graphical Imagery Therapy game is effective in recovering from psychological illness related to brain tumor. |
| [11] | 2014 | 8-16 | Pathologies: Chronic (cancer) | Collaborative (online) | Education | Handheld | Touch | Increased enjoyment | Observations of participants being very receptive, even young ones |

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| | | | | | | | | | who sometimes were not aware of the complexity of the games' challenges. |
| [121] | 2015 | 6-10 | Pathologies: Neurological (cerebral palsy) | Individual | Motivation | Monitor | Controller | Improved motor functions | Results demonstrate a statistically significant improvement in the performance metrics assessing explicit and implicit motor learning. |
| [28] | 2015 | n/a | n/a | Individual, collaborative (co-located) | Motivation, socialization | Robot | Gesture | System discussion | Discussion about the use of spatial augmented reality techniques on mobile robots for better enabling interactions with children. |
| [107] | 2015 | n/a | Pathologies: Neurological (cerebral palsy) | Individual | Motivation | Monitor | Controller | Improved motor functions | Increase in forearm supination/pronation movement precision and smoothness was observed, as well as a reduction in the movement duration. |
| [176] | 2015 | 4-8 | n/a | Individual | Education | Handheld | Touch | System description | Presentation of an educational game to help children prepare for medical procedures. |

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| [143] | 2015 | 5-18 | Pathologies: Traumatology (burn) | Individual | Motivation | Monitor | Gesture | Improved motor functions, reduced pain, and increased enjoyment | Results show that interactive videogames are equally effective as traditional therapy for overall range of motion gains and result in quicker recovery of motion with less pain experienced. No differences were found in compliance and enjoyment. |
| [106] | 2015 | 6-12 | Pathologies: Chronic (cancer) | Individual | Distraction | Monitor | Controller | Increased enjoyment and improved socialization | The activities, which range from watching television, to using computers, games, and toys, to drawing, to a clown, provide fun, feelings of joy, distractions, and interactions with other people. |
| [45] | 2015 | 8-12 | Procedure: Minor surgery | Individual | Education | Handheld | Touch | Reduced children's and parents' anxiety | Children who received the educational multimedia intervention reported lower level of worries about hospitalization, medical procedures, illness, and negative consequences than those in the control (no intervention) and in the comparison (entertainment video game intervention) groups. Parents experienced less anxiety when the |

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| | | | | | | | | | educational and entertainment interventions were applied. |
| [170] | 2015 | 4-18 | n/a | Collaborative (online) | Motivation | Handheld | Touch | Reduced pain, increased enjoyment, and increased amount of Oral Rehydration Therapy (ORT) consumed | Results show improvement in pain control and patient satisfaction, but no effect on ORT. |
| [79] | 2016 | n/a | Pathologies: Pulmonary | Individual | Distraction | HMD | Controller | Increased enjoyment | Users were very immersed in their environments. Seemed to gravitate towards goal-oriented experiences. They were enthralled and were able to use the device without feeling uncomfortable. |
| [64] | 2016 | 6-12 | Procedure: Venipuncture | Individual | Distraction | HMD | Gaze | System description | User-centered design of a virtual reality game to offer distraction from pain and anxiety that may arise during medical procedures. |

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| [117] | 2016 | 7-18 | Pathologies: Traumatology (burn) | Individual | Distraction | HMD | Controller | System description | The DREAM game intends to be an efficient distraction tool to reduce pain and anxiety in children receiving medical treatments. |
| [94] | 2016 | 6-10 | Pathologies: Neurological (cerebral palsy) | Individual | Motivation | Monitor | Controller | Improved motor functions | Feasibility study indicates an improvement in motor functions. |
| [10] | 2016 | n/a | Pathologies: Ophthalmology | Individual | Motivation | Handheld | Touch | Feasibility | The game can effectively be used for automated testing of visual acuity. |
| [75] | 2016 | 7-13 | Pathologies: Chronic (cancer), traumatology (general physical disability), neurological (general) | Collaborative (co-located) | Distraction, socialization | Monitor | Touch, gesture | Increased enjoyment | Participants answered they felt creative, happy, "normal" again and had fun. |
| [32] | 2016 | 4-7 | Pathologies: Ophthalmology | Individual | Motivation | Monitor | Controller | Visual improvements | Improvement shown in both control and study group, but improvement in best corrected visual acuity, near |

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| | | | | | | | | | visual acuity, and stereoacuity in study group was significantly better. |
| [31] | 2016 | 4-13 | Procedure: Venipuncture | Individual | Distraction | Handheld | Touch | Reduced pain | No improvement was found between being distracted by a hand-held game and by nurses. |
| [109] | 2016 | 6-10 | Pathologies: Chronic (diabetes) | Individual | Socialization | Monitor, handheld, robot | Touch, voice | Increased enjoyment, emotional expressions, and knowledge gains | Overall positive experience. Children enjoyed the activities, built a relationship with the robot, and had a small knowledge gain. Parents and hospital staff pointed to positive effects on child's mood and openness. |
| [87] | 2016 | 3-6 | Procedure: Venipuncture | Individual | Distraction | Monitor | Controller | Reduced pain | Pain intensity in the interventional group was significantly lower than in the control group. |
| [88] | 2016 | 3-6 | Pathologies: Traumatology (burn) | Individual | Distraction | Monitor | Controller | Reduced pain | Pain intensity in the interventional group was significantly lower than in the control group. |

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| [140] | 2016 | n/a | n/a | Individual | Education | Monitor | Controller | System description | Participatory design of three 3D virtual environments based on games. |
| [39] | 2016 | n/a | n/a | Individual | Distraction | Monitor | n/a | Reduced stress and increased enjoyment | High satisfaction and low stress, but informative content was not very clear. |