The COSMO@Home Application – Iterative Development and Implementation of the Learning Goals

Marie Sjölinder, Olov Ståhl, Erik Einebrant, László Sall Vesselényi, Niels Stor Swinkels
RISE
Stockholm, Sweden
e-mail: marie.sjolinder@ri.se, olov.stahl@ri.se, erik.einebrant@ri.se, laszlo.sall.vesselenyi@ri.se, niels.stor.swinkels@ri.se

Anas Abdelrazeq, Samira Khodaei Dolouei, Kathrin Hohlbaum
RWTH Aachen University
Aachen, Germany
e-mail: Anas.Abdelrazeq@ima.rwth-aachen.de, samira.khodaei@ima.rwth-aachen.de, Kathrin.Hohlbaum@ima.rwth-aachen.de

Barbara Weyn, Marjolein Verly, Sam Geuens, Jessia Nijs, Marlies Treunen
KU Leuven, UZ Leuven
Leuven, Belgium
e-mail: barbara.weyn@kuleuven.be, marjolein.verly@kuleuven.be, sam.geuens@uzleuven.be, jessica.nijs@uzleuven.be, marlies.treunen@kuleuven.be

Sanne Nauts, Privender Saini, Ozgur Tasar, Annerieke Heuvelink
Philips
Eindhoven, Netherlands
e-mail: sanne.nauts@philips.com, privender.saini@philips.com, ozgur.tasar@philips.com, annerieke.heuvelink@philips.com

Abstract—This work describes the design journey in the development of an edutainment application for children. The aim of the application was to prepare children for an MRI scan. The COSMO@Home mobile application is based on a number of learning goals that are conveyed by a set of mini-games aimed at teaching and preparing children for the magnetic resonance imaging (MRI) scanning procedure. Each mini-game addresses one or more of the learning goals identified by the project as being important to prepare children for the procedure. The learning goals were: 1) Learn about the MRI procedure, 2) Familiarization with MRI sounds, 3) Familiarization with the size of the MRI scanner, 4) Practice the timings, 5) Practice lying still, 6) Learn about accessories such as earplugs and head coil, and 7) Understand that metal is not allowed in the MRI room. During the iterative development, initial tests to explore the general concept were conducted with children without a planned MRI scan and outside the hospital. In a second phase, more complete versions of the prototype were tested with children at the hospital. During the last phase, the application was tested in a real context with children in their homes. The main outcome of the iterative development and the testing was an application that, overall, seemed to convey the learning goals. However, the tests also revealed challenges in addressing the most important learning goal of lying still.

Keywords-design for children; educational software; gamification; game design.

I. Introduction

This work describes the design journey in the development of an edutainment application for children. The aim of the application was to prepare children for an MRI scan. The COSMO@Home mobile application is based on a number of learning goals that aim to teach and prepare children for the MRI scanning procedure. The application consists of a number of mini-games that provide the child with general information about the MRI procedure and about the MRI scanner. In the mini-games, the child receives information about what is allowed and not allowed during the procedure and is also able to practice some of the important things to remember. Each mini-game addresses one or several learning goals that were identified, in expert workshops, as being important to prepare children for the procedure. The learning goals were: 1) Learn about the MRI procedure, 2) Familiarization with MRI sounds, 3) Familiarization with the size of the MRI scanner, 4) Practice the timings, 5) Practice lying still, 6) Learn about accessories, such as earplugs and head coil, and 7) Understand that metal is not allowed in the MRI room.

The aim of this paper is to describe the design journey of developing a set of mini-games that successfully contribute to children achieving the learning goals. Design targeting children is briefly described in Section 2, and the developed application is presented in Section 3. Sections 4, 5 and 6 present the user tests that were conducted in the different stages of the iterative development. The paper ends with a discussion and conclusions (Section 7) about the design process towards incorporating the learning goals in the mini-games and in the application.

II. Designing for Children

Researchers have argued that games are a unique way to engage and motivate people in learning and education [1][2]. There are several advantages of using games for learning. Because a game can be used to model parts of the real world,

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it makes it possible for people to play around with and visit an abstract reality of a real-life setting or place, but in a simplified form [3]. A significant motivation for using educational games in learning is the engagement and joy they bring to the user [4]. As in learning, games also use typical techniques that can be found in educational psychology. Techniques such as rewards, feedback, and encouragement to collaborate are common practices for teachers as well as typical elements of a game. What gamification adds to learning is, according to Kapp [3], another layer of interest that both engages and motivates the player to learn.

Applications aiming at educating and preparing children require consideration of several design aspects. When designing educational games, both motivation to use and achievement of intended learning goals are important aspects. Guidelines regarding games, educational games, and child–computer interaction are all well-documented areas [5]-[9]. Winn [6] stated that the intended learning goals should be central and clearly set before the development of a game is started. Setting these goals can then help the designer throughout the development phase as they provide a practical way of measuring the intended learning outcome. Clear goals and rules within the game are important for the player, and they are also important for creating motivation [9]. If the player does not know what to do or if the goals of the game are unclear, it creates frustration and becomes unmotivating. Feedback is another important tool for learning through games and it can optimize learning by directly giving the player tips and tricks with respect to the performance and actions within the game [9]. Rewards are typical components of games and are a good way of encouraging and motivating the player [4][7][10].

With respect to instructions, it has been suggested that in-app tutorials should be avoided, since there is a tendency for children to not read or remember instructions given in this way. A better solution is to provide guidance through which the user can be active [7]. Further, Chiasson and Gutwin [10] suggest that the interface should be intuitive enough to be used without instructions, or that child users are given guidance until the intended task is understood [10]. An alternative to written text and instructions is graphical metaphors and interfaces in which minimal use of text is required, especially for the youngest users. Giving instructions in speech with corresponding pictures and animations can also help the users to both remember and understand the instructions [10].

In the process of selecting hardware, Chiasson and Gutwin [10] found that touchscreen devices rather than computers are better and more appropriate tools for children. Yet while touchscreen devices are a good choice for child users, there are limitations to the interaction in terms of the child's motor skills.

Based on existing design recommendations and on adaptations towards the specific context, the application in the project was developed in an iterative way.

III. The COSMO@Home Application

A novel preparation protocol called COSMO has been developed to help enable successful MR scans to be conducted on children without the use of sedation. COSMO is designed to achieve MRI examinations with awake children as young as four years of age in a time- and resource-efficient manner without lengthy preparation procedures or repeated hospital visits. The children are prepared by immersing them in an imaginative, child-friendly and engaging story, which is told and performed by trained hospital staff. The aim of the COSMO@Home project is to scale up the COSMO protocol by creating a digital COSMO tool that can be used by children and parents to prepare for the scanning sessions at home. Such a tool will limit the need for dedicated staff members and, as such, is far more scalable and cost-effective than the current approach.

The application consists of a framework or a starting page where different mini-games and other functionalities can be accessed. The app is built around a space theme, and the players are told they need to train to become an astronaut who can fly to space in a rocket. As part of their training, they will need to complete space missions, which means they need to build a rocket and fly it to a distant planet. When they return to Earth, they need to start training for their next space mission. This training is carried out by playing mini-games. Each mini-game is designed to teach the player something about the MRI procedure. The idea is that while training to become an astronaut, they will at the same time learn different aspects of MRI.

The starting page or the "home page" of the application is the space campus from which six mini-games can be reached (Figure 1). The app includes four 3D games: the Memory game, the Metal game, the Scanning game and the Balance game, and two augmented reality (AR, a real-world environment that has been enhanced by computer-generated perceptual information) games: the AR Comparison game and the AR Scaling game.

Figure 1. The space campus with game and activity buildings.

The user can collect rocket parts in each game, and when all games have been completed one time, the player has gathered all the rocket parts and can go to the launchpad and put together a rocket. When this has been done, the player sets off for space. During the space journey, there is a space game in which the player can collect stars. After the space game, the player reaches a planet and meets an alien. The player hands over a gift to the alien, and in return gets a mystery item that can be scanned once back at the space campus. There are five space missions that the player needs to complete in order to become a full-fledged astronaut, and in each one they will visit a different planet and meet a different alien. After completing these five missions, it is possible to continue playing and fly to space, but when doing so the existing planets will be revisited. The training and space mission loop is illustrated by Figure 2.

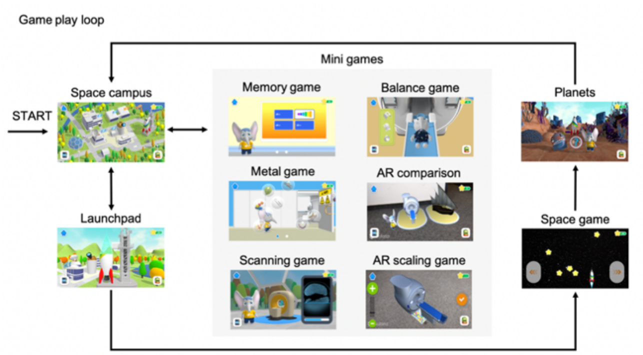

Figure 2. The game play loop, consisting of mini-games and space missions.

Space campus and buddy character: The space campus, or "Home page," consists of a number of buildings. Each building represents an activity or mini-game that the player can engage in. When the player clicks on a building, the camera zooms in and the application then switches to a view from inside the building, where the game or activity starts. The player is accompanied by their buddy character, Ollie. Ollie speaks to the children via voiceover audio, explaining to them all they need to know about their training to become an astronaut and giving them feedback and encouragement when they are playing games or participating in other activities. Ollie is a fully animated 3D character, and the children will see him move around in the scenes, making various kinds of gestures such as waving, pointing, and cheering

Memory game: The aim of the Memory game is to convey knowledge about the sound of the MRI scanner. The player sees a board with a number of cards. When they click on a card, it opens and plays an MRI sound and provides an animation of that sound. The goal for the player is to find cards with matching sounds, which are then removed from the board until the entire board is eventually cleared. The number of the cards increases with each higher level.

Metal game: The aim of the Metal game is to teach the player that metal objects are not allowed in the MRI room. In the game, a set of objects are moving around and the player should remove (click on) the ones that are made of metal. While the game is running, the player sees Ollie walking slowly towards the MRI room, and the goal is to remove all metal objects before he gets there. If Ollie reaches the MRI room before all the metal objects have been removed, the round fails and the player needs to try again. At each level, the number of objects and the speed of Ollie and the moving objects increase.

Scanning game: The aim of the Scanning game is to increase the player's understanding of the MRI procedure and of the duration of a scan session, which can be long. The player places "mystery objects" in the scanner and waits for them to be scanned. While scanning, the player can see a scan image being revealed, and once the scan is complete, they need to guess the true identity of the mystery object. The game uses scanned images of real fruits, and afterwards, the player is presented with a selection of fruits and they need to identify the one that matches the MRI image.

Balance game: The aims of the Balance game are to increase understanding of the MRI procedure, and learn about accessories (different types of coils), as well as to provide information about the need to lie still and to practice lying still. The child selects a coil and then Ollie's scan starts. During the scan, the player needs to hold the phone still; otherwise, the phone starts to vibrate and the scan image starts becoming distorted. After the scan, the resulting scan image is added to the adventure journal, where the player can look at it again later.

AR Comparison game: The aim of the AR Comparison game is to help children understand the size of an MRI scanner by asking them to guess which of two visible objects (an MRI scanner and a random object) is bigger. AR technology is used to make the objects appear in 3D in the physical room. The AR tracking is based on a marker that needs to be placed on a flat surface, for example a table. The child can then scan the marker and the game starts. There are several rounds of comparing the MRI scanner to objects such as a cake, a house or even fantastical objects such as a T-Rex. The objects appear from a magical hat that needs to be pressed. The child receives stars after completing each comparison.

AR Scaling game: The aim of the AR Scaling game is to help children understand the size of an MRI scanner. Additionally, an extended learning goal is introduced in order to allow the discovery of different parts of the MRI scanner. The AR technology is used in order to make the MRI scanner appear in full 3D size in the room. After placing the marker on the floor, the MRI scanner appears in a small size. With plus and minus buttons, the children can increase or decrease the size of the MRI scanner. Once the right size is found, the game proceeds to the extended learning goal, where the children have to discover different question marks on the MRI scanner and also can collect stickers.

During development of the prototype, feedback was gathered iteratively in the different stages through participatory observation of professionals and through questionnaires. In the first phase, the concept of a few mini-games was tested with 15 children (6 in Sweden and 9 in Germany) outside the hospital. In the second phase, a more mature version was tested with 17 children at the University Hospitals Leuven, although still under supervision of the investigators. In the third phase, the application was tested with 13 children using the application independently at home. In total, 45 children participated in the tests during the iterative development of the application. The different phases are shown in Table 1.

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TABLE I. OVERVIEW OF THE DIFFERENT USER TESTS

Location	Date	Aim	Participants
Initial tests – concept and functionalities			
RISE Sweden	August - September 2019	Get a first impression of how the app was perceived by children of different ages.	6 children, 3-15 years old
RWTH, Germany	October 2019	Feedback on first mini-games and on the use of AR.	9 children, 6-9 years old
Tests at the hospital			
KU Leuven, Belgium	November 2019	Feedback on improved version of the prototype with further features. How the learning goals were conveyed.	9 children, 4-10 years old
KU Leuven, Belgium	April/May 2020	Feedback on improved version of the prototype, entire app with all the mini-games and the reward system. How the learning goals were conveyed.	8 children, 4-9 years old
Tests in the home environment			
KU Leuven, Belgium	October - November 2020	Practical aspects related to home usage, feasibility, and inclusion in hospital workflow.	13 children, 5-11 years old

IV. INITIAL TESTS – CONCEPT AND FUNCTIONALITIES

The first phase of the development was supported by initial tests with users. These tests were conducted in Sweden and Germany with children that were not associated with a hospital. The aim of these tests was to get a first impression of how the app was perceived by children of different ages, and also to get feedback on the mini-games and the concept.

A. First Feedback on the Concept

The first test was conducted at RISE in Gothenburg, Sweden in August and September 2019. This first version of the app consisted of two mini-games: the Memory game and the Metal game. The aim of this study was to get a first impression of how the app was perceived. Regarding the youngest children, the goal was to get feedback about to what extent they understood the concept. For the older children, the aim was to get an initial understanding of how to motivate this user group. Six children in a wide age range between three and fifteen years old participated in this study. An introduction was given about the MRI testing, the app, and the purpose of the test. After that, the participants tried the app and played the games. Questions were asked about what they liked about the app and about what they did not like about the app. Observations of usage were made by the test leader in regard to engagement, understanding of the concept, and navigation, as well as in relation to the learning goals.

Result: The overall idea of an app with mini-games seemed to work well, as did the space theme. The metaphorical connection between preparing for MRI scans and preparing for space travels felt meaningful to the children. However, the oldest children felt that the app as a whole was somewhat too childish for their age. It was not obvious to the youngest children that it was possible to access the mini-games by clicking on the buildings. However, when they had received instructions about this, navigating into and back out of the buildings was no problem. The gameplay purpose of the mini-games (i.e., collecting rocket parts) was very unclear without visiting the launchpad as a first step. The younger children did not pay attention to the entire MRI movie, which was something that the older children did do. The older children also felt that the most important part was when the child in the movie was shown as happy or at least undisturbed during the MRI scan. Experiencing someone else's positive experience of the procedure was encouraging.

All of the children figured out how to play the memory game. The learning goal of becoming familiar with the sounds of the MRI scanner, in the Memory game, was very clear to the children. For the younger children, it was not clear to the children which sounds were related to the MRI scanning procedure. The game concept of the Metal game was unclear to the children, and the learning goal (to not bring metal objects into the MRI scanner) was also somewhat unclear. It was not clear which items a player should or should not press. However, most of the items seemed to be recognized. The children expressed that the narration did not emphasize well enough that metal was completely prohibited from being taken into the MRI room. However, when asked specifically, the children had a good idea of what they could and could not bring into the room from among the things the children were wearing at the time. During the user tests, it became clear that it was more challenging than anticipated to achieve a strong connection between the different games and the learning goals. As a result, one mini-game (a Tetris-inspired game) was removed/replaced. Finally, these tests also explored the use of VR for applications targeting small children. Insights gained during the tests resulted in a change from the use of VR to AR due to difficulties for small children to wear the VR equipment.

B. Feedback on the Mini-games and on the Use of AR

The second test during this first stage was conducted by RWTH Aachen University in Germany in October 2019. In this version, an additional mini-game (the Scanning game) had been included and one AR game (the Scaling game). The aim of this test was to get feedback on the improved version with more mini-games, and to test a new AR mini-game. Initial feedback regarding on-boarding (getting into the game) and narrative (spoken information and voiceover) was also gathered. Nine children between the ages of six and nine participated in this test. After an introduction, the children played all of the mini-games by themselves and the test leader only intervened when necessary. During and after each mini-game, the child was asked questions about what they thought about the game (fun/boring, fast/slow, easy/hard, childish/mature), and about what they liked and did not like. They were also asked about what was hard and easy to understand, and if they had understood the purpose of the game. During the sessions, observations were made regarding whether the app seemed engaging and whether the concept of the space campus was understood. The test leader also tried to get an understanding about to what extent the children gained knowledge based on the learning goals.

Result: Almost all of the children were excited about the game as a whole and thought it would be helpful for children to understand what an MRI is. They liked the space scenario, but the connection between MRI and space was still not always clear. Almost all of children knew what a magnet was afterwards, and they could recall what not to take to an MRI. The children also recalled that an MRI is "noisy and takes pictures". Afterwards they also could tell that they learned not to move, and to lie still during the scan. The environment seemed easy to navigate, but the connection between each building and the game that was accessed by clicking on it was not clear. The children thought it was fun to watch the video, and they were able to answer the questions in the video (for example, "Can you hear the noises?").

All the children easily got familiar with the Memory game, and it was easy to get started. The increasing degree of difficulty in the levels seemed to be good, but younger children needed some guidance. After a while, when they had got the gist of it, they did not care about the sounds. The children knew intuitively what to do in the Metal game; they easily found all the objects and were able to transfer this knowledge to reality (the instructor asked them if they, for example, could bring a watch or bracelet to the MRI, and all of the participants were able to say "NO" and explain why). For small children, it was difficult to know if certain objects were made out of metal or not. The aim of the Scanning game was understood, but it needed further explanation. The participants found it nice that there was something in the box (but all of them thought at first that it was a rocket part). With respect to the AR Scaling game, for the youngest children it was difficult to navigate using the phone. Some of them dropped the phone multiple times in excitement. The game was difficult, and the children needed a lot of explanation and support. However, some of the older children found it exciting to walk through the machine. Afterwards, children were able to "walk the size" of an MRI scanner within the room.

V. Tests with Children at the Hospital

In this phase of the development, tests were conducted with children at the University Hospitals in Leuven. In these tests, the aim was to get feedback on improved versions of the prototype, including new features. At the end of this phase, the entire application, with all the mini-games and the reward system, was tested. In these studies, it was also examined how the learning goals were conveyed.

A. *First Test at the Hospital*

The first test at the University Hospitals in Leuven, Belgium took place in November 2019. The aim of this test was to gain feedback on the improved and extended version of the prototype, which consisted of five mini-games clearly connected to the learning goals. The mini-games included in this version of the prototype were: the Memory game, the Metal game, the Scanning game, the Balance game and the AR Scaling game. This version also had a coherent narrative from playing the mini-games to getting rewards and completing the game. This test included a first approach towards investigating to what extent the learning goals were conveyed. This test was built up around a number of modules, depending on how much time the child could spend on the test. Nine children between the ages of four and ten participated in this test. The tests were conducted in the waiting room at the hospital in Leuven. After playing the game, the children were asked general questions about the game and the character and after that more specific questions about the mini-game(s) they had played. These questions were conducted to find out what they thought about the game and if they understood how to play it. The children were also asked if they understood the purpose of the mini-game(s) and about what they learned from each game. Observations were made regarding to what extent the children understood the concept and managed to navigate in the app, and to what extent they seemed to understand the learning goals.

Result: Overall, the children really liked the character Ollie, the game appearance as a whole, and the flying-to-space narrative. The navigation also seemed to work well, but it was still not clear that there were games in the buildings. Once the observers showed how to click on a building, the concept was understood. The goal of collecting rocket parts and building the rocket was not directly clear to all the children in the test. The older children seemed to understand the learning goals; however, it seemed that they gained most of their knowledge from the introduction movie even though several of the children found it too long. The younger children liked the application, but it was not clear that they understood the learning goals and they needed parental supervision. During this test, it also became clear that there were challenges regarding the most important learning goal (lying still). According to the health care professionals it was not practiced enough.

The Memory game and Metal game were the two most popular games. However, even though the sounds of the Memory game were more important to recognize than the images on the cards, the children often used the images, instead of the sounds, to find a matching pair. The Metal game was managed well by most of the children, and they seemed to understand the metal concept. The learning goal (understanding that a scan takes time) in the Scanning game was addressed by the fact that the child had to wait for an image. Some of the children in the test left this game since they thought the waiting was boring. With respect to the AR Scaling game, there were challenges; namely, that the actual size of the scanner became too large, which made the game difficult to play without parental support and a large physical

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space. Due to this, it was not clear if the learning goal of understanding the size of the MRI scanner was achieved.

B. *Test of Complete Version at the Hospital*

The next test in this phase was also conducted at the University Hospitals in Leuven, Belgium during April and May 2020. The aim of this test was to gain feedback on the improved version of the prototype, which consisted of a complete app with all the mini-games (Memory game, Metal game, Scanning game, Balance game, AR Comparison game and AR Scaling game) and the reward system. In this version, improvements had been made related to the size of the MRI scanner in the scaling game, and a tutorial had been added for first-time usage to provide a better understanding of what it was possible to do. This test was conducted using a tablet instead of a smartphone.

The feedback covered both usage and how well the learning goals were conveyed. Eight children between the ages of four and nine years of age participated in the test. All tests took place at the University Hospitals Leuven, either in the patient's room or in the waiting rooms of the children's hospital. In this test, the application was tested using a tablet. After an introduction with general questions, the children played through the mini-games, and it was also made sure that they played through the AR games. After they had played the mini-games, they were asked to put together the rocket and answer questions about the rocket and the space flight. Finally, the children were asked questions about the learning goals, and they also completed a questionnaire with questions about the character, the environment, and about which games they liked/disliked the most and about which games were the easiest/most difficult. During the session, notes were taken about what was easy/hard and about what seemed fun and motivating or boring.

Result: All games/game world looked good on the tablet and seemed to be easier to play on a tablet than on a phone. However, small children found the tablet heavy to hold. Most kids loved to play the game and liked to complete at least one round. Apart from some minor issues, the game world and navigating in the game world worked well, even for smaller children, and Ollie, the character, seemed to be a well-liked figure. The introduction movie was only possible to test with a few children due to a technical issue. However, it seemed to be liked and to convey the learning goals and it was educative.

The Memory game was very well liked and worked well. Even if it mainly was the images that were used for the pairing, it still conveyed the loud sound of an MRI scanner. In the Metal game, it was still a bit difficult for small children to differentiate which objects were made out of metal, and they often found them randomly. The Scanning game was a very well-liked game. The only thing that needed to be improved was the narratives, which needed to explain the waiting time better, and also to convey a stronger connection to the fact that it takes some time to scan an object or a person in an MRI scanner. The Balance game, which had the aim of showing the procedure and emphasizing the importance of lying still, was found to need some improvements. Better instructions were needed to explain the concept and better feedback was required on moving vs. holding the device still to be able to succeed. The AR Comparison game concept seemed to be liked a lot by some children, while others did not like it, which was probably due to issues with the technology. In this version of the application, the size of the MRI scanner was better and easier to handle. However, with younger children, assistance was needed to hold the phone still for the tracking. It was also difficult for younger children to grasp the concept of bigger/smaller objects, especially if they had not seen an actual MRI scanner before. At this stage, more testing was needed to understand if the learning goal was actually conveyed. For the AR Scaling game, the size of the MRI scanner was much better. However, the need for really large areas in which to play the game limits the usability. The game had potential, but the AR concept of the size of the MRI scanner was not always understood by young children.

The answers about what they thought of the games were few in numbers and varied from child to child, but the most-liked games were the Memory game, the Balance game and the Comparison game, and the most boring game was the Scaling game. The Metal game was considered to be the easiest game, and the Scaling game the hardest one, as shown in Table 2.

TABLE II. RESULTS FROM THE QUESTIONNAIRE, IN WHICH ONE GAME COULD BE SELECTED IN EACH CATEGORY

	Most liked	**Most boring**	**Easiest game**	**Hardest game**
Memory	2	1	0	0
Metal	1	1	3	1
Scanning	1	1	1	0
Balance	2	0	1	1
Comparison	2	0	2	1
Scaling	0	5	1	5

VI. USER TESTS IN THE HOME ENVIRONMENT

The aim of the last study during the iterative development of the application was to test the complete application with home usage and workflow around the usage. This test was also a pilot study for a forthcoming clinical trial. The study, which was approved by the ethical committee, was managed by University Hospitals Leuven in Belgium between September and December 2020. The usage of the app took place in the children's homes, and thirteen children between the ages of five and eleven participated in the study. Nine of them had had at least one MRI before and four of them did not have any experience with MRI procedures. One week before the start of test, the parents were contacted. A start package was sent to their homes at least four days before the scan. The package contained an introduction folder, a smartphone with installed app, a marker for the AR games and an informed consent form. At the time of the scan, the children answered questions about which game they liked/disliked the most and which game they thought was the easiest/most difficult. The children also answered questions about general likeability of the app and about their desire to play the app again, and both children and parents also answered questions about anxiety related to the scanning procedure.

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Results: The answers about what they thought of the games were, in this test as well, few in numbers and varied from child to child. However, they were in line with the results from the previous test, with the most-liked games being the Memory game, the Balance game, and the AR Comparison game. With respect to the most boring game, answers were spread out between all the games. In this test, the Memory game and the Scanning game were considered to be the easiest games, and the Metal game the hardest one, as shown in Table 3. Again, it is important to point out that the answers were few and spread throughout the different games, and also that the aim of these questions was just to identify if any of the games were too difficult and/or too boring to be included in the app. In general, all the games seemed to work well, but the Memory game seemed to be really liked and easy to play, and the Metal game and the Scaling game might need further adjustments.

TABLE III. RESULTS FROM THE QUESTIONNAIRE, IN WHICH ONE GAME COULD BE SELECTED IN EACH CATEGORY

	Most liked	**Most boring**	**Easiest game**	**Hardest game**
Memory	3	2	3	2
Metal	1	1	2	4
Scanning	1	2	3	1
Balance	2	2	2	1
Comparison	2	2	1	2
Scaling	0	2	0	2

In the question in which the children rated the overall likeability of the app on a scale ranging from 0-10, the average was m=7.69. A further measurement on how well the app was liked was the question about the desire to play the app again. On this scale (0-10), the average was m=6.77, which is quite in line with the extent to which the participants liked the app. After the app usage but before the scanning procedure on the day of the scan, both children and parents were asked (0-10 VAS scale) about their anxiety related to the scanning procedure. The reported anxiety for children dropped, compared with a baseline, from 2 to 1 (mean anxiety). For the parents, the reported mean anxiety dropped, compared to a baseline, from 5 to 3. This is a positive trend, indicating that after app usage the children were less anxious on the day of their scan. The observations made on the scanning day also showed that the children had fewer questions and that they were much better prepared. Only in a very small group of children was additional training needed. With respect to the learning goals and the need for additional training, the most important learning goal to address further was the lying still goal. All other aspects seemed to be sufficiently addressed at home and needed no additional training in the hospital. With respect to the entire context in terms of home usage and workflow, the app could be used at home without the supervision of a researcher and it worked well within the clinical workflow. However, further testing is of course required to draw definitive conclusions.

VII. CONCLUSION

In one of the tests at the hospital, the app was used on a tablet. All the games and the game world looked good on the tablet and seemed to be easier to play on a tablet than on a phone. However, small children found the tablet heavy to hold, which is line with Chiasson and Gutwin [10], suggesting that while touchscreen devices are a good choice for child users, there are limitations to the interaction in terms of the child’s motor skills. During the development of the application, important motivational features and rewards were included in the application [4][7][10]. These were used for general motivation to increase the learning [3]. Since very young children were a part of the target group, instructions were mainly based on graphics and spoken explanations according to previous work and/or guidelines [10]. What was noted in the tests was that even though the aim of the spoken explanations was to keep them short and simple, in some cases they had to be further shortened to enable getting the message through to the youngest children as well. It has been suggested that in-app tutorials should be avoided, since there is a tendency for children to not read or remember instructions given in this way [7]. The tests that were conducted during this development showed the opposite. Since the application consisted of a quite complex path through the environment, with games, rocket parts, building a rocket and going to space, a tutorial describing this path had to be added. This was especially needed for the younger age groups, which might not already have the game literacy that older children might have.

With respect to the learning goals of *learning about the procedure* and *learning about accessories such as earplugs and head coil*, the introduction movie and the Balance game were aimed at conveying these learning goals. In the tests, it was shown that the children gained much of their knowledge from the introduction movie. However, it was also shown that the older children, to a greater extent than the younger ones, finished watching the entire movie. The learning goal of *understanding that metal is not allowed in the MRI room* was addressed in the Metal game. One insight during the tests was that it was, to some extent, difficult to understand what the objects represented and to differentiate between metal and non-metal objects, especially for the youngest children. The learning goal of *practicing the timings* was addressed in the Scanning game and in the Balance game. The challenge regarding the design in this case was to both convey the concepts of a long period of time and waiting, and at the same to create a game that is not boring. The aim of the Memory game was *familiarization with MRI sounds*. This game was very well liked and easy to play. It might have been the case that the pairing was mostly done using the images instead of the sounds. However, the game still contributed to making the MRI sounds more familiar. The learning goal of *familiarization with the size of the MRI scanner* was addressed by the AR Comparison game and the AR Scaling game. Using an AR technique with paper-printed markers could to some extent be complicated, especially for young children. Both physical and digital interaction with “walking around” a large object could also be a challenge, as in the case with the Scaling game. This game requires both a large physical space and quite demanding interaction. In general, the tests showed that AR gaming is still quite difficult for young children as it requires a lot of additional knowledge, the ability to hold the phone still while pressing buttons, and the attention capacity needed to look at the phone while moving around. It could be advisable to further develop AR games for children in more cooperative ways that allow playing with a parent or older sibling. Despite these challenges, at the end of the development process, the understanding of the size of the MRI scanner seemed to be understood by most of the children. Finally, the learning goal of *practicing lying still* was addressed by the Balance game, where the child was supposed to keep the device still during the scan procedure. Based on feedback from nurses at the hospital, this was the most important learning goal, but the task in the game too weakly resembled actually lying still in a real context. As a result of this, one further AR game, the Box game, was developed. The aim of this game is to train children to keep their heads lying still during an MRI scan. This game consists of a physical box asset that enables the children to experience being in a head coil. The game requires some set-up before the gameplay, which is why it is advised in the beginning to get help from a parent. During the gameplay, the child navigates through a narrow canyon with a rocket. The head movement of the child is tracked and the less the child moves their head, the faster the rocket flies and reaches the goal. Additionally, there are phases in which the children are allowed to move their head, indicated visually with clouds and auditive sounds. While they can't move their heads, the MRI sound is loud and the rocket flies through the canyon. This new, lying still, game has been included in the latest version of the application and will be tested with children in the forthcoming tests.

In general, most of the learning goals that were set up seemed to be conveyed successfully by the application in these smaller tests that were conducted as a part of the development. The learning goals and the effect of using the application will be further evaluated in a forthcoming larger clinical study.

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