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ESCUELA DE INGENIERÍAS INDUSTRIALES

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Grado en Ingeniería de Diseño Industrial y Desarrollo de Producto

Hybrid Toy Construction

Autor:

Alonso Gil, Alicia

Responsable de Intercambio en la Uva:

Nieves Fernández Villalobos

Universiteit Antwerpen

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TFG REALIZADO EN PROGRAMA DE INTERCAMBIO

TÍTULO: Hybrid Toy Construction

ALUMNO: Alicia Alonso Gil

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CENTRO: Ontwerpwetenschappen, Campus Mutsaard. Universiteit Antwerpen

TUTOR: Marieke Van Camp

Resumen: Este proyecto, 'Hybrid Toy Construction', se enfoca en enriquecer la experiencia de juego de los niños a través de los juguetes. Al comparar las diferentes experiencias de juego de los niños con una interfaz de usuario tangible (TUI), una interfaz de usuario física (PUI) y una interfaz de usuario gráfica (GUI), se comprobó que los niños prefieren usar un juguete con una GUI sobre una TUI o una PUI.

El objetivo del proyecto es la creación de un juguete híbrido para niños de cinco a seis años. Para ello, el juguete contiene elementos físicos (PUI) en forma de un tren, pistas, estaciones y otros objetos inteligentes, así como elementos digitales (GUI) en forma de aplicación. Ambas realidades (la física y la digital) se comunican mediante Bluetooth, estando relacionadas a través de una aplicación para enriquecer la experiencia del usuario.

El juguete tiene el propósito de estimular los sentidos de los niños y fomentar su desarrollo mediante el uso de la diversión y juegos educacionales.

Palabras clave: juguete híbrido, aplicación, PUI (Interfaz de Usuario Física), GUI (Interfaz de Usuario Gráfica), enriquecimiento de interacción

Abstract: This project, 'Hybrid Toy Construction', is focused on enriching children's play experience with toys. By comparing children's play experiences with a Tangible User Interface (TUI), a Physical User Interface (PUI) and a Graphical User Interface (GUI), it was determined that children prefer using a GUI over a TUI or a PUI.

The goal of the project is the creation of a hybrid toy for children, this meaning, that the toy contains both physical elements (PUI) in the form of a toy train, tracks, stations and other intelligent objects, as well as digital elements (GUI) in the form of an app. Both realities (the physical and the digital) are communicated through Bluetooth, interacting with an app to enhance the user experience.

The toy is purposed to stimulate the children's senses and to encourage their development by using fun and educational games.

Keywords: hybrid toy, app, PUI, GUI, enriched interaction

Alicia Alonso Gil | Jan Gomez Roberts | Víctor Martínez Núñez | Kevin Schelfer | Tine Vande Verre

FINAL REPORT

H!TO: HYBRID TOY CONSTRUCTION

EPS program

Supervisor: Marieke Van Camp
Coordinator: Sarah Rohaert

Authors:
Alicia Alonso Gil
Jan Gómez Roberts
Víctor Martínez Núñez
Kevin Schelfer
Tine Vande Verre

University of Antwerp, Department of Product Development

ACKNOWEDGEMENTS

The successful completion of this project would not have been able without the support and guidance of several people. We thank our supervisor, Marieke Van Camp, for steering our project into the desired direction whenever we lost focus on our final goal, for offering resources, and for providing useful feedback during weekly meetings. Furthermore, we thank the EPS program and our EPS coordinator, Sarah Rohaert, for having created the opportunity to work on a project in a multidisciplinary and international context; and the University of Antwerp for providing the necessary infrastructure. As this project required verification of our prototype iterations, many children were needed in order to perform as many user tests as possible. We would like to thank Lieve Beurghs, for searching for candidates; primary school Sint Antonius, for allowing a user test on such short notice; and Melissa Govaert, for being our crucial contact person in that same school. We want to thank Jochen Vleugels, for his assistance with the electronics; and Achiel Standaert, for his usability related feedback regarding our hybrid toy. Finally, special thanks to Marc Lambrechts, for providing the electronics' backup so that the user test could still be carried out.

Hybrid Toy Construction Team:
Alicia Alonso Gil
Jan Gómez Roberts
Víctor Martínez Núñez
Kevin Schelfer
Tine Vande Verre

ABSTRACT

This project, 'Hybrid Toy Construction', is based on a previous project by our supervisor, Marieke Van Camp. This previous project focused on enriching children's play experience with toys. By comparing children's play experiences with a Tangible User Interface (TUI), a Physical User Interface (PUI) and a Graphical User Interface (GUI), it was determined that children prefer using a GUI over a TUI or a PUI.

The goal of the project is the creation of a hybrid toy for children, this meaning, that the toy contains both physical elements in the form of a toy train, tracks, stations and other objects, as well as digital elements in the form of an app. The toy would be used to stimulate the children's senses and to encourage their development by using fun and educational games.

The target group for this toy were five to six year old children, and after multiple iterations and brainstorms, a physical hybrid toy train was constructed, which interacts with an app through Bluetooth to enhance the user experience. This app includes games and tutorials, the latter of which helps the users understand how to interact with both the app and the physical toy.

However, we learned that, despite the tutorials being relatively simple to complete, some design decisions and our intended way of interacting with the app were at times too complex for the children to understand. This led to confusion while playing with the toy.

Key words: hybrid toy, app, PUI, GUI, enriched interaction, research through design.

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1. INTRODUCTION

This first chapter will be used to describe the basis and origin of this project and what the general goals are. The different members of the team will also be introduced.

1. INTRODUCTION

1.1 THE PROJECT

The motive of this report is documenting the execution and findings of the EPS project 'Hybrid Toy Construction' which took place in the University of Antwerp between 19th February (2018) and 14th June (2018).

EPS stands for European Project Semester. This program is composed of a main project and different modules ranging from environmental issues to European Law. All these modules and how we applied them to our project are further explained in Appendix A. This study program also tries to include and mix a wide range of nationalities and disciplines, enhancing the experience and multicultural aspect of the project.

This project is based on a previous research by the project's supervisor, Marieke Van Camp, which intends to study the development of a comparative user study with children aged five to six with the purpse of rematerializing the user interface of a digitized toy using tokens.

The goal of the 'Hybrid Toy Construction' project is the creation of a hybrid toy for children aged five to six this meaning, the toy contains both physical elements in the form of a toy train and tracks, as well as digital elements in the form of an app with a Graphical User Interface (GUI). The toy is used to stimulate the children's senses and to boost their development by using fun and educational games.

In the toy market, most toys are based either on a Tangible User Interface (TUI), which means that the majority of the interaction is with the physical toy itself, or based on a Graphical User Interface (GUI), which means that the user interacts with a digital screen. This project gave us the unique opportunity to attempt to combine these two interfaces and create a toy with a Hybrid User Interfawce (HUI).

1.2 THE TEAM

The team that is behind this project is composed by five members of diverse nationalities with different disciplines and backgrounds. Each one has a different way of working and point of view, as well as different skills and personalities, this is what enriches the group.

Alicia Alonso Gil

Nationality: Spanish
Education: (4th year) BEng Industrial Design and Product Development
University of Valladolid (Spain)
Skills: 3D modelling, simulation programs, graphic design, rendering
Email: alicia.alonso.gil@gmail.com
Phone number: +34 633 49 69 06

Jan Gómez Roberts

Nationality: Spanish, British
Education: (3rd year) BEng Electrical and Electronic Engineering
Glasgow Caledonian University (United Kingdom)
Skills: Circuit design and low-level programming
Email: jgomez201@caledonian.ac.uk
Phone number: +44 74 92 55 09 16

Víctor Martínez Núñez

Nationality: Spanish
Education: (3rd year) BEng Industrial Design
ELISAVA, University of Barcelona (Spain)
Skills: 3D modelling, rendering
Email: victormartinez.marcel@gmail.com
Phone number: +34 655 62 82 62

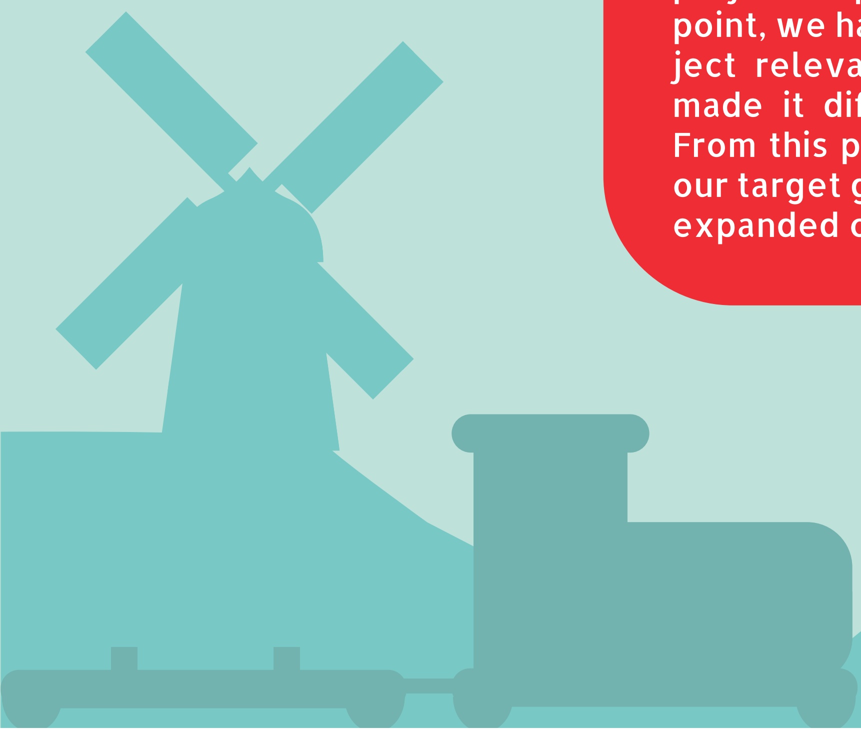
Tine Vande Verre

Nationality: Belgian
Education: (3rd year) Product Development
University of Antwerp (Belgium)
Skills: Sketching, 3D modelling, graphic design, rendering
Email: tine.vande.verre@gmail.com
Phone number: +32 479 11 35 93

Kevin Schelfer

Nationality: Dutch
Education: 3rd year) Applied Computer Science
Saxion Enschede (Netherlands)
Skills: Software development, low-level programming
Email: k.schelfer@hotmail.com
Phone number: +31 623 32 96 35

2. BACKGROUND



This project arises from a research proposal and the dissertation of Marieke Van Camp, the project supervisor. Using this as a starting point, we had to figure out what made our project relevant, what made it important, what made it different.

From this past dissertation, we also identified our target group and stakeholders. This will be expanded on during the course of this chapter.

2. BACKGROUND

2.1 RELEVANCE OF THE PROJECT

At the onset of the project, consideration and reflection on the purpose of the design and materialisation of a hybrid construction toy were performed. Specifically, the main focus to be developed was innovation and contrast with other products in the market. Some of the questions we encountered included:

- What makes it important?
- What makes it different?
- How is it relevant?

The early development of toddlers and children is of utmost importance. In this period, it is determined what they will be like in the future, as this is when they build social, emotional and thinking skills. The current market situation is led by an increasing usage of purely electronic games of which a large quantity of them just seek entertainment and to gain money through microtransactions, leaving aside the development of the child. To avoid this, it was set that the main goal of this project was to create a product that would help develop children's basic motor and cognitive skills whilst also stimulating their creativity.

Once we had realised the importance of taking care of every detail of the product, we started researching similar products in the market. During this research, we noted the existence of a wide variety of toy trains, from simple trains with no add-ons to the more complex trains with wagons, stations and many other elements. However, a lack of trains that combined both digital and traditional analogue parts was noted. This means that the development of this hybrid train toy would make it special and stand out in the current toy market, as it is a relatively new sector.

To achieve the educational aspect of the toy, we investigated other toys in the market and child psychology, aiming to study what the most important aspects are to develop during this period. This topic is further developed in the child psychology and the market research sections, chapters 4.1.1 and 4.2 respectively.

2.2 PREVIOUS RESEARCH

The project arises from research proposal and a dissertation of Marieke Van Camp, the project supervisor and doctoral researcher at the University of Antwerp for the Department of Product Development, together with Lukas Van Campenhout and Guido De Bruyne. This dissertation's objective is the development of a comparative user study with children aged five to six with the purpose of rematerializing the user interface of a digitized toy using tokens.

According to Van Camp, many recent studies have focused on this relation between tangibility and children, and despite the widespread belief in that tangible interaction can benefit children's play experience, empirical evidence is very limited. Therefore, the supervisor's thesis is intended to measure and empirically validate the effect of tangible interaction on children's play experience using research through design approach, by developing a prototype of a programmable toy train with a Tangible User Interface (TUI) based on tokens.

To verify the prototype, a comparative user test has already been realised by Van Camp with two similar established toys, one with a Physical User Interface (PUI) and one with a Graphical User Interface (GUI), on 34 children aged five to six to determine which type of user interface was preferred. Insights into the selected user interface were acquired through a laddering interview method. According to Van Camp, the results obtained suggest that children prefer a GUI over a TUI or PUI. This is due to the versatility, countless possibilities and high level of stimulation that a GUI provides.

Consequently, this project is an iteration parallel to the supervisor's thesis, taking as the starting point the statement: Create a "digitally enriched toy train with a token-based interface".

2.3 TARGET GROUP

The target group of the project is children of both genders aged five to six. The target group has been a condition imposed from the previous project being developed by Marieke Van Camp (the project supervisor) on which our work is based.

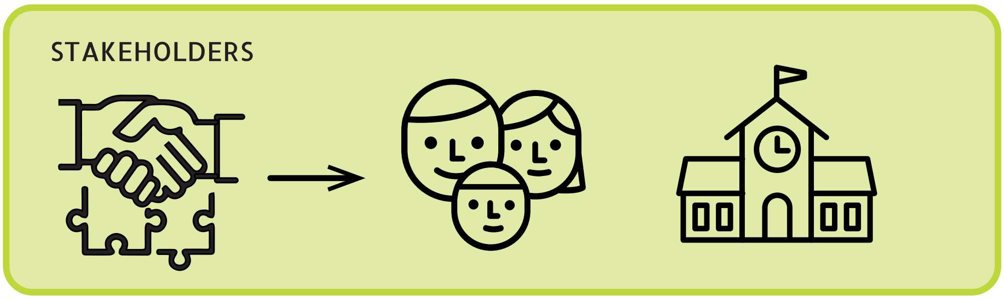
2.4 STAKEHOLDERS

In this section, the most relevant interested parties involved in this project are briefly mentioned. Further details about how we create value for the stakeholders and how to involve them in can be found in Appendix B.

- **Children** of both genders aged five to six are the main stakeholders since these are the users, and therefore the design has to be focused on them and has to meet their needs.

- **Parents**, close relatives or guardians since they are the buyers, as they have the pur chasing power, and they are the ones who decide what toys their children can play with.

- **University of Antwerp**, since the project is developed within the framework of the University of Antwerp as an iteration from research proposal and dissertation of Marieke Van Camp, the project supervisor and doctoral researcher at the Department of Product Development of the University of Antwerp.



Conclussions: From this chapter, we can gather that the main driver of our project is to explore the opportunities and difficulties of designing a hybrid toy. As previous research conducted by our supervisor suggests that children prefer GUI (graphical user interface) over PUI (physical user interface) or TUI (tangible user interface), we were challenged to combine the best of both digital and physical toys into a new toy train. This hybrid toy's objective is to contribute to children's development, which is of the utmost importance, through letting them practice a wide variety of skills. Finally, we also identified that our target group are children of both genders aged five to six. Additionally, our stakeholders are children, parents and the University of Antwerp.

3. PROJECT GOALS

This chapter will be reserved to discuss in detail what are the objectives of this project and how they are going to be achieved.

3. PROJECT GOALS

According to Marieke Van Camp, most of screen-based games on the current market limit the interaction between child and product to swiping and pushing movements. Therefore, children are not receiving enough stimuli to develop essential motor skills, however, these digital games offer more variety for subgames and allow for graphically appealing interfaces. Consequently, compared to traditional physical toys, these two aspects make digital toys more persuasive and appealing to children, although the use of interactive technologies by children has also raised fears due to the long exposure children can have to these technologies.

In order to draw children into playing with physical toys, the player-experience of these must be enhanced. This could be done by combining a physical game with an app, based on our supervisor's thesis and the complementary development of a programmable toy train with a Tangible User Interface (TUI) based on tokens. Due to our "client" being the research group on design for interaction & technology driven design of the University of Antwerp, the focus of our project is:

1. The combination of a physical toy train and digital technologies attending to the user experience.

Alongside this main goal, three additional objectives have been defined by the team:

2. Endow the train with an educational dimension that helps children develop their motor and cognitive skills.

3. Develop an ecologically sustainable toy and include it within a sustainable business model.

4. Create a unisex toy.

Now that the main objectives of the project have been determined, these will be further developed and argued below:

1. The combination of a physical train toy and digital technologies attending to the user experience.

The goal of this project is to create a hybrid toy with which children can have both physical and digital interactions, the digital aspect being by means of an app. Therefore, the design is centred around the user. It intends to generate a unique experience, capturing, attracting, entertaining and educating the user. This is performed in order to stimulate the motor skills and senses of the children.

The app contains games which are both educational and fun, although the toy is still playable without the app, since it is only an added value so that the child can still enjoy it the same way with only the toy itself. To reach this goal, several prototypes of the toy were developed, after which children between the ages of five and six were asked to play with th em and provide feedback.

2. Endow the train with an educational dimension that helps children develop their motor and cognitive skills.

Taking into account the abilities and psychology children in that age group possess, this toy would focus the daily use of technology into a more productive and enriching activity to broaden, strengthen and develop their motor and cognitive skills accordingly.

During the growing stage the toy is aimed at, children tend to play with others in social games. The toy pretends to take advantage of this playtime to make it educational whilst keeping it fun.

Due to the rapid development of children at this age, it is necessary to make the toy capable of adapting the difficulty of the games, so the user does not lose interest by becoming more challenging for the child.

A measurement of the development of the children’s motor and cognitive skills are the games they will play, depending on the level of difficulty the child is able to surpass.

3. Develop an ecologically sustainable toy and include it within a sustainable business model.

During the designing process of the toy, the material has to be taken into account as it will have to comply with European Laws. Also, one of the team objectives is to use ecologically friendly materials that can be recycled in the future.

The sustainability and care of the environment is a point that is present throughout the life cycle of the product. It is a value that will be developed and included in the project. For this, sustainable and recyclable materials will be used, taking care of the carbon footprint.

4. Create a unisex toy

Usually, this type of toys tends to be aimed at a male audience. The project intends to eliminate these barriers and make it inclusive, equally appealing to boys and girls.

The measurement of this objective is achieved experimentally, through the evaluation that the product receives during the user tests.

Conclussions: to finish our project successfully, our main project goal must be achieved. This goal is the combination of a physical train toy and digital technologies attending to the user experience. The verification of this design through user testing should provide knowledge on how to design hybrid toys and further improve our own prototype. In addition, three additional goals have been defined: to endow the train with an educational dimension that helps children develop their motor and cognitive skills, to develop an ecologically sustainable toy and include it within a sustainable business model and last but not least, to create a unisex toy.

4. RESEARCH

Due to the nature of this project, special emphasis had to be put into the user experience. In view of this, comprehensive researches were performed, ranging from a market study to a psychology investigation, this to make an adequate toy for the target group and stakeholders, ensuring the success of this project. Our business model will also be detailed in this chapter.

4. RESEARCH

4.1 STATE OF THE ART

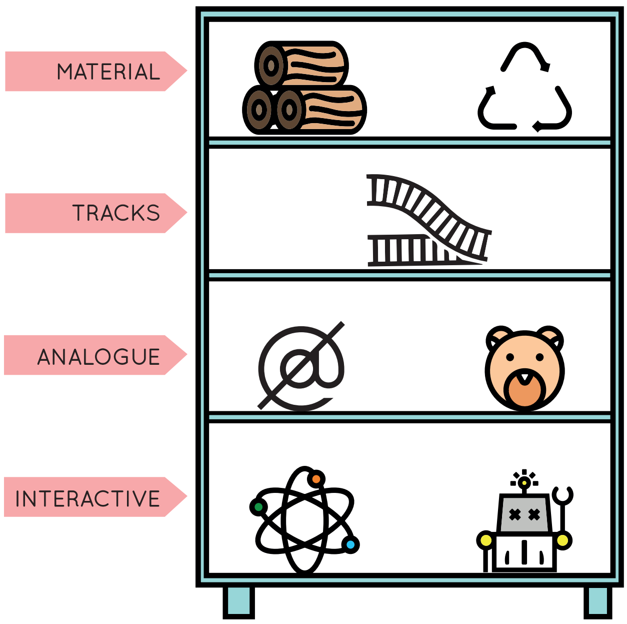
During the research phase, we decided to undertake a "state of the art" study by means of a market and intellectual property research as this term is extremely relevant in advertising and marketing, as well as in patent law. These are further explained in the subchapters below and their corresponding appendices (Appendix C and Appendix D).

Additionally, "state of the art" is prevalent in our project field as microcontrollers are in almost every consumer product, including toys, and this has pushed researchers into a race for innovation and improvement as it is a relatively new field.

4.1.1 MARKET RESEARCH

A market research has been performed to find out about the current situation of toys, with a view to finding a possible market niche, to observe what the main strengths and weaknesses are, and to identify the main competitors. The collection of toys and images that influenced the progress and development of the project can be found in Appendix C.

On the current toy market, there are already a large number of toy trains, most of which are analogue and do not include any interactive electronic components.



However, with the development of science and the increasing importance of technoogy, the development of these skills and concepts is being promoted from an early age, with educational programs such as STEM (Science, Technology, Engineering and Mathematics).

Nevertheless, simple challenging games with no technology involved can also be integrated into the track and turn the game more interesting, while developing certain skills, to help children explore and develop tactile, visual, auditory and physical experience.

Most of the toy trains have similar types of tracks, we saw this as an opportunity to develop a concept that includes a different track typology, to make the game stand out against competitors.

4.1.2 INTELLECTUAL PROPERTY

During the market research we also realised that intellectual property research had to be done: what rights applied to our project and why did they apply. All the features that can have these rights applied can be found within the main report in chapters 5.5.1, 5.5.2, 5.5.3 which regard the first, second and third iteration correspondingly and finally, in chapters 5.5.4 and 5.6 which pertain the final iteration and its components.

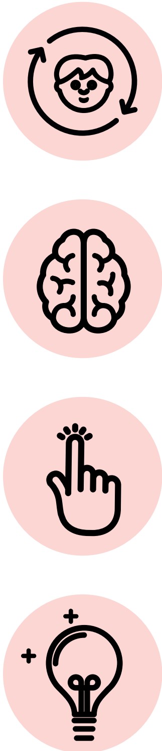
To begin this, we had to search rights that could apply to a toy train and its different components. From this we saw that we could apply trademark rights to our brand name and logo. Copyright could also be applied to the concept of our canvas model and the different iterations of our game story. Also, design rights to the aesthetic lines on the tracks that simulate railways, the fake wheels that hold the train on the tracks, the raised tracks, the character design, the design of the tokens and lastly but not least, the design of the buildings. However, we could not apply patent rights to our product as we have not invented something novel or discovered anything that makes things easier or more efficient.

On the aspect of the Arduino, we could freely use it without repercussions as it is included in Creative Commons however we could not imply affiliation to Arduino or include their name in our product or the name of the company.

The intellectual property is further explored in Appendix D.

4.2 PSYCHOLOGY RESEARCH

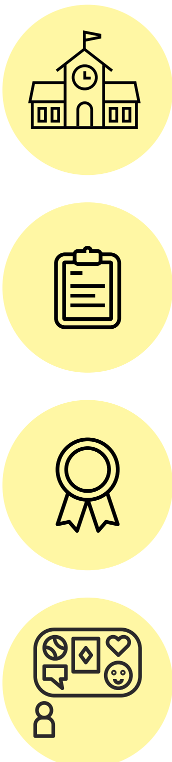
4.2.1 BENEFITS OF TOYS



Toys are a fundamental tool for the development of children. Through toys, the child will understand his surrounding unvironment, he will learn more effectively skills such as body-mind coordination and will develop its logical capacity, attention and observation. Thanks to toys, children progress and are able to accomplish more complex tasks.

Playing has shown strong and consistent relationships between children's playfulness and their cognitive and emotional development, providing a mechanism through which they learn to control aggression. Toys help to enhance imagination and creativity, to develop the fine motor skills of the fingers through manipulating pieces and to stimulate spatial intelligence. That is the reason why it is necessary to provide the children with enough playing time and to guarantee effective toys that stimulate their abilities.

4.2.2 PSYCHOLOGY OF 5-6 YEARS OLD



Playing is how children learn and build their social, emotional and thinking skills. "Exercise play begins to emerge during the fourth and fifth year of life and typically occupies around 20% of children's behaviour" (Whitebread, 2012).

At the age of 5, children start primary school. As Peter K. Smith showed in his PhD, social play increases dramatically from 2 to 6 years of age. They begin to create stronger links with their classmates and prefer playing with friends rather than on their own since they acquire social coordination skills and social scripts. Games with rules are challenging and make them feel participant and more mature. "Children need and seek multiple forms of joint involvement with adults, this enables adults to connect with children and provide guidance" (Baumer, 2013), that is why they need other´s approval and feel very proud of their achievements.

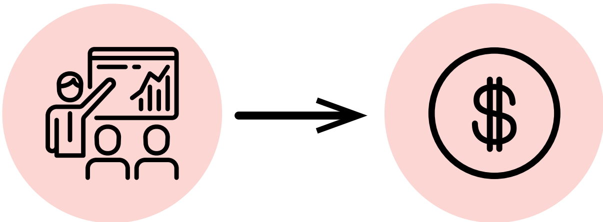
Sensory perception is one of the pillars that supports the mental activity of children, as it is the action they perform with objects that provoke the first mental reactions. The sense of sight is stimulated, among others, by colours. Certain colours stimulate children´s brain so they can associate the colour with real objects or situations around them. Colours can also provide excitement to children while they play. Through different sensory stimuli, different skills are promoted: toys in monochromatic and bright colours will stimulate eyesight; toys of varied shapes and textures allow children to learn about spatial relationships, patterns, shape recognition or tactile experience.

Elena Smirnova (Smirnova) pleads that Educational toys must be simple and open for varied flexible actions. The toys that restrict imagination because of their firmly determined nature, narrow down the space for the child's creative activity. Too complicated and too perfect toys predetermine the child's actions and force the child into a groove, making playtime a monotonous routine work. Simpler and less definite playing material permits a wider range of playing activities. In addition, it is important to seek possibilities of autonomy during the game, as well as direct experimentation, creativity and spontaneity. Children like role-playing and are able to imagine that they are someone else and may fantasise about being airplane pilots, police officers, doctors, or teachers (Marianne Szymanski, president of www.toytips.com).

There are gender differences when playing. Children tend to choose partners of the same gender. "It is usually attributed to processes of social identification, of which gender identity is one of the main aspects and tends to increase as children deepen their understanding of gender differences. In large groups, children of the same gender and age similarity tend to be drawn together to form play subgroups." (Gosso, 2013).

Ideally, the focus of toys should be towards interactivity and user experience (Socaciu, 2011). Marianne Szymanski suggests that five years old is a good time to introduce interactive educational toys that teach math and verbal skills, such as phonics boards or minicomputers. "Choose toys that say positive things like 'Good job. Let's try again' instead of ones that make negative beeping noises whenever children get an answer wrong."

4.3 BUSINESS MODEL



Throughout the research phase of the project, the team had to decide what our business model would be, meaning, we had to describe the rationale of how our "organisation" creates, delivers, and captures value, in economic, social, cultural contexts. Through this research, we decided to continue with the "hybrid toy" business model.

In this model, the buyers would be the parents, grandparents or guardians of the users, since they have the purchasing power. Early adopters of our product could be parents of children with available smartphones that are interested in educational games that enhance their children's motor and cognitive skills by interacting and getting in contact with physical and digital components, or need time for themselves and get it by the means of distracting their children with a fun and educational toy.

Going on to the value propositions, our product would deliver hours of fun and play to our users, whilst developing their skills and imagination and as previously stated, more free time for the parents which in this case are the buyers.

On the side of the revenue streams, our main revenue stream would not be the starter kit but the add-ons/complements to the game. We would sell the starter kit, composed by the basic elements which allow to play the game, with little margin for profit to get as many customers as possible into the ecosystem and once they are in, sell them complements and in-app purchases with a larger margin of benefits.

To calculate the cost structure, we would have to include the labour hours, all the infrastructures such as factories, labs…, software licenses, logistics, material costs and finally, transportation.

Whilst developing this business model we had to consider what our Achilles heel would be, meaning, what disadvantages this model would bring. We saw that due to the nature of our toy, whilst using the app, distraction may occur due to other apps and notifications. Additionally, our product may be more expensive due to its hybrid nature.

This business model is reflected in the iterations subchapter since it conditioned the design of the basic pieces that compound the game, and for further information on the different business models, we researched, please refer to Appendix E.

Conclussions: From the research we accomplished we can see that in the current toy market, there already are a large number of toy trains, however, these are mostly analogue, not including any electronic components. Additionally, most of the trains have similar tracks, leaving an opportunity for development and improvement in this sector.

On the intellectual property side, we saw that we could apply trademark rights, copyright, design rights and software rights. This is further explored in Appendix D.

We also noted that toys are a fundamental tool for the development of children, helping them learn and build their social, emotional and thinking skills.

Finally, we chose to go with the "hybrid toy" business model. Details on this can be found in Chapter 4.3 and Appendix E.

5. PROJECT PROCESS

To achieve all our goals in this project we had to carefully organise and draft a plan. After this plan was created we started coming up with various concepts for the toy. Once one was decided on, it was further modified and expanded branching into multiple prototypes and iterations of the train and app. All this process will be detailed in this chapter.

5. PROJECT PROCESS

5.1 PROJECT PLAN

Before work on the project process was started, a project plan was made. This project plan divided the work into four main sections. Each of these sections represent a different phase in the project process. These phases are discussed below. For further details, read Appendix F.

Phase 1 – Research

During this phase, a considerable amount of research was conducted in order to be able to properly brainstorm in later phases. This research includes:

- Market research, which gave us a broad view of similar toys on the market.
- Psychology research, which helped us understand our target group.
- Field research, where we studied children in a school in order to gain a better understanding of how they play with toys.

Phase 2 – Brainstorm & development

The second phase consisted mostly of brainstorming and the creation & development of concept ideas. The goal of this phase was to develop a concept for the hybrid toy which would then be prototyped in a future phase. While developing the concept, brainstorms were held about various aspects of the toy, such as the track design, train design, (app) games, the app interface and extra features such as tunnels, bridges, etc.

Phase 3 – Formalisation and Prototyping

In this phase, the concept was developed into multiple iterations of a prototype. Each iteration required rapid prototyping techniques to verify dimensions and interactions, evolving from a low to a high fidelity prototype. Meanwhile, the illustrations and the programming for the app and electronics for the train were being executed. After each iteration, the strengths and weaknesses were assessed, which determined the focus and aim of the next iteration.

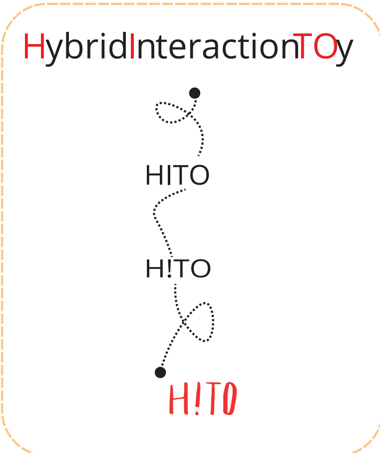
Phase 4 – Verification

The final phase of the project intended to verify our "final prototype". During this phase a user test was performed with eight children from the same school. From those results, final suggestions for improving the game were extracted. Finally, we formulated some general guidelines to take into account when designing hybrid toys.

In the subchapters below, an in-depth overview is given of the actions performed during the project process.

5.2 CORPORATE IMAGE

The corporate image reflects the project ' spirit and its aesthetic approaches the target group. The brand name we created is: "H!TO" . This name arises from the combination of the first letters of the project name (Hybrid Interaction Toy). The combination of the letter H with I forms the word "hi", (greeting), so it seemed like an interesting approach to emphasise the interaction between the user and the game. The imagotype (Figure 1) expresses fun, joy, dynamism, modularity and vitality.



To achieve this consistent appearance, we made use of the three RGB colours with some modifications, to make them warmer and contrast each other, plus one extra colour (orange) to balance out the logo. All four colours are cheerful, playful and convey an image of dynamism and vividness.

The logo´s shape consists of three basic geometrical shapes. Being composed of different elements located within a main figure generates the sensation of dynamism and being able to move the components between them to create different combinations or construct larger objects as if it were building blocks.

A detailed explanation of the corporate image can be found in Appendix G.

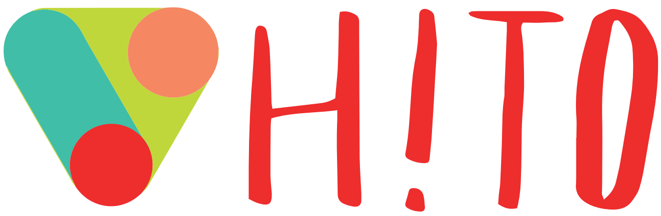


Figure 1: Imagotype

5.3 INITIAL CONCEPTS

After the research phase, we came up with three distinct concepts for the hybrid interaction toy. These concepts are the merchant train, the obstacle circuit and finally the maze train. The concepts are explained more in depth in the corresponding order.

MERCHANT TRAIN

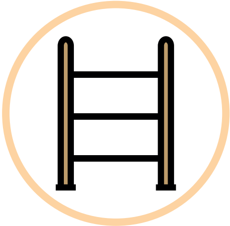
The first concept the team came up with was the merchant train. The main parts that compose this concept are the train, the wagons, the rails with sockets for the RFID tags, RFID objects, the stations, the scenery objects, the smartphone application and finally a conductor identity card.

The user will be provided with different items such as vegetables and fruits. At the start of the game, the smartphone application will prompt the user to place certain items into the train wagon. The smartphone will also inform the user about the destinations for each item. The user will have to scan the item in the first wagon and then place it in the second wagon. This is done because if the RFID reader were in the wagon the user places the items in, each item would interfere with the reading of the rest of the items. Once the user places the items inside the wagon he or she will have to press the ready button on the smartphone. After this, the user will have to scan their conductor identity card in the first wagon to launch the train.

Each station is marked by an RFID tag that will be placed slightly before the station to give the train time to stop, this is done so the user can choose at which station to stop the train. This can be accomplished by pressing the stop button on the smartphone. This will stop the train at the next station.

Once the train arrives at the desired destination, the user will have to scan again the corresponding item in the first wagon and then place it into the train station. The app will know if the user has placed the correct item at each station will have an identifying tag which the train will have read before scanning and placing the items in the station.

Following the placing of the items, the user can press the launch button on the smartphone. The user will continue placing the items at each corresponding station until finalising the delivery. The smartphone will inform the user if they have successfully delivered the items and how long they have taken to accomplish this.



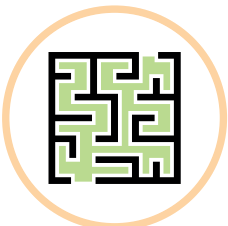
OBSTACLE CIRCUIT

The second concept the team came up with was the obstacle circuit. The main parts that compose this concept are the train, the rails which will consist of a black line on different wooden boards, obstacles, lifts, the scenery objects and finally the smartphone application.

The train will follow a black line on the wooden boards which will have different shapes and routes. The train will be able to do this by the use of an infrared sensor.

Different obstacles will be placed on the black line, and depending on the colour of the obstacle, the train will dodge it in a different way to continue on from the other side of the obstacle. In addition to static obstacles, there will be automated obstacles. Once the train arrives in front of one of these obstacles, it will stop, and the user will have to use the smartphone application to move the automated obstacle. Once this is done the train will continue on its journey.

The circuit will be composed of different floors which will be accessed by manual elevators and ramps. Once the train arrives to the elevator it will automatically stop. Once this happens the user will have to manually move the elevator with a wheel. Once the elevator reaches the top the train will automatically start again. The train will know how to do this by the usage of a colour sensor which will detect if there is a wall in front of it. The colour for the wall in front of the elevator will be orange, to help the train differentiate with other obstacles.



MAZE CIRCUIT

The third and final concept is the maze train. The main parts that compose this concept are the train, different shaped walls and a smartphone application.

The train will start by pressing a button on the smartphone. The game consists on the user attempting to create the most difficult maze possible using different shaped wooden walls. Once the maze is built, the train will have to be placed at the entrance and started by using the smartphone. The train will travel through the maze and detect walls by the use of an infrared sensor. Once it detects a dead end it will backtrack and remember the route it just did towards the dead end. After this it will try out another route until it gets out of the dead end. The train will do this pattern until finding the exit.

5.4 FINAL CONCEPT

The concept we decided to focus on was the merchant train concept. This is mainly because we thought it was the most entertaining to our target audience, and the most expandable in terms of content and features. The other concepts have not been completely discarded though, as elements from those concepts, such as obstacle detection, could potentially be added to our prototype in the future. More information related to future improvements can be found in the subchapter 7.4.

The tracks associated with this concept are the ones with the option of integrating tokens. The benefits these bring range from providing the ability to reprogram the tag to perform a different function, which increases in the product's versatility and capability of becoming evolutive and challenging to fit the child's needs, to the easiness of installation. This means that it can conveniently be inserted in the desired track without disassembling the entire path and can be replaced if lost for a reduced price rather than acquiring the entire track. However, this version of the tracks come with a disadvantage which is due to the tokens reduced dimensions, they could easily be lost or swallowed. More information dealing with the different tracks we researched and came up with can be found in Appendix H.

In our adaptation of the merchant train concept, the game will not just be a list of items that need to be collected in order to complete the game. Instead, our version contains an actual story as well, to provide context to the actions the user is performing. The main reasons for this change were to get the user more interested in the game, as their actions will have reasons behind them, and to allow for even greater versatility. By adding stories to the merchant train, we could keep expanding the app with new stories in which the user would have to perform different actions, without the core game concepts becoming uninteresting. The last reason for adding a story is that it would require the users to think while playing in order to remember previous hints and to figure out what to do next.

5.5 ITERATIONS OF THE PHYSICAL PROTOTYPE AND APP

5.5.1 FIRST PROTOTYPE / ITERATION

The first prototype that came from our concept revolved around simplicity and modularity, as this would result in a very versatile prototype. The purpose of this first prototype was to explore the possibilities for future games, features and/or designs. Most of the physical elements exploring the possibilities of the merchant train concept revolved around building blocks. The building blocks for this prototype consisted of three basic shapes: cubes, cylinders and rectangles (Figures 2,3), which could be used to build more complex constructions such as the stations, bridges, fences... (Figures 4,5)

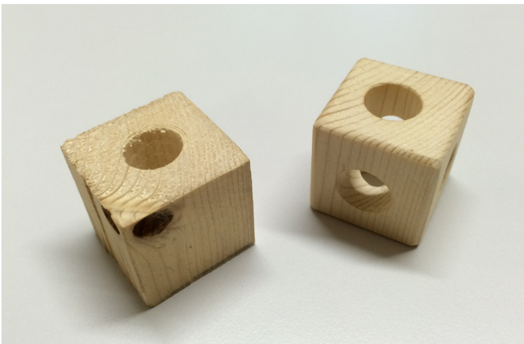


Figure 2: cubical building blocks

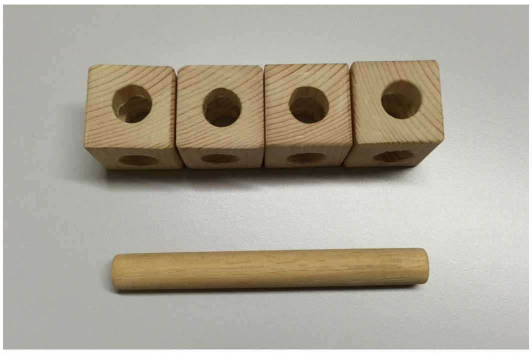


Figure 3: cubes and cylinder building blocks

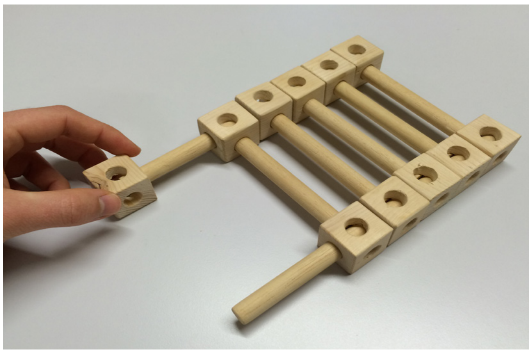


Figure 4: structure with building blocks

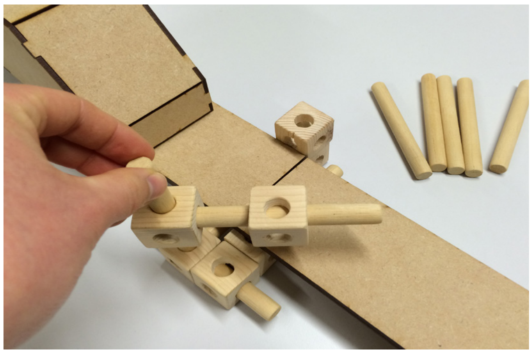


Figure 5: fence with building blocks

The rectangular shapes were defined as the tracks, with grooves on the faces of the ends, where rectangular flat pieces would be introduced in order to join the tracks with each other (Figure 6). The fact that these connector pieces were slotted in grooves meant that they would not be visible once two track pieces were slotted together, which would lead to a clean aesthetic. The reason why these pieces were not part of the tracks but were independent pieces was to enable the usage of the tracks as a modular element for building the stations or other elements of the scenery, combining it with the other basic building blocks. As the tracks could be used in the construction of buildings, no actual graphic design was applied on their surface, as otherwise they would be less appealing to be used.

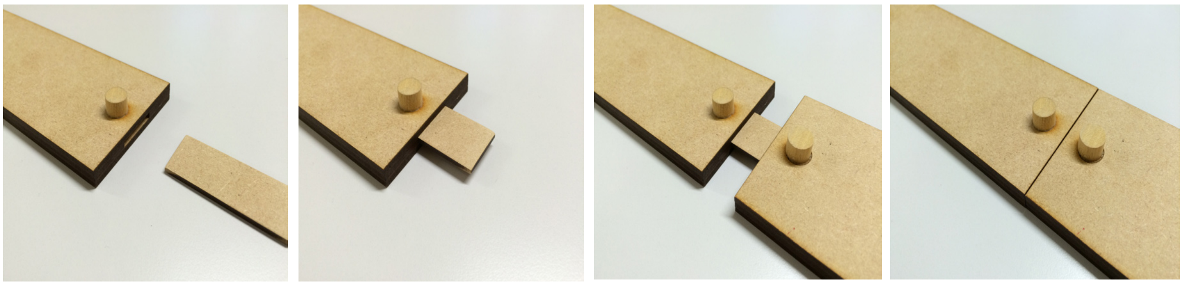


Figure 6: tracks with external joining part

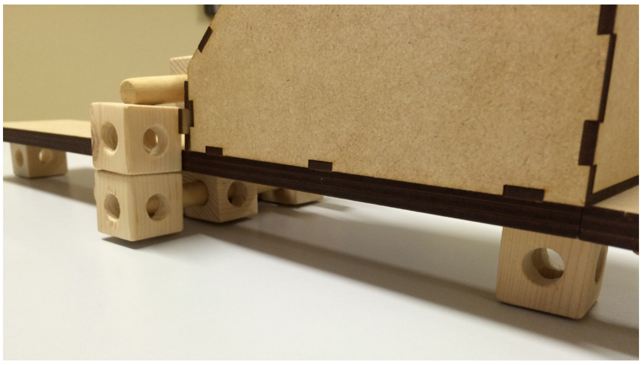
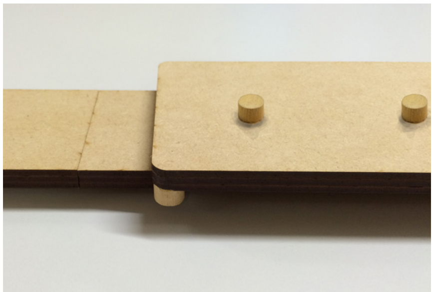


Figure 7: elevated tracks with building blocks

These tracks had small cylindrical protrusions on the underside so that the tracks could be combined with the cubes, defined as the connection elements because of its hollowed structure, to form different buildings whilst also serving to raise the circuit (Figure 7). We thought it was a very attractive idea because normally the train circuits are directly placed on the ground. Introducing this concept, we got a morphological variation, and we managed to suggest that the tracks were floating above the ground.



On another note, these small modular cubes could also be the goods to be transported. In order to do this, the wagons had small ledges on the upper face on where to pile up the goods (figure 8).

Figure 8: ledges in wagon

However, there were several problems with these building blocks that were found once the iteration was prototyped:

- By only using three different shapes of building blocks, the eventual shapes of the buildings were limited and rigid.

- After discussing with our supervisor, we were reminded that the focus of our project should be in the interaction between physical and digital play elements, instead of the construction aspect.

- The distances between the cylindrical protrusions were not standardised, which could cause complications when assembling buildings.

- The cubical connector blocks didn't contain any connector-mechanisms, and the wooden material had changing tolerances depending on humidity and other external influences, which would result in the connection between the cube and the cylindrical protrusions to be insufficiently stable.

- The connector pieces were only 3mm thick, as everything was prototyped in sheets of 3mm MDF wood laser cut to materialise the prototype in a quick and precise procedure. This means the pieces would break easily and, as they were small and separated from the tracks themselves, they would be easy to lose.

- The wagon had an elevated friction with the tracks due to its substantial contact surface, so it was difficult to move with ease the wagon along the tracks.

In parallel, the model of the train and the wagon was being developed using a 3D modelling software, SolidWorks, in order to determine proportions and dimensions of the final toy and ensure all the electronic components would fit inside. However, as the functionality and interactivity of the app with the train was constantly modified, it was not entirely certain the exact electronic components that were to be used, so the 3D model was in constant changing.

5.5.2 SECOND PROTOTYPE / ITERATION

Taking into account the problems encountered with basic shapes during the previous iteration regarding the aim of the project, we designed the stations by means of flat faces that were joined together through small flanges which were located at both ends of the pieces (Figure 9).

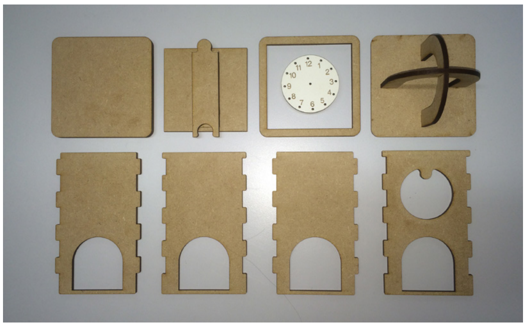


Figure 9: stations

This caused the scenario to leave less room to the imagination since the child could no longer create the stations to his liking. On the other hand, the centre of attention of the project is the train, not the construction aspect, and it avoids the fact that the child may lose interest before getting to play with the train itself.

To make the scenario more appealing, each station included a distinctive element that differentiated each building. A first tower (Figure 10), with a hole to insert an add-on clock, and a structure that resembled a dome were developed. In those add-ons, it was intended to include an RFID sticker so that the train could detect when it had reached a certain station (Figure 11). This was not viable because for the train to be able to read the station it passes through, it needed to be only a few centimetres away from the tag. For this reason, we decided to implement the station tokens into the tracks, as this guarantees the shortest distance between the RFID reader and the tag.

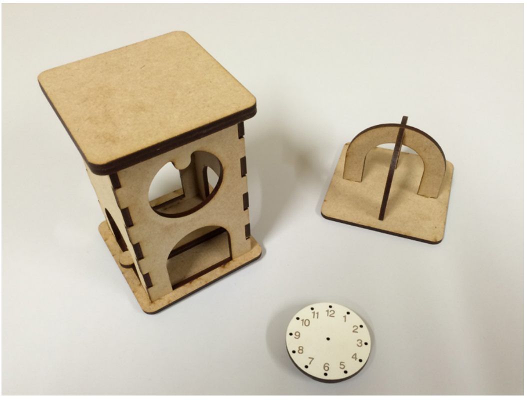


Figure 10: tower station

Figure 11: tower station with clock add-on

For the design of the token, we considered that they had to have a minimum size to fit the RFID sticker inside, as well as so that they could not be swallowed by the child nor lost.

In addition, since the tokens must be able to be placed and removed easily, we made them accessible from the side of the tracks, to have direct and comfortable access, considering the motor skills in the children's fingers.

Each token arranged in the tracks represents a station, as it was not technically feasible to identify the station in any other way since the train had to read the tag from a very close distance. The fact that the engraving of the icon represented the station meant that that token could only be used in case the app's game included that specific station.

In order to solve the problem with the tag detection, we considered the possibility of placing the buildings on top of the tracks, so that the train would be able to pass under the doors of the building, and placing the tokens in the tracks. Later, once we prototyped a real size version of the train in which all the electronic components fitted, we realised that this idea was unrealistic. The reason was that in order for the train to be able to pass through, the buildings would have had to be upscaled, which made them look too oversized and unappealing to our target user.

As for the tracks, we prototyped them with the joining part included in the piece itself. This meant, one side of the end had a groove, and the other had a rectangular protuberance. With this, we managed to reduce the number of pieces and the possibility of losing them, thus ameliorating the way of assembling the tracks.

Moreover, we included engraved line drawings (Figure 12) by laser on the tracks so they would resemble real train tracks better and look more striking and attractive.

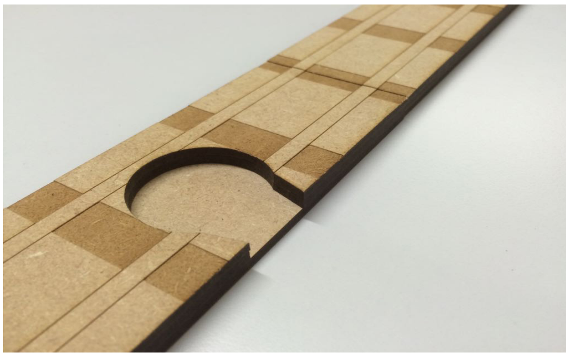


Figure 12: engraved drawings on tracks with hole for the token

App

This iteration of the prototype is the first to include concepts for the app. In our midterm version of the merchant train concept, the sole function of the app was to provide an inventory of the goods that were being transported between different stations. However, the added value of the app is quite disputable in this case as it only offers one additional feature. As expected, this weakness was pointed out by our supervisor who stressed the lack of a "fun factor" in this feature.

To increase the added value of the app we attempted to make it guide and challenge the child, rather than display an overview of transported items. We came up with the idea of an app that would confront the child with a problem case at the beginning of the game. The only way to complete the game is by solving subproblems which provide new clues.

The program used for the realisation of the graphics that have been implemented on the app has been Adobe Illustrator. Some graphics have been taken from free graphics databases, but the vast majority have been subsequently edited or personally designed to match the physical and digital reality.

The graphic style followed has been a flat style. This consists in the use of simple geometric figures, combined with different colours that contrast and generate some depth, without the need to use perspective. We chose that style since we wanted to keep the app child – appealing, minimal and not overwhelm the user with a complicated interface, thus making it intuitive and understandable. This style is simple both to make the graphics and to be understood and communicated to children from five to six years old, so it suited our needs adequately.

In the first concepts of the app game, the idea was that the hands of the local clock-tower were stolen, and that the user had to find them (Figures 13,14). This story was based around the physical clock tower station. In order to do this, the user had to interact with elements in both the physical and digital world, and travel between different stations (Figure 15) in order to obtain new clues about the stolen hands. The game would consist of having the user do seemingly unrelated favours for the local townspeople, which, after the user has completed them, would come together in one cohesive story that would lead the user to the thief.

Figure 13: beginning of the game
Hands stolen

Figure 14: Tower without hands

Figure 15: map with stations

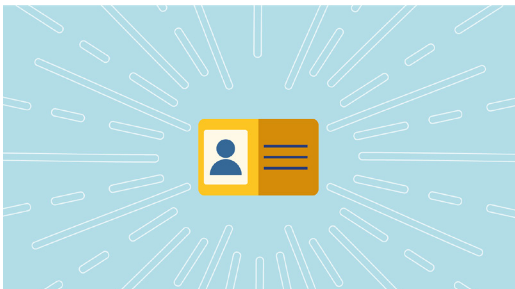


Figure 16: driving license

The idea of the child having a card with a tag inside simulating a driving licence (Figure 16) was developed, and when scanned with the train's RFID, the train would start moving from where it was located to the previously selected station.

However, after a meeting with our supervisor we concluded that this idea had some major disadvantages:

- There is a downside that lies within the need for an extensive collection of physical parts which would be time consuming to develop.
- The complexity of the game might be overly challenging for our target group.
- The joining method for the buildings were too tight and difficult to assemble.

Therefore, we moved on to the next iteration of our prototype in which we focus on simplifying the whole concept.

5.5.3 THIRD PROTOTYPE / ITERATION

In the next iteration, taking into consideration the extensive collection of physical elements that were developed for the app game, these were redesigned implementing the concept of modularity and versatility. Standard joint grooves were designed so that all the pieces could be joined together. The lateral walls, as well as the rear façades, had basic and neutral shapes. The frontal façades, however, were designed in a way that represent the stations involved in the app game. Moreover, different add-ons for the frontal façade were designed in order to give each station a distinctive appearance. Consequently, a tower, a bakery, a windmill and a tree were developed. The advantage that these buildings provide is that all the pieces can be combined, both the walls and the façades, randomly, to the user's taste.

A coloured version of the stations was made (Figure 17) with the same colours as the ones used in the application. This aesthetic was very attractive and cheerful; however, we thought the scenario of the game was too overloaded.

Figure 17: coloured version of the bakery station

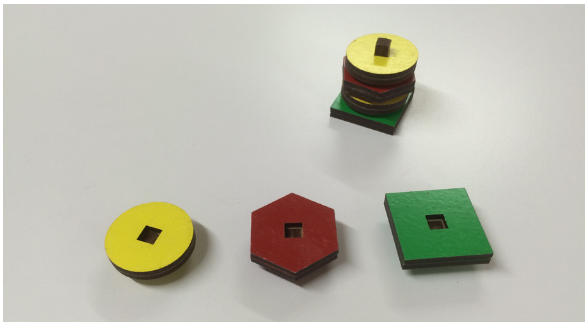


Figure 18: goods with basic geometrical shapes

The previous building blocks that were used as goods to be transported (the cubes with holes) were replaced by small pieces with basic geometric shapes (Figure 18). We preserved the idea that they could be placed on top of each other and also on the wagons. To achieve this, the pieces were designed so on one side they had a hole and on the other side a protuberance. We developed three basic geometric figures, with three basic colours. Each piece of a geometric shape had a colour associated with it. A yellow circular piece, a red hexagonal piece, and a green square piece.

We chose basic geometric shapes to give the game more modularity, and to deprive them of a figurative character/nature, being able, according to the game, to symbolise one object or another depending on the situation. For example, for a game, the red figures could be apples and the yellow one's wheat, and for another game, the red ones symbolised flowers and the yellow lemons.

Figure 19: token with engraved station

The same was hypothesised about the tokens. At first, the tokens were designed to have the shape of the station they represent engraved on their upper face (Figure 19). That meant, for example, that the token that represented the bakery station, had a cupcake engraved on its upper face, which clearly indicated that the bakery building had to be located in that place.

The fact that the engraving of the icon represented the station meant that that token could only be used in case the app's game included that specific station. Consequently, we thought about making tokens with a number instead of an icon so that they were more generic, and they could be linked to any station. For example, the token with the number 1 in a game represented the windmill, but for another game on the app, the token with the number 1 served to represent the town hall.

As these goods and tokens needed to be recognised by both train and app, they contain an intelligent tag inside in order for the train´s RFID reader to detect them. (Figures 20,21). The dimensions of the tokens and goods were established so that the intelligent tags could fit inside of them. However, in order to avoid the user placing the yellow cylinder in the token's holes, their size was reduced (Figure 22).

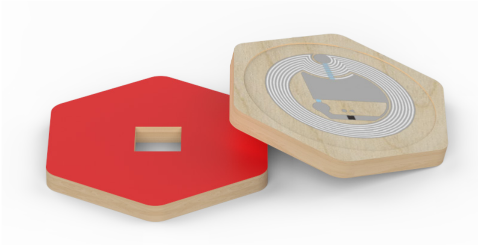


Figure 20: good with tag inside

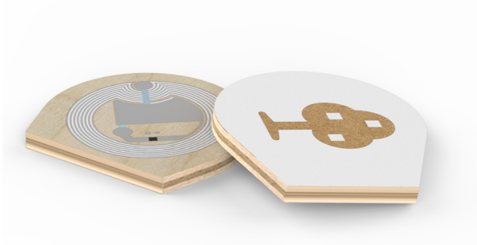


Figure 21: token with tag inside

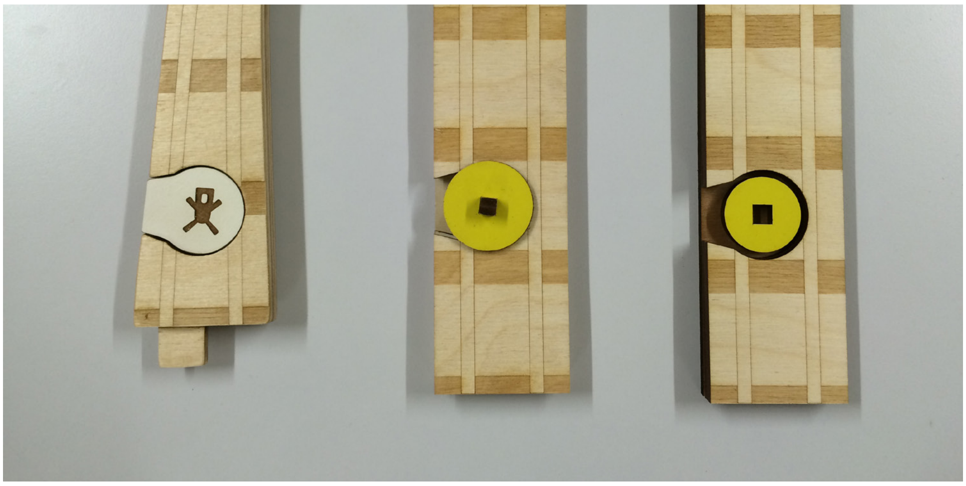


Figure 22: comparison size token and yellow cylindrical good

App

The next iteration of the app game would be much smaller in scope than the previous concept, the amount of characters being reduced to three: the user (represented by the 'driver'), a baker, and an old lady. In this game, the baker wants to bake a new type of cake, but he doesn't know the recipe (Figure 23). The user can help the baker by both discovering said recipe, and by gathering the required ingredients.

Figure 23: baker asking for ingredients

The recipe can be obtained from the old lady, but only after helping her; she is in distress because her cat is stuck in a tree. In order to help her, the user would have to travel to the different stations to find a ladder, as they cannot rescue the cat without one (Figures 24, 25, 26, 27).

Figure 24: old lady asking for a ladder

Figure 25: old lady traveling from stations

Figure 26: station from where the lader needs to be taken

Figure 27: old lady asking for a ladder

Once the recipe is obtained, the user will know what ingredients they have to gather (Figures 28, 29) for the baker in order for him to be able to bake the cake.

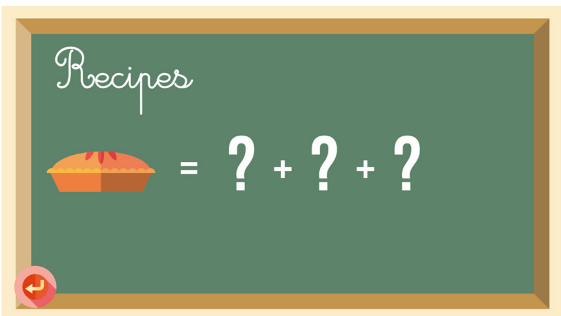


Figure 28: recipie without ingredients

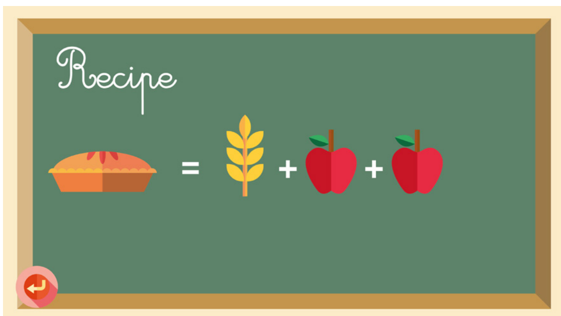


Figure 29: recipie with ingredients

These ingredients can be found in the various stations, and the user must drive to each station in order to gather all of them (Figures 30, 31, 32, 33). Once gathered, the user can return to the baker to deliver both the recipe and the ingredients, who will finally bake the cake. Game completed!

Figure 30: apples can be find in the tree station

Figure 31: wheat can be find in the windmill station

Figure 32: transported elements are shown in the app

Figure 33: baker did the cake!

Some small characters were designed (Figure 34), representing the characters in the stories of the mobile application, and with which the child must interact and play. All the characters inside have an intelligent tag (Figure 35), so that when the child scans them on the train, the application detects who is on the train. This is done to know who is being transported, and once the user wants to drop that character off in another station, he or she will have to scan it another time for the application to know that the character has been taken to the current station. All the characters have a small hole in the bottom that enables placing them in the train or the wagon, as these have cube shaped pins, so the characters can be inserted into them.

Figure 34: driver, old lady and baker characters

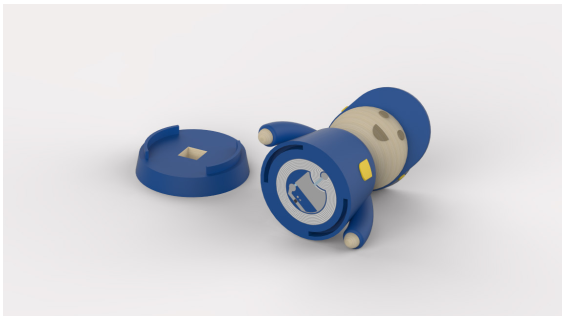


Figure 35: character with intelligent tag inside

After performing a pilot user test however, we realised the children were often struggling with the basics of the prototype and the game:

- Children did not build the stations or the tracks in the intended manner
- The link between the physical objects and the app was unclear
- It was difficult to understand what to do in the story.
- Children had difficulties when joining tracks and tried to join them the wrong way around.

Due to this feedback, and after a consult with the usability teacher, we concluded that the app should probably include tutorials in order to help the children understand the interactions between the digital and physical components better. However, this app was rescued later on and a simulation surrounding it was created with Flinto, an app prototyping program.

5.5.4 FINAL PROTOTYPE / ITERATION

Taking into account the problems discovered after performing the pilot user test, several actions were executed:

- To start with, a modification in the design of the joints of the tracks was made to make more polyvalent unions (Figure 36). This was achieved by placing on both sides of the ends of the tracks a groove and a ledge. In this way, we the curved tracks can be joined in both directions, or, more specifically, form a semicircle path or an S path (Figure 37), in order to create circuits with greater variety.

- The focus of the app was reoriented into providing simple tutorials for the users, instead of providing actual games, in order to help the user understand how to interact with the various aspects of the toy set. This is further developed in the app section.

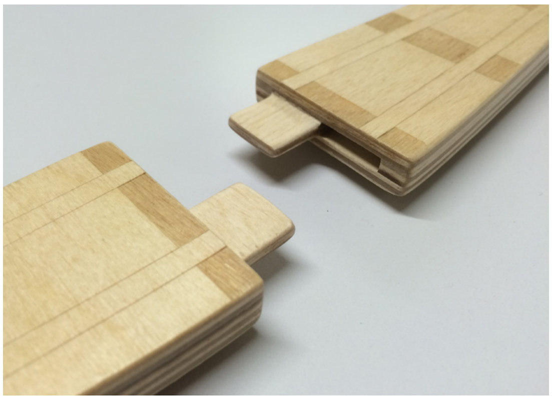


Figure 36 : Detail of the joining system

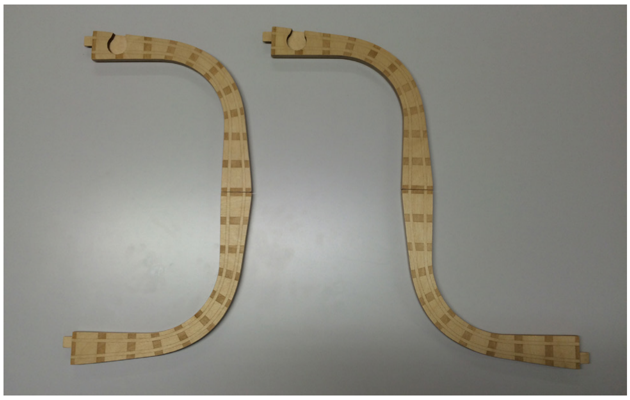


Figure 37: semicircle or S path

Once determined the exact electronic components that were going to be implemented, a 3D model of each component was sought in order to design the train toy according to their exact dimensions and to fit everything inside correctly. This way, we could design the train without wasting empty spaces to avert ending with a bulky toy. Inside the vehicle, supports and mounting bosses have been strategically designed (Figure 38, 39) and located to fix all the electronic components with screws. As a result, the risk of accidentally disconnecting cables due to sudden movements has been reduced. More details regarding the electronic components can be found further on in this chapter.

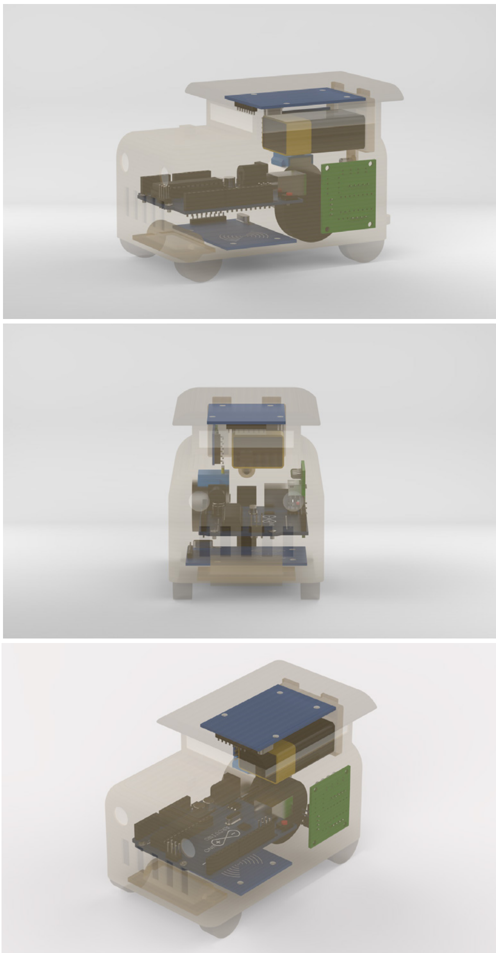


Figure 38: inside of the train with components

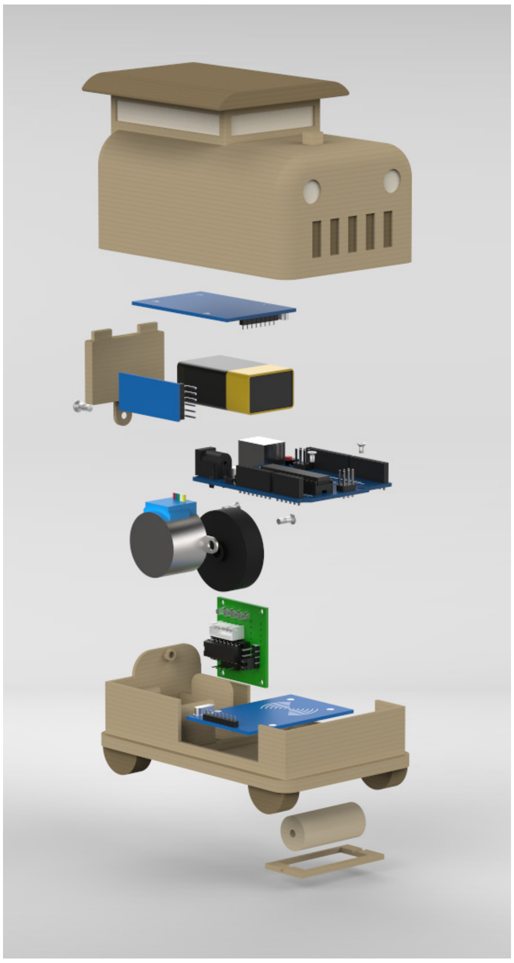


Figure 39: exploded view of the components

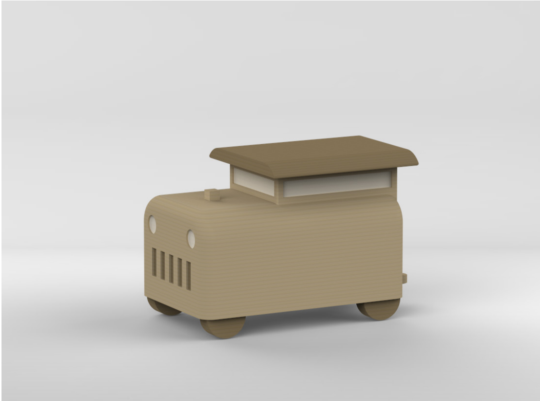


Figure 40: train's appearance

The final train design (Figure 40) has a simple and minimalist shape, similar to a driver's cab, to provide the child with an association between toy and reality. To make a more child-appealing and friendly aesthetic, and comply with safety regulations for toys, all the edges are rounded. It has a small ledge in the front, where the driver must be placed.

The toy includes two RFID readers, one located in the upper part of the driver's cabin and one in the lower part of the train, because we encountered the problem where if placed too close to each other, both readers could interfere with each other. The first RFID reader, which is the element that detects the interaction between the child and the app, scans the goods and the driver, and the second, which is the element that detects the interaction between the toy and the app, detect the different stations.

In the same compartment as the second RFID reader is stored, the battery that feeds the toy is located (Figure 41). Since it is a battery of high wear, a lid was designed on the back of the train to access it and replace it, attached to the main body by a screw and thus prevents the child to easily access the battery and the other internal electronic components. A switch has been implemented in the physical prototype of the train (Figure 42), in the same back face as where the lid for the battery is located.

Figure 41: render of the back of the train

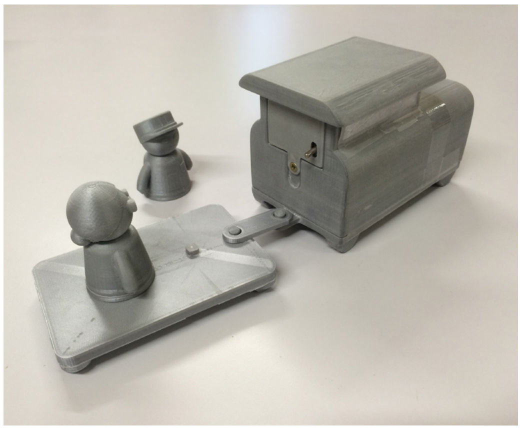


Figure 42: 3D printed pieces: train with switch

As the tracks do not provide support for outer wheels, they had to be implemented inside the train. Our first solution was that it only had two wheels centred on its underside, one behind the other. However, due to the components that had to be located inside, we realised that we did not have enough space to connect both of them to the engine, which would be the stepper motor. Moreover, the train would have to be balanced with support wheels. For this reason, we had to modify the design to have a single central wheel, guided by an engine, and two small free wheels located at the back (Figure 43). The purpose of these wheels was only to avoid the instability of a single driving wheel, so there is no engine attached to them.

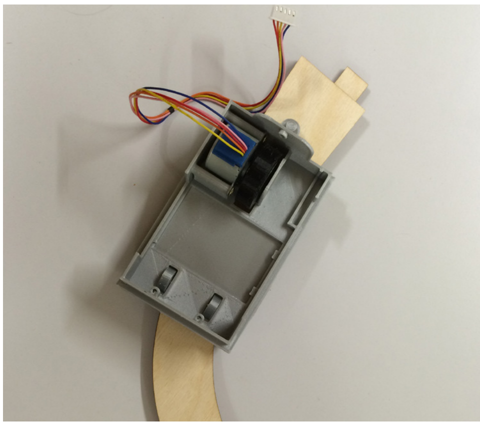


Figure 43: prototype with two small wheels at the back

These two wheels were eventually replaced by one single central cylinder-shaped wheel. The reason why the two wheels were changed is because one of them derailed on the curved track (Figure 44), therefore, not maintaining constant contact. This single cylindrical wheel solves this problem and eases the mobility of the train around curves better (Figure 45).

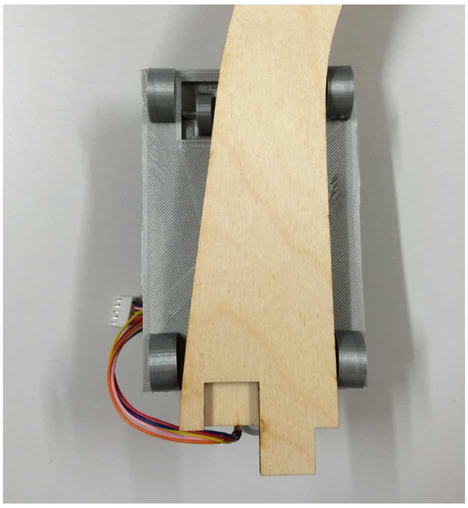


Figure 44: one wheel derails the curved track

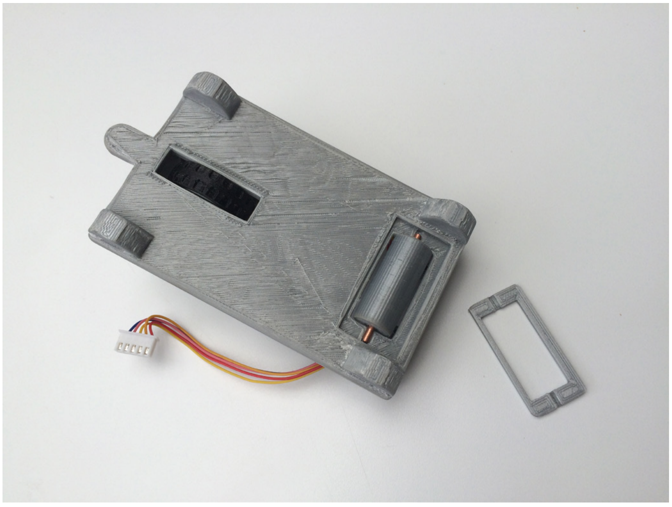


Figure 45: cylindrical wheel

To stay within the tracks, the train has four fixed ledges, simulating the four wheels of the vehicle, located in each corner of the underside of the train, as can be seen in Figures 41, 44 and 45, so that these protrusions are outside the tracks and keep the train in place.

The train is joined to the wagon by means of a simple intermediate piece that has the function of a joint (Figure 46). It was necessary that this piece could rotate slightly

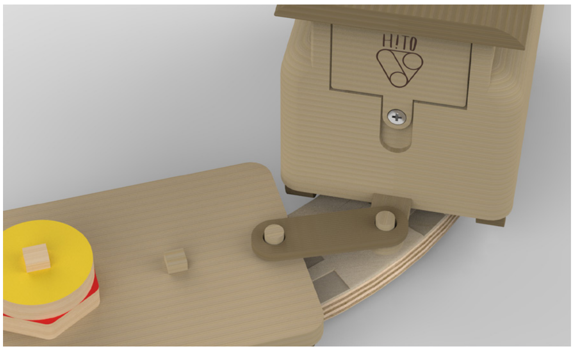


Figure 46: connecting piece

around the connecting protrusions of the train and the wagon, to endow the whole set with a loose fit. Otherwise, the set would not be able to move in the curved tracks because of the ledges located at the bottom of the toy which would get stuck in the track.

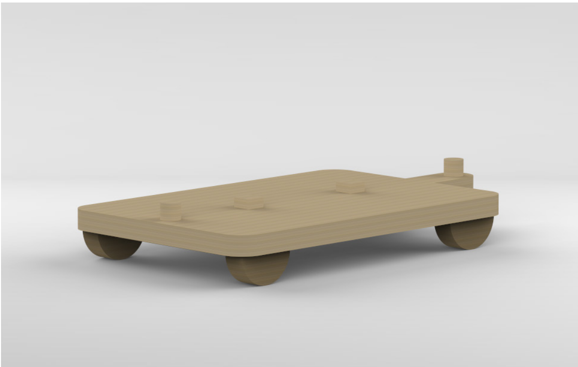


Figure 47: wagon's appearance

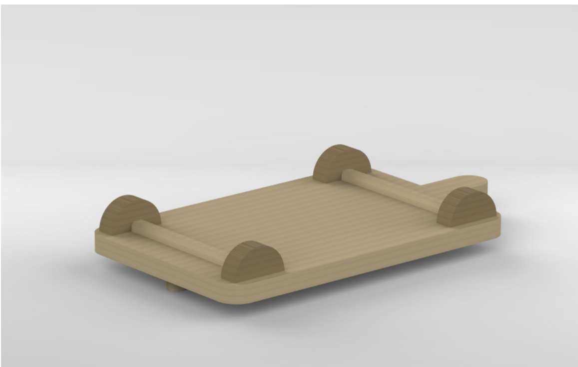


Figure 48: wagon's lower face

For the design of the wagons, we followed the simplicity and minimalism implemented in the train design and, therefore, all the edges are rounded (Figure 47) . For this element, the use of wheels was not necessary because it does not have an engine but is dragged by the train. That is why we decided to dispense with the wheels and replace them with the same system as the train explained above. That means that it has four ledges, simulating the four wheels of the vehicle, located one in each corner of the lower face. In order to reduce the friction produced when dragging the wagon over the tracks, we included two thin longitudinal surfaces in the lower face (Figure 48), which go from one side of the false wheels to the other.

The shape of the wagon and train has direct implications with the design of the curved tracks. This is because as the four ledges that keep the toy on the track are fixed, when making the curve some slack is needed so that it does not get stuck (Figure 49).

Figure 49: path of the wagon/train along the curved tracks

That is why the curved tracks were designed with a slight narrowing (Figure 50). To make the calculation of the curve the wagon described, we applied an experimental method (Figure 51). By drawing the curve with a pen.

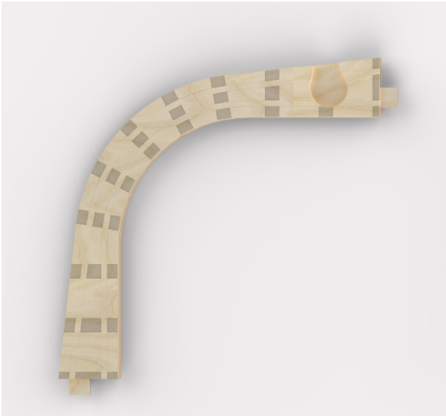


Figure 50: curved track

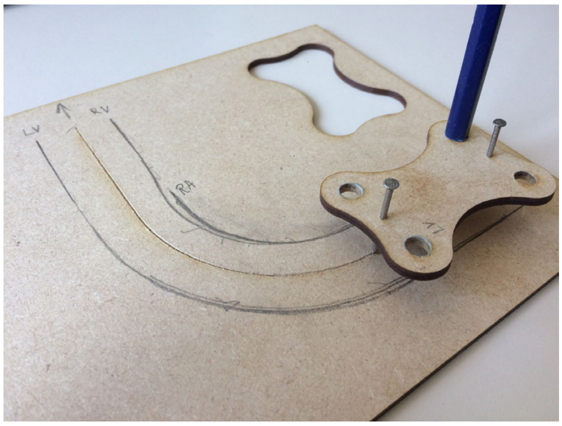


Figure 51: experimental way to calculate the curve

The material chosen for the final prototype has been wood for all the elements, except the ones that, because of the complex geometry, had to be 3D printed. Due to our great interest in sustainability and circular economy, we researched alternative materials (Appendix I), such as bioplastics, which we could use for our toy. However, we realised that all those new bio-based materials, which sound promising, had not been developed enough nor tested to be implemented in a product with such high safety standards as a toy. That is the reason why we discarded the use of those plastics and we considered using wood. Moreover, products made from wood are timeless, durable, hard, resistant to scratches and shocks, they can easily be cleaned. Wood is a safe material and implies good quality.

Due to the complicated internal geometry of the train, prototyping the toy in a conventional way such as cutting the different faces and joining them later would be a very complicated and long task, and since making an injection mould to obtain the model would be very expensive, it was decided that we would implement 3D printing technology. Through this technology, it has been possible to obtain the model with great accuracy and with a relatively low cost and time consumption.

To acquire harmony between the tracks, which are made of wood, and the train, we have opted for the implementation of plastic filament with wooden reinforcement (Figure 52) , which gives the user a similar visual, tactile and olfactory sensation to wood but with the advan-

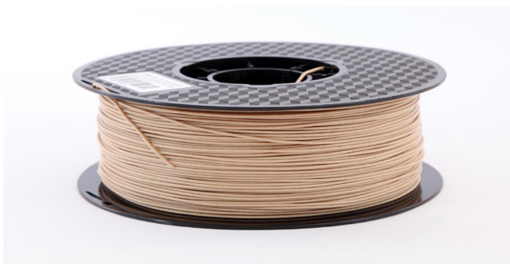


Figure 52: PLA wooden filament

tage that this material is lighter than wood. This filament was also used for 3D printing the characters (Figure 53).

However, after 3D printing some pieces with this filament, we realised that the quality and accuracy were insufficient, which is why we covered the 3D printed pieces with a thin wooden layer and painted the characters to make them more attractive and stand out from the rest of the set. In this way, the characters had an aesthetic which resembles the one in the app.

Figure 53: 3D printed character with wooden filament

Moving on to the tracks, these were finally designed in such a way that they could be stacked, to increase the effectiveness when putting away the game (Figure 54). The concern arises from the fact that the tracks have the protrusions to raise them, and in this way when stacking one on top of another, some space is lost. That is why these supports are designed to optimise the stacking surface. These protrusions were designed with an elongated shape and arranged on the underside of the tracks, near the ends, to ensure a greater contact surface and therefore greater stability.

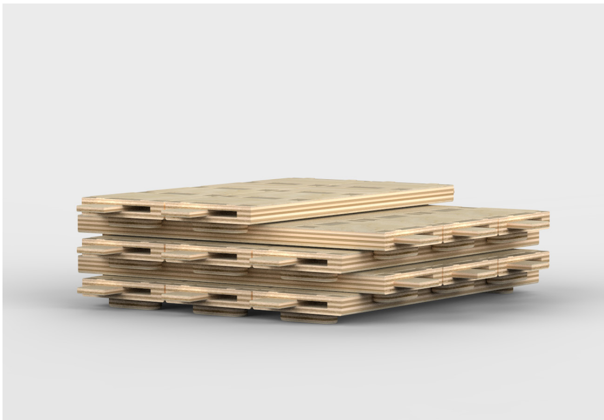
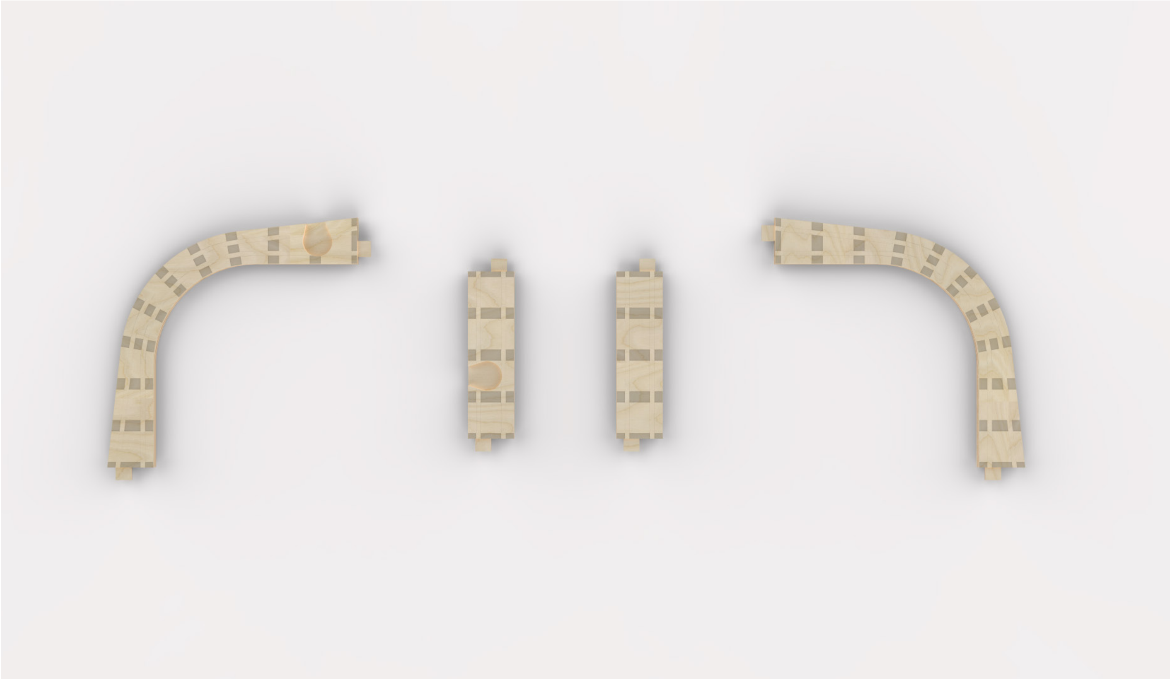
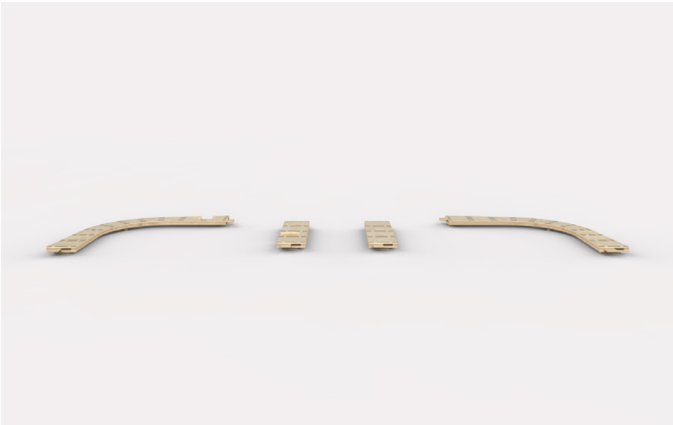
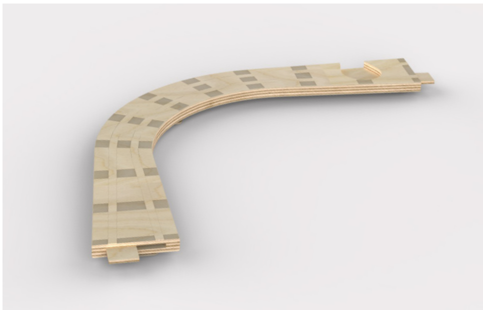


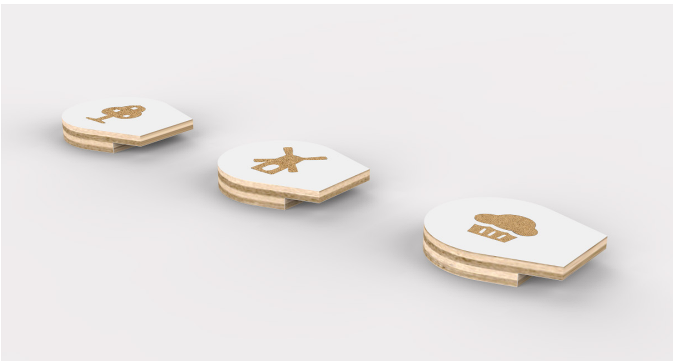
Figure 54: tracks stacked

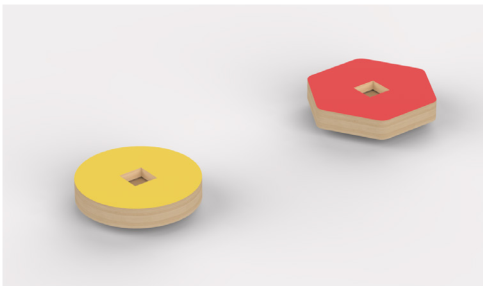
For the final toy set, a basic kit was created. This kit consists of four straight tracks and four curved tracks (Figure 55, 56, 57 ,58). Two of the straight tracks and one of the curved tracks have a token hole since only three stations are used in the app games. Therefore three tokens are also included (Figure59): one representing the bakery, another representing the tree station, and the final one representing the windmill. The kit also includes three characters (Figure 61): the driver, the grandmother and the baker. It also includes the walls, façades and add-ons necessary to build the different stations : bakery (Figure 62), tree (Figure 63) and windmill (Figure 64), and the interactive goods (Figure 60): four red hexagonal pieces and four yellow circular pieces.





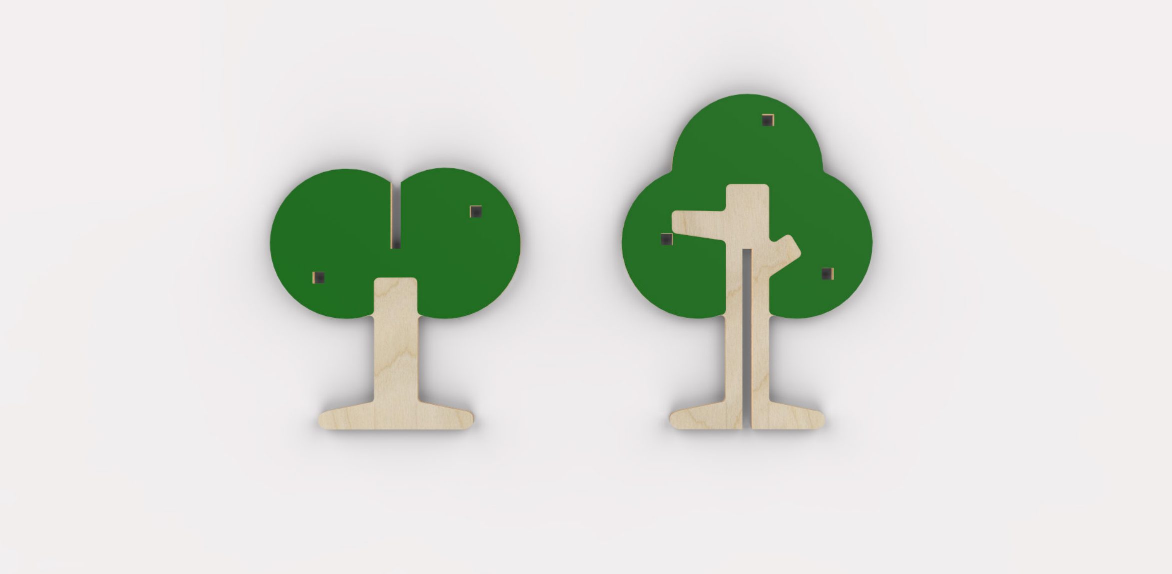


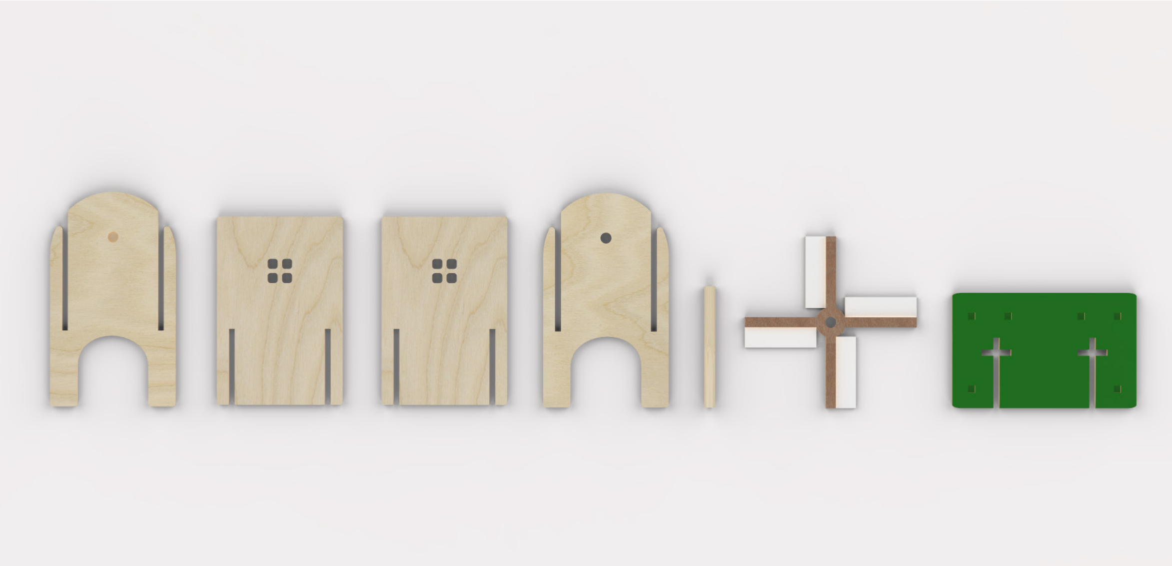




From left to right:

Figure 55: curved and straight tracks
Figure 56: curved and straight tracks
Figure 57: straight tracks with hole for token
Figure 58: curved track with hole for token
Figure 59: tokens representing each station
Figure 60: goods
Figure 61: characters





From above to belowt:

Figure 62: front view of the pieces that compose the bakery station

Figure 63: front view of the pieces that compose the tree station

Figure 64: front view of the pieces that compose the windmill station

We considered a first possibility of having a basic and completely modular kit of pieces with which all the games could be played, this meaning, the goods and the tokens were common for all the games, neither extra tokens or goods were needed. On the other hand, we also considered the possibility of selling a separate kit for each app story, so that the tokens could be customised for each station, and if the user wants to expand the game, it would be necessary to buy other tokens to unlock new games in the app. The same would happen with the characters in the game. There is a character that is fundamental and common to all games, and that is the driver. The other characters are personalised and linked to a specific story. It is intended that the characters of the app's game have an equivalent form in the physical world. For example, for one of the app's game, the grandmother and the baker may be necessary, but for another game, a hairdresser and a thief are needed.

In the end, we decided to go with this last approach for our business model due to the possibilities. This model allows us to increase the lifespan of our product by means of story add-ons that could be released over time, therefore increasing the sustainability as well. We considered it to be a better revenue stream, by selling the basic kit with a low-profit margin to get more people to buy our product, and once they were in the ecosystem, sell the add-ons with a better profit margin. The basic kit that we finally opted for is shown in Figures 65, 66 and 67. More on this topic can be found in Appendix E.

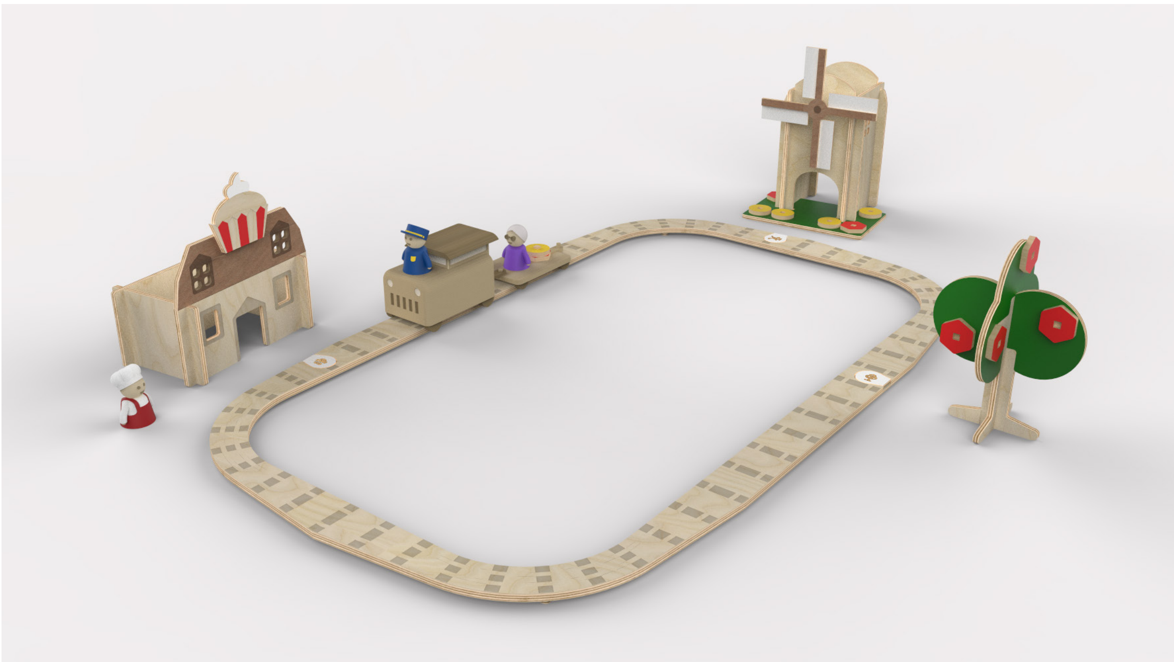


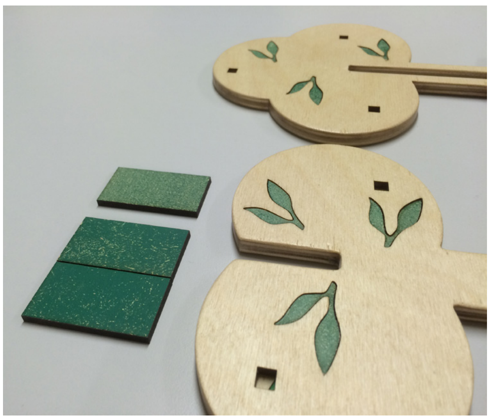
Figure 65: basic set

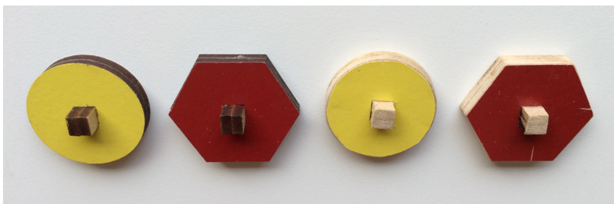
Figure 66: basic set

Figure 67: kid playing with basic set

Going more into depth, compared to previous prototypes' iterations, the final stations, tracks, and intelligent objects are made from birch which is stronger, lighter, and more aesthetically pleasing than MDF (Figures 68,72), in combination with okoumé in some façades to add contrast (Figure 70).

In contrast with the coloured version of the stations of the previous iteration, we wanted to create a more neutral and natural aesthetic which is not overloaded, respecting the appearance of the wood. The material that we have chosen for this final iteration (birch) has a beautiful vein and a warm and very nice colour, which we considered it an appropriate aesthetic for the toy. We decided to keep the number of colours limited to only a few flashes. The stations are not coloured anymore (Figure 70), and the cupcake add-on has its colour replaced by an engraved colour (Figure 69), matching the wooden aspect. A redesign of the appearance of the tree has also been performed reducing the green-painted parts to match with the overall design of the toy set (Figure 71).





From left to right:
Figure 68: bakery versions in MDF and coloured
Figure 69: cupcake versions in MDF and Birch
Figure 70: final appearance of the Bakery made in Birch&Okumé
Figure 71: final appearance of the tree with flashes of colours
Figure 72: goods in MDF compared to goods in birch

Moreover, some additional changes have been applied to each station:

- The field plate has been cut in half to make it smaller and some grooves have been applied to be able to attach it to the wind-mill (Figure 73).
- The logotype of the brand has been inclu-ded in some of the pieces that compound the set (Figure 74, 75) , by means of laser engraving in the wood, on the back side of them, in a discrete size that is not too ob-vious but serves to identify the brand.

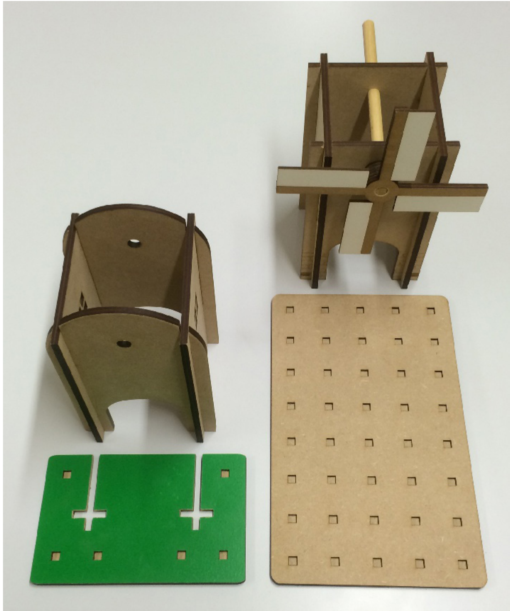


Figure 73: iterations on field plate and windmill

Figure 74: implementation of the logo in the stations

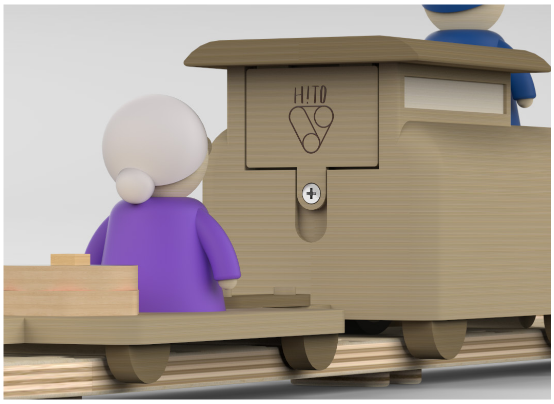


Figure 75: implementation of the logo in the stations

Finally, the various pieces that compound the physical toy set were laser cut and glued together where necessary. Then the imperfections and all burned edges were sanded out and lastly the whole set was varnished twice, to give the wood a layer of protection and obtain a glossy finish.

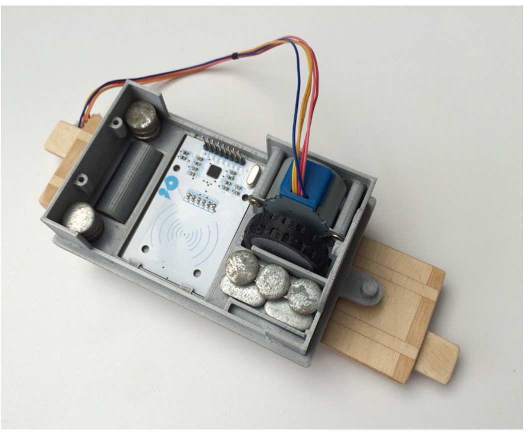


Figure 76: components inside the prototype

All electronic components had to be fixed into place. The wheel was press fit onto the motor, after which this unit was positioned with two 12x3mm screws. In order to balance out the weight of the motor, additional weights were glued in the other three corners, which further improves the grip between wheel and track too (figure 76). The RFID reader was snapped into place beneath 3 ledges.

Next, the Arduino board was positioned, resting on a mounting boss which was used for fixing the stepper motor, and fixed in place with two screws on the opposite side (figure 77). The motor driver was slid into place across the stepper motor. Moreover, all cables were soldered into place to reduce the space needed to store them, except the ones connected to the battery, Bluetooth module and second RFID.

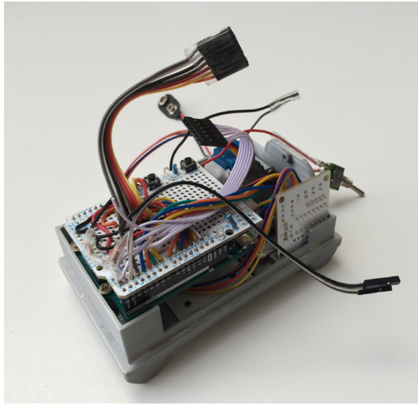
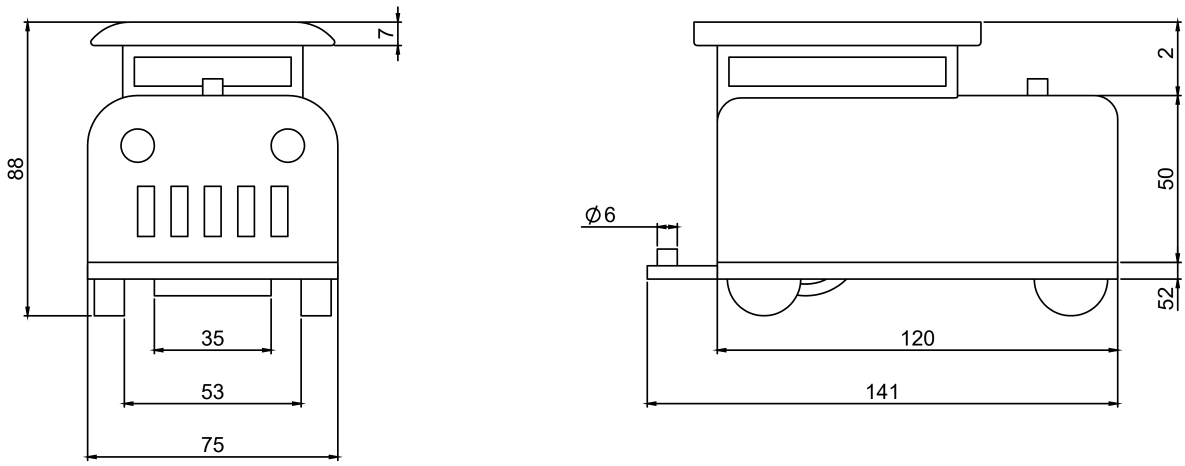


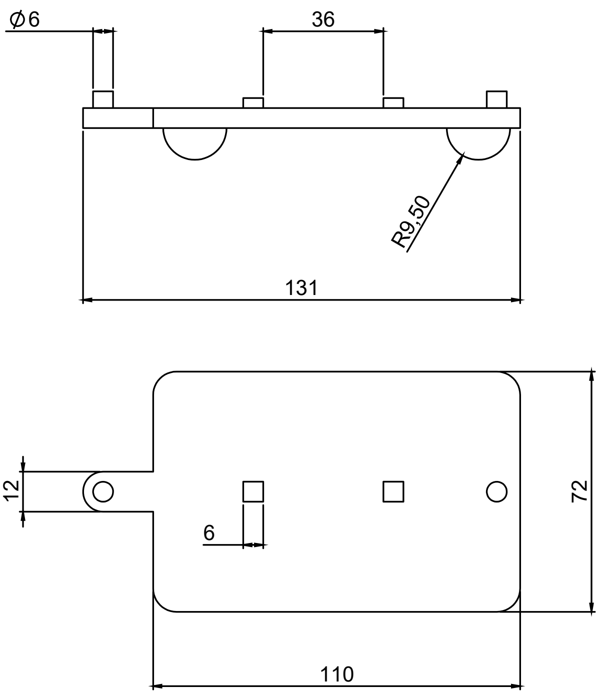
Figure 77: components inside the prototype

Below, general measurements (in mm) of the pieces that compose the game are specified.

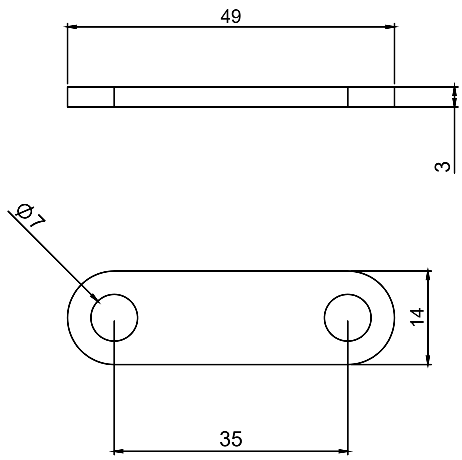
TRAIN



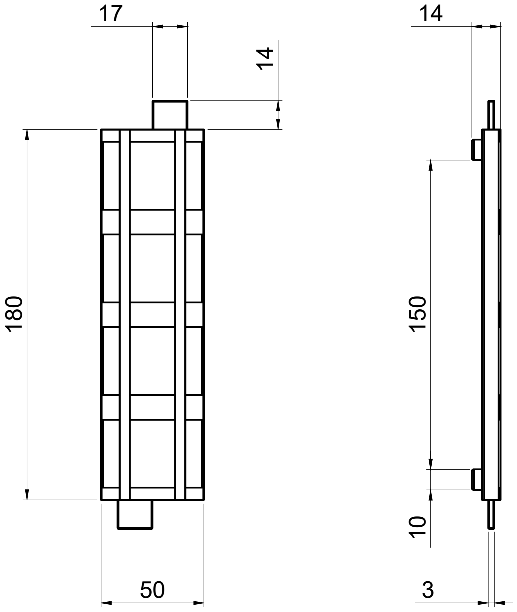
WAGON



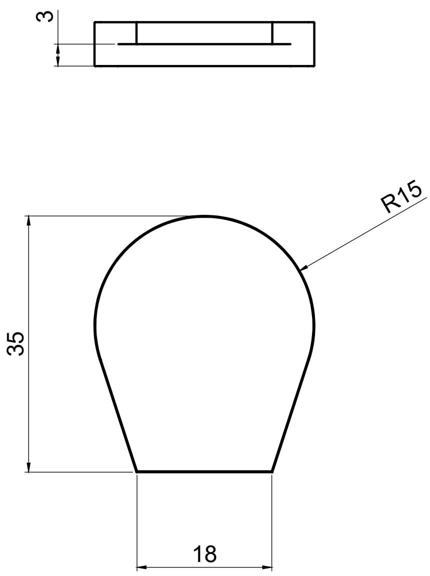
CONNECTING PIECE



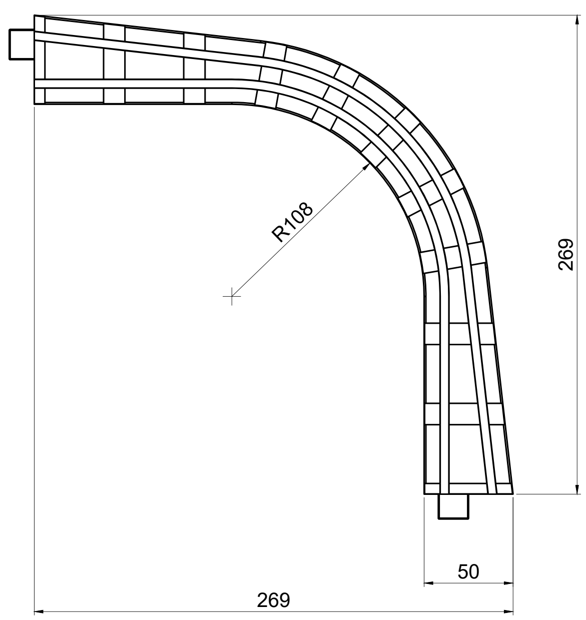
STRAIGHT TRACKS



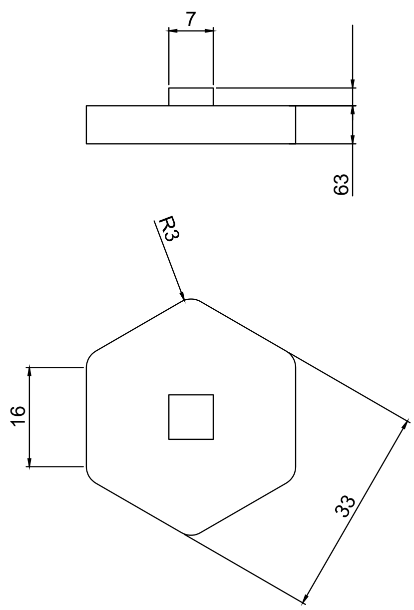
TOKEN



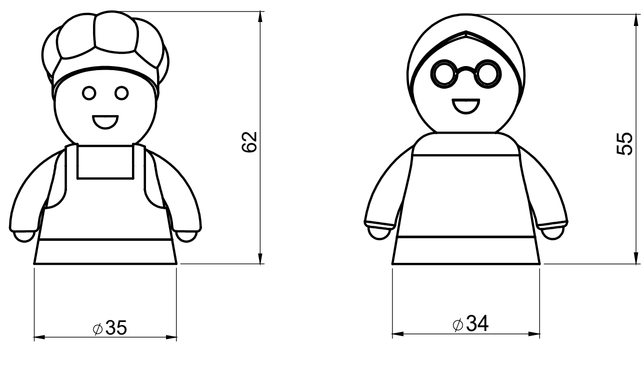
CURVED TRACKS



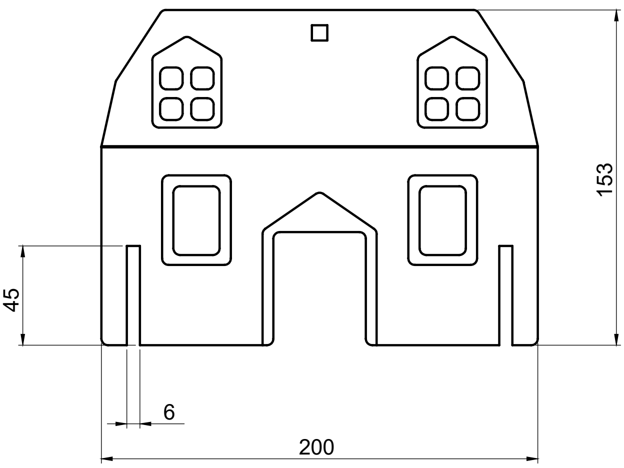
HEXAGONAL GOOD



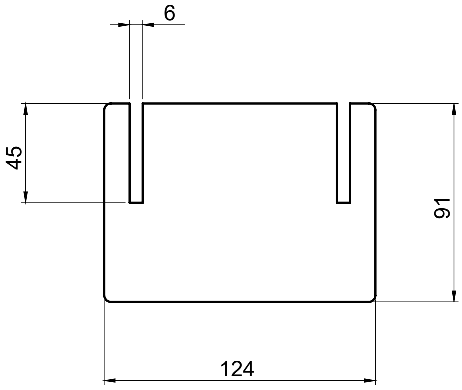
CHARACTERS



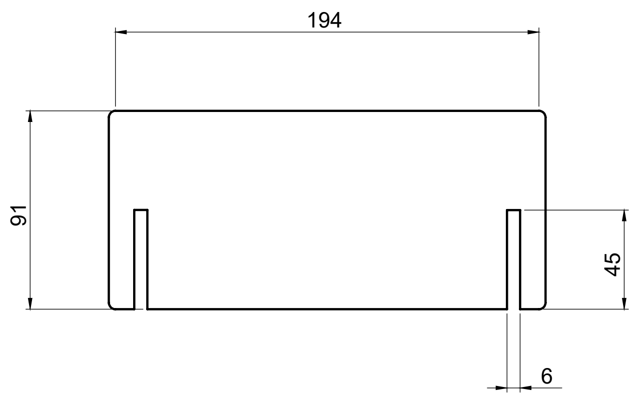
BAKERY STATION FRONT FAÇADE



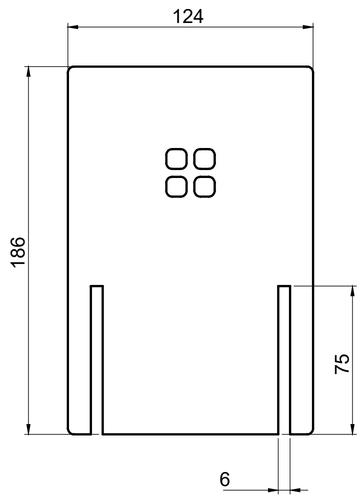
LATERAL WALL 1



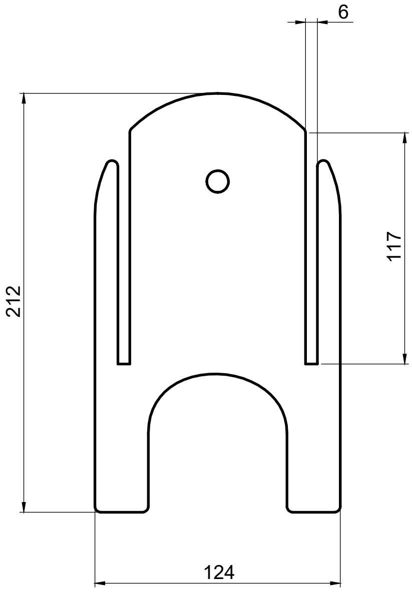
BAKERY STATION BACK FAÇADE



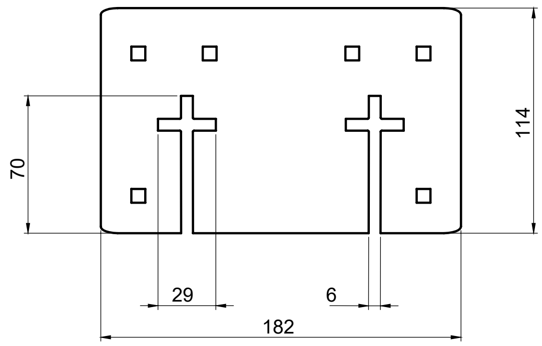
LATERAL WALL 2

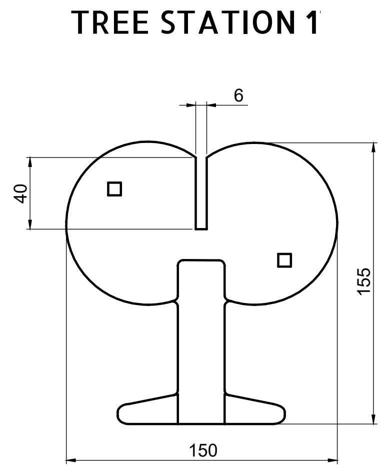


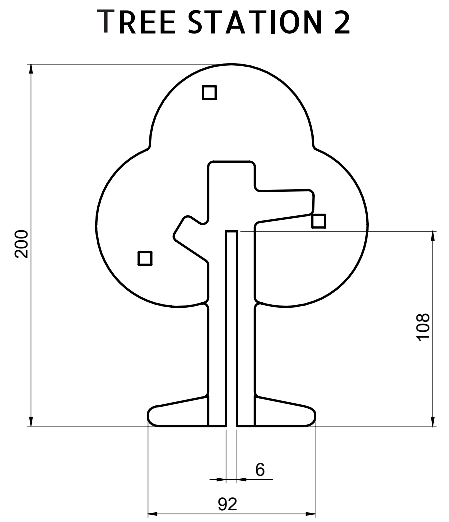
WINDMILL STATION FAÇADE



WINDMILL FIELD







App

In addition to the physical train, the app provides a second element for the children to play with. By having the app connect to the train using Bluetooth, an interactive user experience can be created where the user has to perform tasks in the physical world which will then translate to the digital game.

This type of game that connects both realities is called GGULIVRR. GGULIVRR stands for Generic Game for Ubiquitous Learning in Interactive Virtual and Real Realities. It is a game where you have a mobile app / game in which you can discover learning content through interacting and getting in physical contact with it. A GGULIVRR game is designed for young learners to practice and enhance 21st-century skills whilst generating and playing mobile contextual games. To play the game the user needs to physically get in touch with real objects by scanning an intelligent tag, for example, an RFID tag. Then the user obtains contextual information about the specific object which can be part of a whole storyline. (H. Bollaert, GGULIVRR: Touching Mobile and Contextual Learning, dec 2012, https://www.openeducationeuropa.eu/en/article/GGULIVRR%3A-Touching-Mobile-and-Contextual-Learning)

For example, applying this concept to our project: once the user scans the 'driver' character in the real world (Figure 78) , a map with all the stations will open in the app (Figures 79, 80).

Figure 78: Scanning the driver on the train

By clicking one of these stations, the train receives a signal informing it must drive to that specific station. The train will then keep driving until it reads the RFID tag which corresponds to the selected station, after which it sends another signal to the app to notify the user that the train has arrived.

Figure 79: map with the stations

Figure 80: app's feedback when a stations is reached

After the feedback from the previous iteration of the app, the focus of the app became to provide simple tutorials for the users, instead of providing actual games. These tutorials serve as a manual to help the user understand how to interact with the various aspects of the prototype, which will be explained in further detail later. While informative, these tutorials are also intended to be somewhat engaging and fun, in order to keep the user interested in playing and to prevent them from skipping useful information.

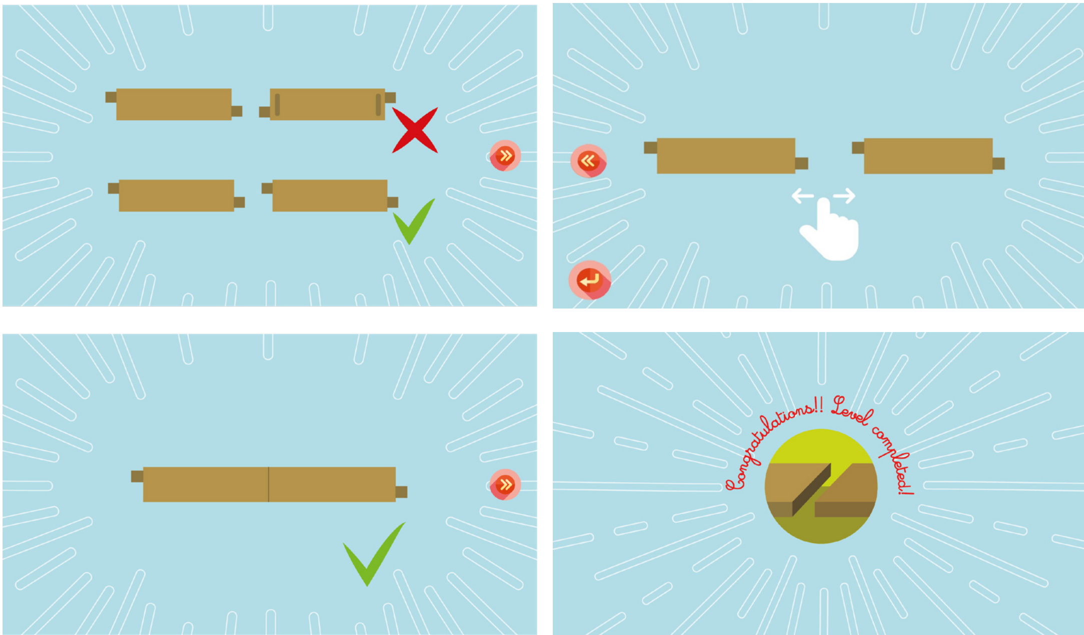
The app is made using Xamarin Android, a programming language similar to C#. Xamarin Android (using Visual Studio) was chosen instead of Android Studio as the majority of Xamarin code can be re-used for the creation of iOS apps as well. This reusability was thought to be a considerable benefit, should this app ever become available to iOS devices. The code for the app can be found in Appendix L.

Figure 80: game menu with the 7 tutorials

In the app, seven tutorials are available, with a new tutorial 'unlocking' each time the user has completed the previous one(s). In order to select a game or tutorial to play, the user has to select one in the game menu (Figure 80).

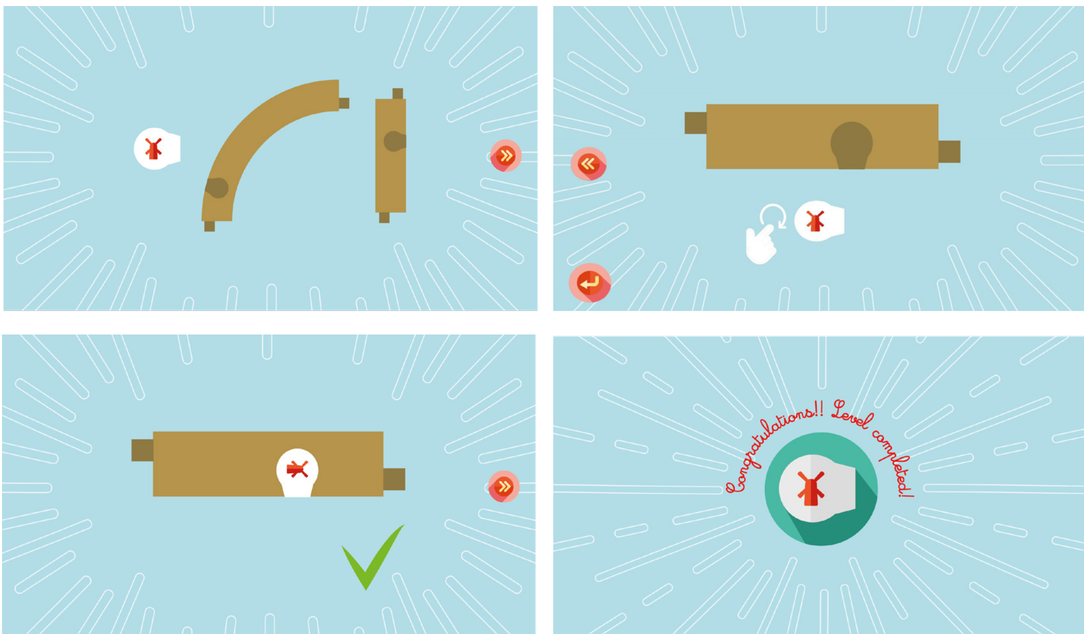
Below, the core concepts of each tutorial are briefly explained:

1. In the first tutorial, 'Tracks', the user is introduced to the tracks and is shown how to connect them. The user has to drag, rotate and connect various track pieces to one another in order to complete the tutorial (Figures 81, 82, 83, 84).



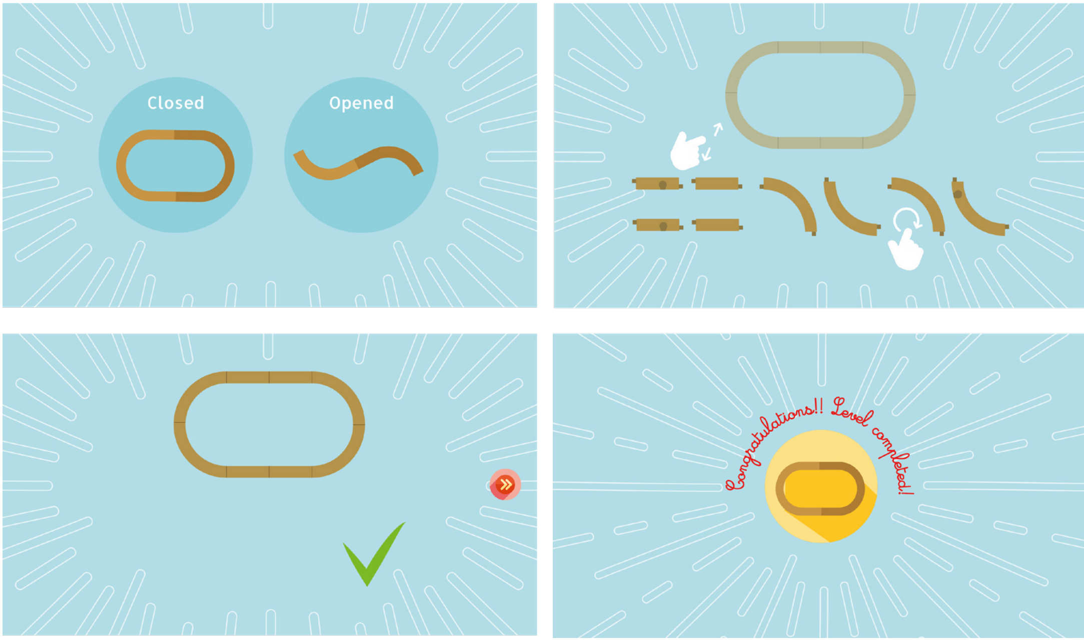
Figures 81, 82, 83, 84: tracks' tutorial

2. The 'Tokens' tutorial is somewhat similar to the previous tutorial, but introduces the placement of RFID tags, or RFID 'tokens'. In order to complete the tutorial, the user has to place RFID tags in their corresponding slots in the tracks, and afterwards has to place the tracks with tags in them in the correct position (Figures 85, 86, 87, 88)



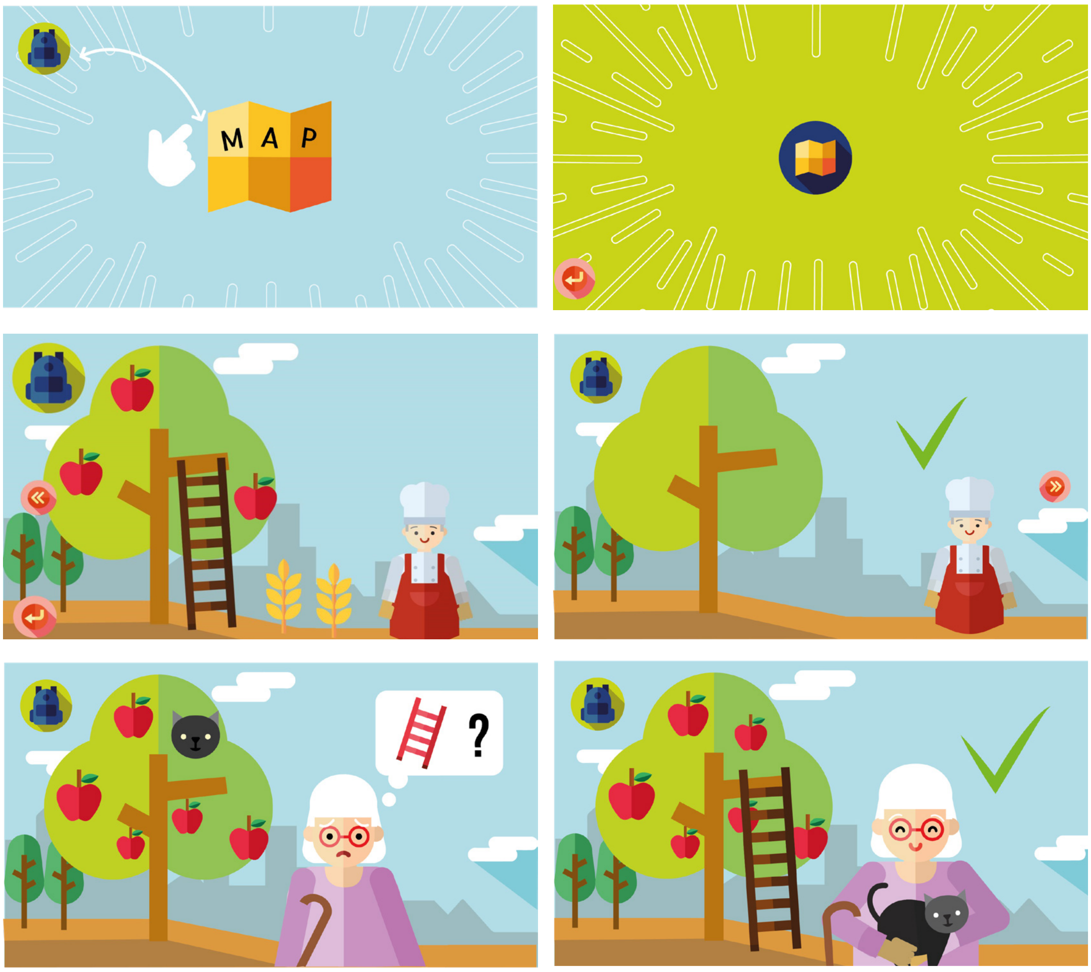
Figures 85, 86, 87, 88: tokens' tutorial

3. The 'circuit' tutorial shows the user how to assemble a proper circuit. The user can choose one of two options: either to build a closed circuit, or an open circuit. A preview of what the circuit should look like is given to the user, and the user has to place all of the tracks in their correct positions. Once the user has assembled both circuits, they will have finished the tutorial (Figures 89, 90, 91, 92).



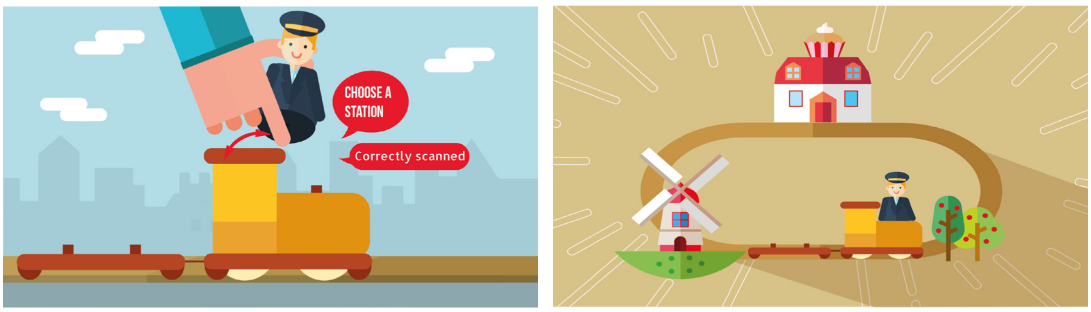
Figures 89, 90, 91, 92: circuit construction

4. The fourth tutorial teaches the user how to interact with an element which was going to be used in many of the games: the backpack. In the backpack, the user can store various items they have collected during the game, in order for them to be used at a later point in time or in different locations. The user can store items in the backpack by dragging them towards the backpack icon. In the tutorial, the user has to help the baker (from the earlier app concept) to harvest apples and wheat. This can be done by dragging these items to the user's inventory. Afterwards, the user can play a version of the 'old lady's story' from that same tutorial, where they have to use a ladder (which was also used for the earlier harvest) in order to help the old lady's cat out of the tree. Once this is done the tutorial is complete. (Figures 93, 94, 95, 96, 97, 98)

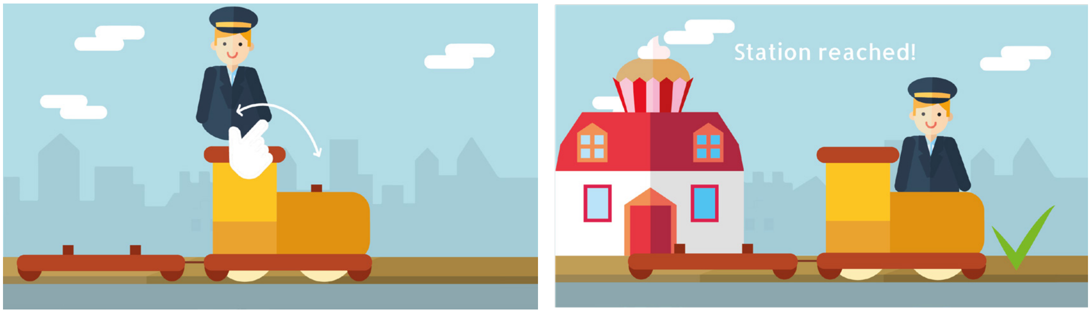


Figures 93, 94, 95, 96, 97, 98: backpack's tutorial

5. In the 'train' tutorial, the interaction between the train and the app is introduced to the user. The tutorial starts with an example in which it is shown that the user can scan the 'driver' character in order to open a map in the app. After this example, the user is told to try it for themselves, and once the map opens they are able to select a destination. Once selected, the train will begin to move, and will continue to drive until the selected station is reached. When reached, the app updates, and the user will have finished the tutorial, however, they can return to the previous screen in order to continue driving the train. While the train is driving, a 'loading screen' is shown (Figures 99, 100, 101, 102).

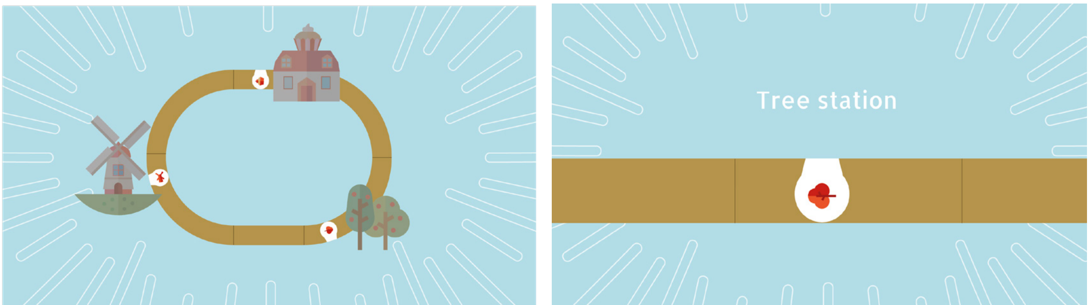


Figures 99, 100: train' s tutorial



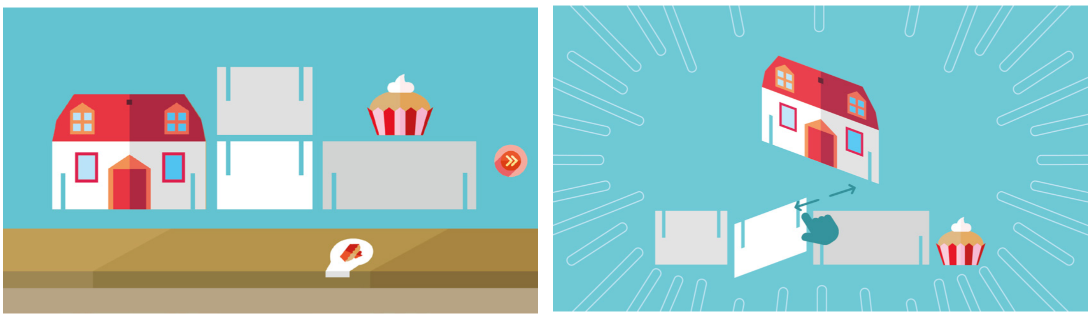
Figures 101, 102: train's tutorial

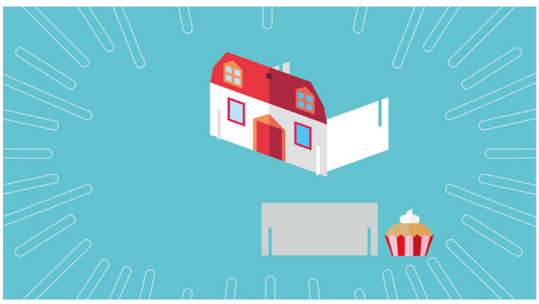
6. Now that the user is aware of how to assemble a circuit and how to drive the train, they will be introduced to the assembly of the stations. Initially, the map is shown with all the stations greyed out. When the user clicks a station, the corresponding RFID tag is shown and afterwards they'll receive instructions on how to assemble the selected station (Figures 103, 104).



Figures 103, 104: stations' tutorial

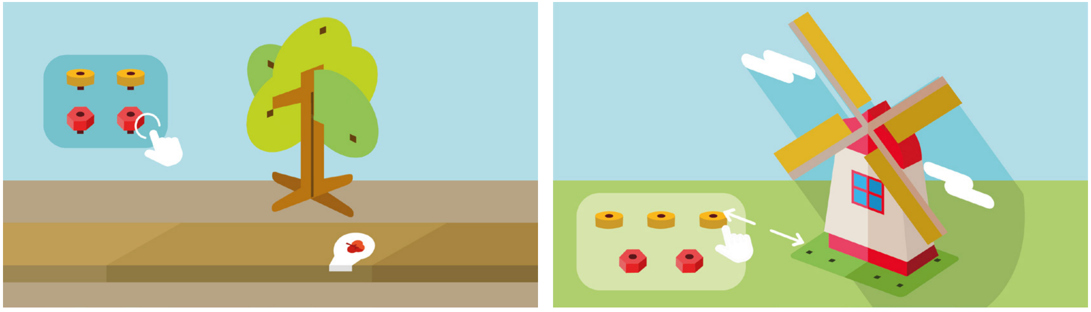
The instructions show the user all the pieces required to build the station. In order to prevent the user from skipping steps, and to ensure that they realise how the separate pieces fit together, the user has to drag each piece into the correct position in the app as well (Figures 105, 106, 107).





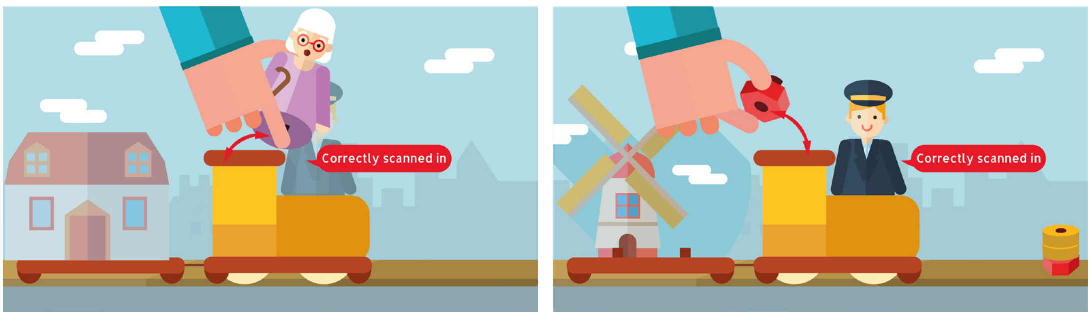
Figures 105, 106, 107: pieces that compose the station

The 'mill' and 'tree' stations also have a second stage to the construction phase; once the initial assembly is complete, the user is asked to add the yellow tokens (representing wheat) and the red tokens (representing apples) to their respective stations, as these are used in a similar manner in the first game (Figure 108, 109). Once all stations are built, the user can move on to the final tutorial.

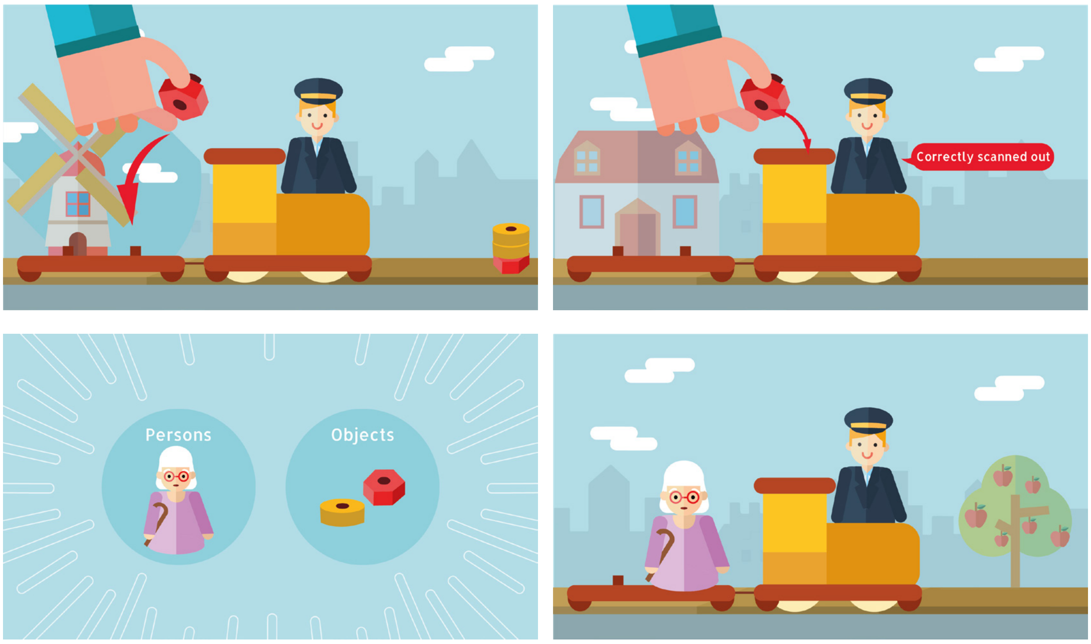


Figures 108, 109: filling the field and the tree with the goods

7. The last tutorial, 'Scanning', teaches the user about a variety of objects which can be scanned other than the driver. Once the user starts the tutorial, they are presented with a similar menu to the one used in the ‘circuit’ tutorial, and the user is given a choice between two options. The first option, ‘people’, has the user transport the old lady from the earlier tutorials to another station. In order to do this, they have to scan the old lady (Figure 110), similar to the driver, and then drive the physical train to the desired station in order to be able to continue the tutorial. Once the train has arrived at the station, the user has to scan the old lady again in order to ‘drop her off’. The second option, ‘objects’, is similar to ‘people’, but instead of the old lady the user has to bring ‘apples’ (the red tokens) to the bakery (Figures 111, 112). The main goal of this tutorial is to make it clear to the user that various ‘people’ and ‘objects’ in the games can be scanned and transported to different locations (Figures 113, 114, 115, 116). A secondary goal is to show the user that the location of the physical train is able to have an impact on the games in the app.



Figures 110, 111: scanning old lady and goods

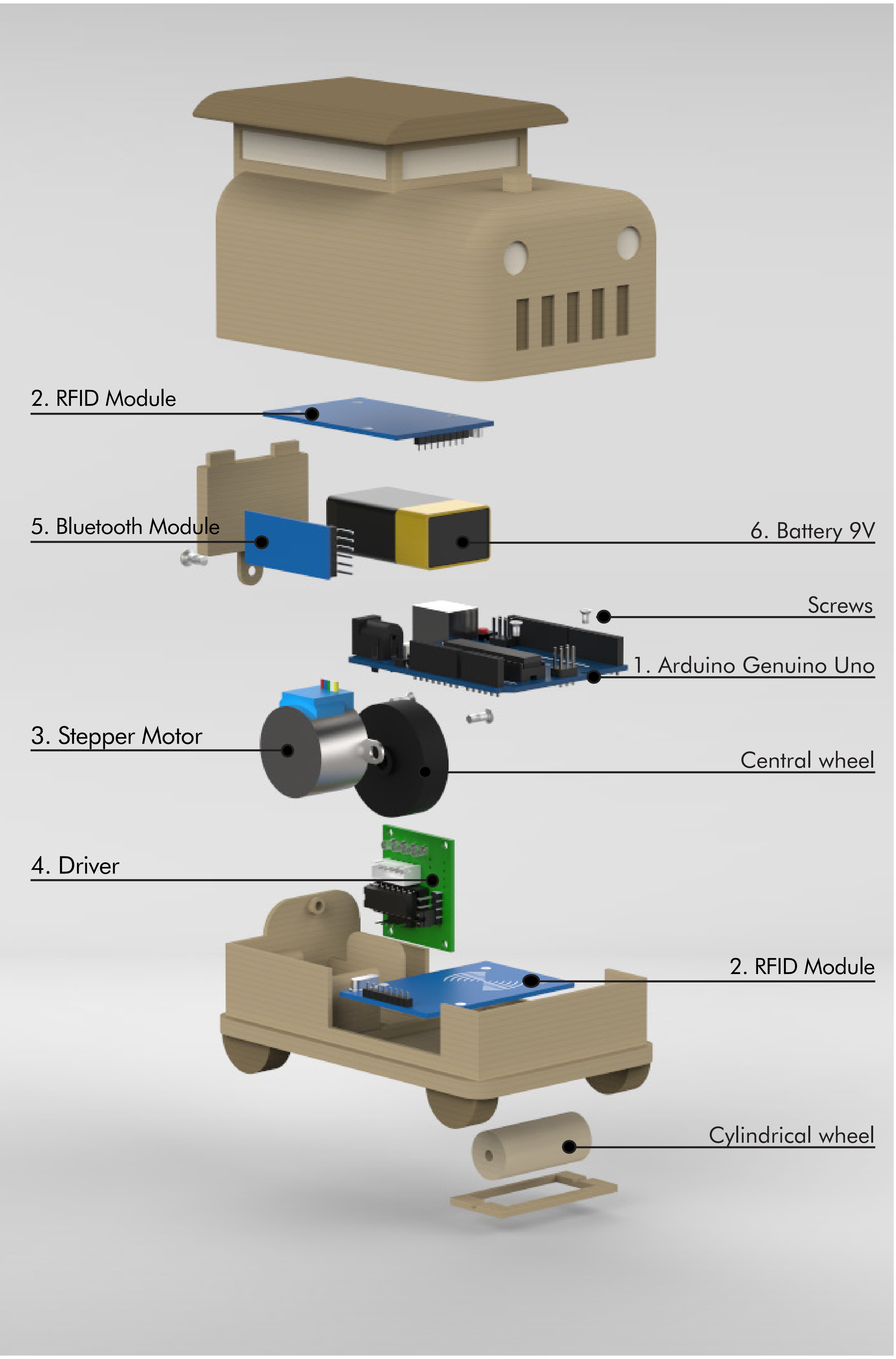


Figures 113, 114, 115, 116: scanning tutorial

After the tutorials were finished, enough time was left to create a prototype/simulation for the earlier mentioned Bakery game. This prototype was not implemented in the actual app, but was created as a simulation using Flinto, a Mac program used to create interactive and animated prototypes, as an actual implementation would take too much time.

Figures 117: bakery game

Electronic Components



Figures 118: exploded view of the inside of the train

1. Going on to the components that made the final prototype work, the main components and brain of the whole system was the **Arduino Genuino** Uno.
The Arduino Uno (Figure 119) is a microcontroller that has fourteen digital input/output pins and six analogue input pins. This number of pins is ideal as the final prototype includes two RFID readers, a stepper motor with its corresponding motor controller and finally, a Bluetooth module, which we will go further into depth about later.

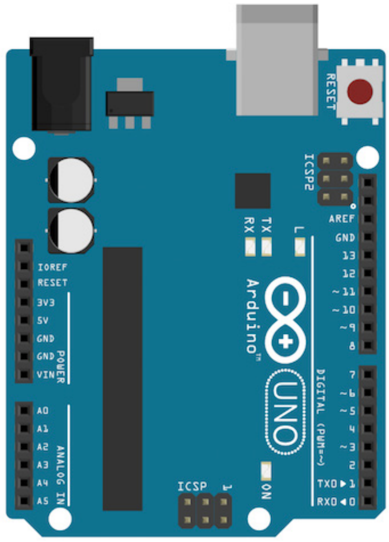


Figure 119: Arduino Uno

2. This train required two RFID readers as one would be placed at the bottom of the train to recognise the different stations and the other, would be placed on the top of the train to recognise the different items and characters.
The chosen RFID was the **RC522 Module** (Figure 120). This was done due to its low-cost ease of programming, low-voltage and small size. To make use of these RFID readers, RFID tags were required. We went for the standard RFID tags that could be stuck onto small items and characters.

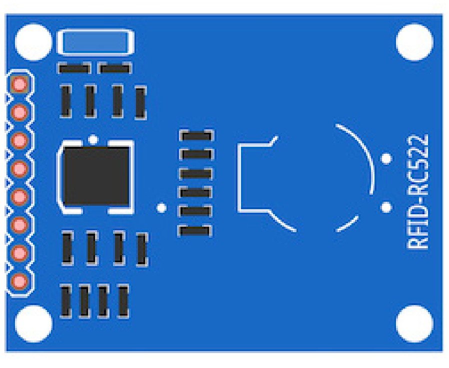


Figure 120: RC522 Module

3. Moving forward to the motor, at the onset of this iteration of the train the plan was to use a DC motor due to the programming in conjunction with the RFID's being much easier, however, we soon realised that it would not be possible to use this sort of motor due to it not being able to pull the weight of train. Due to this, we decided to use a **stepper motor** (Figure 121), specifically the **28BYJ-48**, which boasts of a relatively low voltage usage whilst maintaining its strong torque which is crucial at the time of moving large weights such as the train.

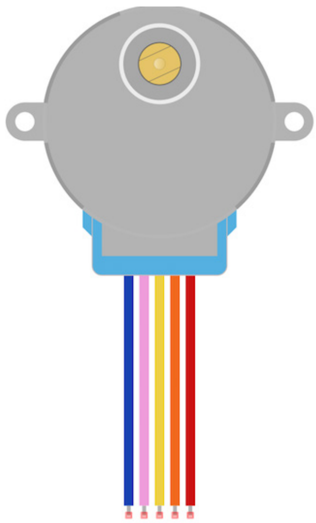


Figure 121: Stepper Motor 28BYJ-48

4. To make use of this motor the **ULN2003 driver** was required (Figure 122). A driver has the function of taking a low-current control signal and then turning it into a higher-current signal that can drive a motor.

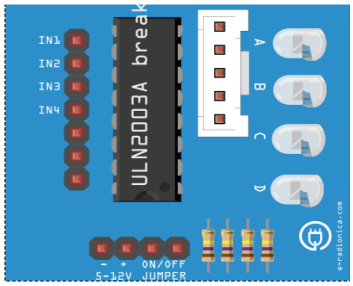


Figure 122: ULN2003 driver

5. Due to the nature of the game, it being able to connect to a smartphone application, a Bluetooth module was required (Figure 123). We chose the module **HC-05**. This was done because it is a widely spread and available **Bluetooth Module**, with many examples and coding available online, making the prototyping much easier.

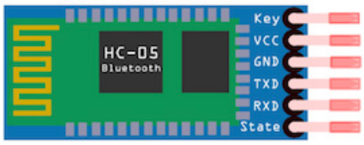


Figure 123: HC-05 Bluetooth Module

6. Finally, to power all of this, a standard **9 V battery** was used (Figure 124).

Figure 124: 9V Battery

More detailed information for all the components are included in Appendix J. Additionally, in the Figure 125 below, you can find a schematic of the final prototype.

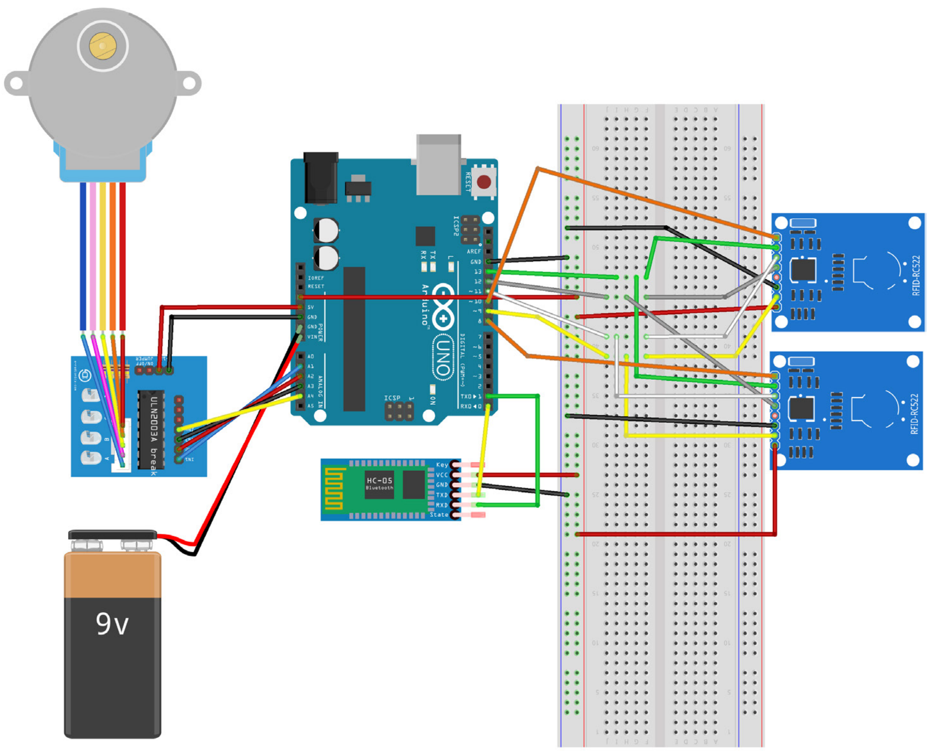


Figure 125: Prototype circuit schematic

Conclussions: From this, we can see that the project was divided into four main phases: research, brainstorming and development, formalisation and prototyping, and finally, the verification. In conclusion, we can clearly see from this project process how we evolved from initial concepts, built on one of them and from that went through several iterations until arriving where we stand now, with our final prototype.

6. USER TEST

Multiple user tests were performed through a specific methodology to gather information and contrast them with our expected results and from this, make changes where appropriate. These user tests and their results can be seen in the following chapter.

6. USER TEST

6.1 DESCRIPTION

The aim of the final user test was to verify the degree to which our hybrid toy can be considered intuitive. As there are great differences between physical and digital toys we attempted to combine both, therefore expanding the interactional opportunities which, in its turn, might make the toy more attractive and challenging for children. However, increased possibilities often result in higher complexity. For this reason, we wanted to gain some insight into the "intuitiveness" of our hybrid toy. In order to measure this characteristic, we introduced three metric parameters.

The first parameter is time, or, more specifically, the time it took each participant to complete one tutorial.

The second parameter is the amount of different errors made within one tutorial. These errors have been defined as any movement other than the one needed to obtain the desired result. Since errors can be made on multiple levels we divided them into 3 categories: digital, physical and interactional. Digital errors apply to wrong gestures made in the app whenever something in the app needed to be executed. Physical errors have been defined similarly, referring to mistakes made with the physical parts, for example, when building a station. The last category of errors contains the different types of interactional errors, which apply to any situation where the link between the app and the physical toy was unclear to the child.

The third parameter is the amount of additional hints provided by the test leader. These hints were categorised into two groups: those provided upon demand and those automatically given after the same type of error had occurred several times.

In order to verify the fun factor of our toy we assigned a label to each participant. This label indicates their level of excitement based on their corresponding user test videos. We provided three categories: bored, neutral, interested. If a child yawned during the test, he would be allocated to the first label, "bored". If the child showed surprise or smiled, he was given the third label, "excited". Any dubious situations have been labelled as "neutral". It should be noted that this labelling method could be considered subjective as it requires the researcher to interpret the emotions of the participants. Nonetheless, some basic insights into the fun factor of our toy could be extracted through this method.

Finally, we suspected there might be a correlation between previous knowledge or experience and the intuitiveness of our toy. Therefore, we collected some data on the children's prior experience regarding app games and toy trains.

6.2 METHOD

6.2.1 How

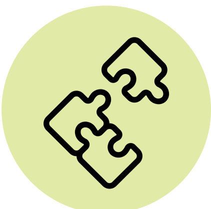
At the beginning of the test the children were asked the following questions in order to gain some insight on their previous experience with both apps and trains:

- Do you have a smartphone or tablet at home on which you play games?
- Do you have a toy train at home?

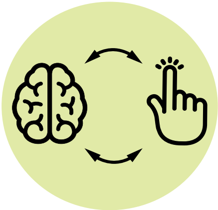
We did not ask them any questions after the actual user test. As the whole test had been recorded, their emotions and level of interest can be verified there.

After the questions on their previous play experience, the user test was divided into three phases of about ten minutes each.

During the first phase the children were asked to complete Tutorials 1, 2 and 3 in the app. Those tutorials all focus on becoming familiar with the tracks, the station tokens and building open or closed circuits. Each tutorial would start off with an image of the physical pieces needed for that tutorial. To verify if they were able to detect the link between the illustrations in the app and their physical equivalent, the children were asked to collect the pieces they recognised in the app. Next, they had to join both illustrations of the tracks together through sliding them towards one another. Finally, they were asked to connect the physical pieces and put the station tokens in the right places. If they had time left upon completion, they could start the fourth tutorial which teaches them how to collect digital objects in the app by dragging them into a backpack.



During the second phase they were asked to construct two stations: the tree station, and either the bakery or windmill stations. Since Tutorial 6, which contains instructions for correctly assembling the stations, had not been developed yet, we could not test if delivering them a digital build manual would speed up the process compared to not providing them with any clues. Instead, we only handed them those parts that made up the station together with the name of the corresponding station. As such, we attempted to evaluate how difficult it is to build the stations without a build manual.



The third phase was meant for testing if the child was able to understand that certain actions made in the app trigger a reaction in the train and vice versa. They were asked to complete Tutorial 5 which requires them to scan the driver and navigate the train to the desired station. If there was still time left, they could complete Tutorial 7 as well, which teaches them how to scan items other than the driver on the train.

The whole test has been recorded by two cameras, provided by the University of Antwerp's Department for Design Sciences. One camera recorded the whole scene from a front view perspective. The other camera was placed behind the participants and slightly to the left or right in order to record their hand gestures while playing the app games.

6.2.2 When

Monday 28 May 2018, from 08:30 until 15:30.

6.2.3 Where

Primary school Sint Antonius
Opperstraat 32, 1770 Liedekerke, Belgium

6.2.4 With whom

Our sample group consisted of 8 children from the same school, Sint Antonius, in Liedekerke. Half of them were boys and the other were half girls. Their native language was Dutch and none of them had foreign roots. At the moment of testing all of them were 6 years old.

6.3 THE RESULTS

During the user test it became apparent that certain types of errors were made by most of the children. As our sample only consisted of 8 children, statistical analysis could not provide trustworthy results. Instead, we listed some crucial actions (Table 1) and typical mistakes (Table 2) with their corresponding percentages.

In general, the crucial actions were clear to the children and had been executed properly. Joining tracks together into circuits and inserting the tokens did not cause any problems except in one case. Moreover, the first tutorial, which introduces the tracks without the tokens, might be redundant, as the children tended to have more problems joining them in the app.

Next, for building the stations, only 50% were able to complete this action without any hints. Therefore, including the 6th tutorial which contains build instructions might be necessary. Additionally, as the amount of individual hints provided to the three children who built the windmill station was less than for the five ones who built the bakery (Appendix K3), we believe assembling the windmill is more intuitive than the bakery. A possible explanation is due to the windmill having two walls with doors which help communicate the orientation of those particular pieces. Moreover, the two side walls have a window which, again, clarifies their orientation. The bakery however, has three plain, similar walls which only differ in size. As a result, the position of those pieces can only be deducted by looking at the station as a whole.

Another crucial action was to position the station near the right tokens, as those tokens determine where the train will stop. Five out of eight children would see the link between the graphical reference and the actual building; this percentage should be much higher, however. Finally, only five out of eight children were able to correctly scan the driver after being given several hints. None of them understood how to perform this action correctly the first time. This implies that the visual instructions, which had been displayed at the beginning of that tutorial, were insufficient to explain how to navigate the train.

Even more confusion was caused by the image for scanning the driver onto the train. Since it contained a white arrow all children assumed they had to digitally drag it on n top of the train. Once they had scanned the train, the map would appear, after which none of the children had trouble choosing a destination. However, some of them did not realise this selection had instructed the train to start driving, as they kept looking at the screen, expecting something to happen there.

This confusing between purely digital, purely physical, digital actions causing physical reactions and vice versa was observed several times. A possible explanation might be that some physical items were tagged and others were not. In one particular case the child would physically move two tracks towards one another while intently staring at the screen. When nothing updated in the app he concluded that the track illustrations could not be moved.

Crucial actions	Children able to perform the action
Join tracks physically	7/8
Place tokens into tracks	8/8
Build tree station without any hints	4/8
Build bakery/windmill station without any hints	4/8
Spontaneously place station near according token	5/8
Scan driver onto train with hints or making errors	5/8
Choose station in the app to travel to	8/8

Table 1: crucial actions and their corresponding percentages of correct performances

As for the 'typical errors', a striking observation was that none of the children detected the illustration of the token in the 2nd tutorial. Possibly, this was due to the fact they did not expect to need another piece when considering tracks (subchapter 6.4.2, 'App illustrations' paragraph).

Another observation was that all children positioned the driver onto the protuberance, even though the illustration in the app showed them to place him on the roof. Despite the fact this mislead the children into not scanning the driver, this also proves that pin-hole connections are a straightforward and intuitive way for joining parts together.

Similarly, none of them had trouble understanding how to connect the intelligent items to the tree, nor did they hesitate to put the cupcake sign on the bakery.

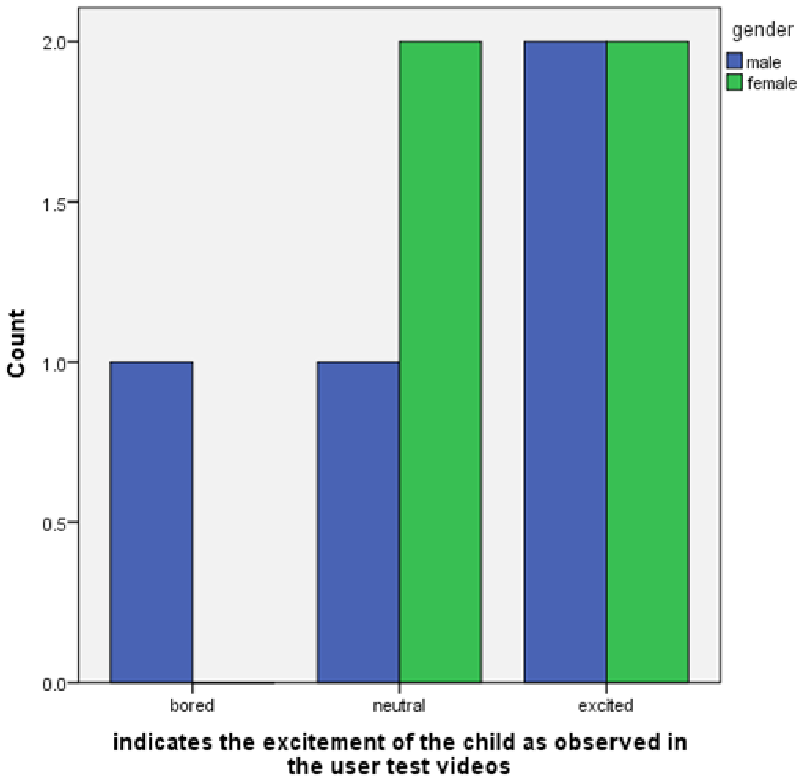
The last typical observation to be mentioned here, is the fact that nearly all children attempted to use different gestures when interacting with the app. For example, they would make a rotating gesture with their thumb and index finger in order to turn the tracks in the app, even though they were told to click them.

Tutorial	Typical errors	Performed by
1	(accidentally) click the fixed track when asked to join both together	5/8
2	Click the illustration of the hand which indicates the track can be rotated, rather than the actual image of the track	6/8
2	Not detecting the illustration of the token in the app 8	/8
3	Not knowing the tracks have to be dragged upon the example circuit	3/5
3	The movable illustrations are small and require multiple attempts to drag them to the desired place	5/5
4	Click the ladder in the text balloon instead of going to the backpack	4/8
Tree	/	/
Bakery	Assembling the bakery with the façade turned inwards 4	/5
Windmill	Put the wings upright into the building instead of using the holes in front and rear facades.	2/3
5	Attempt to directly connect wagon to train (without connector piece)	4/8
5	Put the driver on the protuberance instead of the roof 8	/8
7	/	/

Table 2 : typical errors comitted in each tutorial

In order to gain some basic knowledge on the attractiveness and fun factor of our toy all participants were given a label according to their observed excitement levels in the user tests.

As four out of eight children clearly showed interest, and three more have been labelled 'neutral', we can conclude the children seemed to like the hybrid toy concept despite its complexity. One girl pointed out she liked the game because she had to build the stations herself. When comparing the fun factor variable of both genders (graph 1) it suggests that boys and girls equally enjoyed our toy, and that less girls looked bored by it. Therefore, we have achieved our goal to make a unisex toy (as can be checked in Chapter 3).



Graph: excitement of children according to their gender

6.4 CONCLUSSIONS

6.4.1 Designing hybrid toys: lessons learned

Our main design goal was to develop a hybrid toy which enriches the user's experience as it contains the best of two world: digital and physical. In general, we can conclude that there was confusion about when a digital or physical interaction is needed, as sometimes actions made in the app only trigger reactions in the app and other times they trigger a physical reaction. The situation for the physical pieces is similar: sometimes they are required for triggering functions in the app and sometimes they are nothing but building blocks. So even though hybrid toys offer countless opportunities for interaction, they also come with increased complexity. Therefore, the design driver should be clearly specified at the beginning of the project in order to effectively select the desired possibilities. Furthermore, consistency in required interaction types, graphical interface and physical interface is of the utmost importance in order to maintain the intuitiveness as much as possible.

Secondly, we suspect there is a correlation between the user's previous play experience with tablet games and the "intuitiveness" of our hybrid toy. Children who pointed out to spend lots of hours playing digital games appeared to have less problems with the app tutorials. Similarly, previous play experience with construction toys or trains might make building the stations for our toy seem more intuitive. Another surprising insight obtained through the pre-test surveys, was that at least 50% of the children pointed out they owned a tablet.

As four out of eight children clearly showed interest in our toy, and three more have been labelled 'neutral', we belief it is possible to design a unisex hybrid toy train.

6.4.2 Suggestions for future iterations

- **App**

During the user tests, we noticed several problems with the interaction between the children and the app. The first of these problems is that the vocabulary used in order to explain the tutorials was too complex. For example: The children knew words such as "tablet" and "game", but had difficulty understanding words such as "swipe", “touch screen”, “scan” or “app”. Furthermore, the children found the wording of ‘stations’ to be confusing, as they have a very typical idea of what a train station is supposed to look like. A future solution could be to hand teachers and parents a list of the most important terms used in our tutorials and ask them if there are words which the children might not understand. Moreover, the written parts in the app should be replaced by audio.

Secondly, the children did not notice many of the interactions between the app and the train, and vice versa. An example of this is that most children did not realise when they had scanned an object correctly. A solution to this problem could be to add auditory feedback in both the app and the train in order to draw the children’s attention towards the specific changes (e.g. a sound in the app that notifies the child after an item has been scanned).

Next, in the first two tutorials, the user would have to slide one track towards the other in order to connect both pieces. One of these two pieces is fixed in place, in order to simplify the programming process and due to time constraints. The problem with this, however, is that as a result the children would assume both pieces were fixed in place if they tried to move the incorrect one first. A solution to this problem would be to either manage to make both pieces moveable, or to give visual feedback to the user on which track piece can be moved.

Another problem encountered during the user tests, was that in the 5th and 7th tutorials, the children had to scan the driver character in order to open the map with the stations. While the children remembered that they had to open the map, most of them did not understand that scanning the driver was directly related to opening the map. On a related note, many of them did not seem to understand the purpose of the 'example' screens in the 5th tutorial, which could have contributed to this confusion.

Finally, despite giving the children instructions on how to play the tutorials, they did not always understand what they had to do while playing. An example of this is in the 3rd tutorial, where the user would have to assemble a train circuit by moving tracks over to the indicated locations. The users would not understand where to place the tracks or what the objective was. A solution could be to add an automated example of the tutorial which shows the user what actions are required.

- **App illustrations**

The aim of the second tutorial was to introduce the children to the tokens by displaying both tracks and a token. However, none of the children noticed the icon of the token by themselves. This could be due to the fact that they are new elements, as well as quite small and light in comparison to the larger, darker tracks. Another explanation might be that the colours of the token in the app and the ones used for the physical part were inconsistent. Keep coherence between the app´s graphics and the physical elements to evidence the connection between both. A simple solution to this problem could be to introduce the tokens properly beforehand by explaining what they are and what their function is.

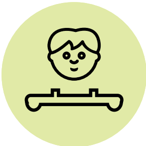
- **Train**

Finally, there were also some problems with the interactions with the train itself. Firstly, as the top part of the train to scan RFID tags is a flat surface, children tended to leave tokens up there once it had been scanned. Since there is enough space for multiple tokens, they often placed a second item next to the one they had scanned before. Unfortunately, this would cause errors with the RFID reader, as it can only read one tag at a time. To solve this problem, the top of the train could have a three-dimensional surface, instead of a flat one. While implementing this, however, it should be noted that the RFID reader should still be able to read the tags.

The second problem with the train was that the children did not fully understand how to scan the driver properly. While they understood that the driver had to be scanned on top of the train, the presence of the physical protuberance in the front of the train suggested that that was the only location the driver could be placed.

The third problem is directly linked to the design of the curved tracks. We had designed the curved tracks to be narrower in order to prevent the train from getting stuck in the middle of a turn. However, during the user test it became clear that these altered tracks sometimes cause the train to derail as they undermine its stability.
The last problem is the high amount of friction between the four positioning wheels and the curved tracks, which causes the train to get stuck sometimes. This risk could be

reduced by means of greater train speed. However, the train already derails sometimes and increasing its speed would amplify this effect. Therefore, another mechanism for keeping the train on track would be required.



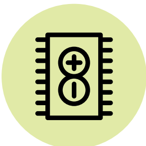
- **Wagon and characters**

Problem 1: It is impossible to put both characters into the wagon when facing sideways, as their arms would overlap.

Problem 2: The Grandma character does not entirely match the illustration in the app, since her hair has been done differently.

- **Building blocks (stations)**

Problem 1: The standardised grooves do not entirely allow just any combination: when joining the two side walls of the bakery together the pieces will not line up perfectly.



- **Electronics**

Problem 1: The maximum speed of our train is about 1cm/s which is rather slow.

Solution 1: In order to increase the speed either the diameter of the wheel needs to be enlarged or the motor needs to be changed.

Problem 2: The battery supplies energy for driving to another station for approximately five times, which is less than 15 minutes when playing continuously.

Suggestion 2: Arduino operates with 5V. When using a 9V battery such as we implemented significant energy loss occurs.

Suggestion 3: In order to balance out the train, additional weights had to be fastened, which causes a negative impact on the battery’s life span.

For more information about the user tests as a whole, please refer to Appendices K1, K2, K3 and K4.

Conclussions: In conclusion, from the user test, certain types of errors became apparent. These can help to improve our own prototype in the future, as well as highlight the more general challenges when designing a hybrid toy. We saw a repetition in the confusion of purely digital, purely physical, digital actions causing physical reactions and vice versa. For this reason, we believe the vast amount of possibilities when designing hybrid toys tends to undermine their usability due to an increase in complexity. Thus, making clear design choices beforehand, and implementing consistency are necessary. Furthermore, children who stated to play app games often (50% owned a tablet), seemed more confident when navigating in the app, which suggests there is a link between the intuitiveness of our hybrid toy and the children's previous play experience. Finally, four out of eight children showed interest in the game, with a perfect balance between both genders, and only one boy looked bored.

7. CONCLUSIONS

The results and our reflections on what we learned and experienced over this project are reflected in this chapter.

7. CONCLUSSIONS

7.1 THE RESULT

At the onset of the project, the main goal was to combine a physical toy train and digital technologies (in the form of an app) in order to enrich the play experience. As the intent was to generate a unique experience, capturing, attracting, entertaining and educating, the design had to be centred around the user.

One of our objectives was to stimulate the motor skills and senses of the children. The development of fine and general motor skills is achieved through the movement of the children. They must build the circuit and the stations, joining and fitting the pieces together, as well as placing the "intelligent objects" into their correct position. This will help them develop their spatial intelligence and motor hand skills. Then, to play with the train, they will have to move it over the lanes, transporting the intelligent objects to different stations.

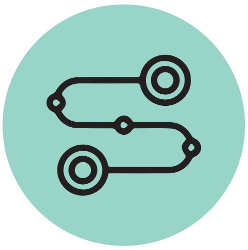
The app aids with the stimulation of senses by containing games which are both educational and fun. The development of cognitive skills as well as deductive thinking and logical capacities is achieved through the operation of the game itself. To play it, the user needs to physically get in touch with real objects, then the user will get contextual information/feedback in the app. The user will have to understand the link between the digital and physical realities, and how the actions committed in one affect the other.

The empowerment and improvement of creativity and imagination is achieved thanks to the modularity and versatility of the game. The user can play with or without the app's games, since it is only an added value, meaning that the child can still enjoy it the same way with only the physical toy train itself, creating different circuits and inventing stories surrounding it.

To reach these goals, several prototypes were developed, after which children between the ages of 5 and 6 were asked to play with them and provide feedback which was implemented in the next iterations to improve them.

To sum up, we were able to construct a hybrid toy train which can interact with an app that enhances the user experience. The app includes games and tutorials which can interact with the physical train through a Bluetooth connection. The user can start and select destinations for the train by using the app. Additionally, it can scan various objects with RFID tags, after which the app is notified which one had been scanned. Currently, the app contains seven tutorials which explain and help the user with the core concepts that are going to be used in the games.

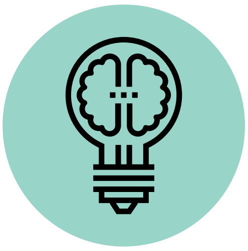
7.2 HOW WE GOT THERE



Due to the various iterations, consults and pilot tests, we were able to refine our prototype in order for it to be simple and fun for children to use. During and after each iteration of our prototype, we had meetings with our supervisor and/or with our usability teacher, who were able to provide useful feedback and steer us in to the correct direction. Examples of useful feedback included: whether certain elements of the games were fun or too complex, whether the design of the physical elements was interesting enough, and whether or not we got side-tracked from our goals.

The pilot tests provided useful insight, making us realise that children did not immediately understand what they had to do whilst playing the game. This caused us to temporarily postpone the implementation an actual game in the app, and instead directed our focus towards creating tutorials which introduce the users to the concepts which were going to be used in the games.

7.3 WHAT WE LEARNED



The first observation that should be noted was that the toy seemed to be equally appealing to both boys and girls. From the eight children who tested the toy, four (two boys and two girls) seemed to be clearly interested.

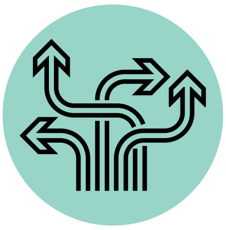
Secondly, we concluded that children did not always understand what to do whilst playing the game, even though to us the possible interactions seemed obvious. This is reflected in the link between physical reality and digital reality, which was the concept they had the most difficulties with. We also learned that our intention with the games/tutorials had to be very explicit, for example, the children were unable to understand that scanning the driver character would open the map in the app.

This was the main problem with our tutorials, even though the tutorials themselves were simple and fun, our intended interactions and design decisions were still too complex and not intuitive enough for the children to immediately understand. However, the 'intuitiveness' of our hybrid toy seemed to be related to the user's previous play experience with tablet games, as children who spent more hours playing digital games appeared to have fewer problems whilst interacting with the app. A similar conclusion can be drawn for the physical aspects of the hybrid toy; the physical aspects of our train could be more intuitive to children with more experience playing with trains or construction toys.

Finally, we learned that, if new play elements are introduced, they would have to be explained properly, as the children will often not understand how to interact with them.

In Appendix L, the personal reflections of the team members about the project can be consulted.

7.4 WHAT COULD HAVE GONE DIFFERENTLY



The main problem during the project was the time limit; in case there was more time available, the final design for the prototype and app could have been refined and expanded even more to grant a better user experience by creating low-, medium- and high-fidelity prototypes. A good example of this is the fact that auditory instructions and sounds were intended for the app, however, could not be implemented due to time constraints.

In the future, the ideal situation would be that the train could recognize obstacles or walls and stop automatically when any of those were detected. In this way, we would achieve more interaction between the child and the toy since the user would have to pay attention to the different objects located on the tracks and would have to remove them from the path of the train so that it could continue moving. This could then be linked to the app in the form of, for example, a police control. The app could show the user that the police is stopping the train, and the user would have to perform a task before the police would allow them to continue, after which the user can open the gate. However, due to time constraints, these additions have not been explored any further.

Related to the problem of time constraints, another problem was that the programmer for the app had no prior experience with either app or game design. This caused an increase in development time, as research was required every time a new feature was added to the app. This inexperience also led to a simplistic app with no complex logic behind the games (for example: no accounts for multiple users, no character creation, no scoreboards...).

8. RECOMMENDATIONS

This chapter as the title says will be focused on our recommendations, these ranging from aspects of the hardware to the way we organised the user tests.

8. RECOMMENDATIONS

Our general recommendation would be to spend more time developing the low, medium and high-fidelity prototypes, to debug the prototype and make it fit the needs and tastes of the target group, and then test them to receive feedback which could be implemented in the next iterations as improvements.

Making physical prototypes has been very necessary and convenient. It has allowed us to do many more experiments and make decisions with more security. It has allowed us to communicate better among ourselves, pointing out and explaining what we liked, what we did not, seeing possible malfunctions or possibilities with design potentials.

A recommendation for the development of the app would be to either use Android Studio or an app-prototyping tool (we used Flinto). This is because apps made in Xamarin Android are roughly three to four times the size of apps made in Android Studio in terms of memory size, and Android Studio is further developed than Xamarin Android both in terms of designer tools as well as online available knowledge.

The Flinto tool allowed us to make a prototype/simulation of the application in a very simple way, but with a very useful, visual and effective result. Thanks to this, we could see the interactions that occurred between the user and the application. In this way, it was much easier to understand the different scenes that had to be designed graphically. We could also identify incoherencies, failures or conceptual gap, and make more explicit the link between the elements. This has been a very useful program, the pity is that we discovered it two weeks before finishing the project, and we could not use the simulation of the application for user tests, for which, in a first pilot user test, we had to use the printed graphics of the scenes or display them in the computer, no being real interaction between the children we tested and the app.

One recommendation in terms of graphic design, is to make use of online libraries. In them you can find many free icons and content created by professionals, so the appearance and quality are very good. It is a useful source to turn to for inspiration or to download ready-made graphics. This is mainly since with the time allocated for the app, it is not feasible to develop all the visuals, and this is an external help that facilitates and speeds up the creation of the app. In our case, thanks to the budget we had, we could buy an online course on illustration and graphic design using the illustrator program.

This course was very useful because it allowed us to learn to use this program with much more dexterity, it also taught us to interpret the forms of reality and convert them to a drawing. This tutorial also explained notions of composition, colours and effects which were later on applied into the app´s graphics.

It is important to make a feasible first project plan and to comply with it, leaving time for possible contingencies. For our porject we did a Gant chart in an online platform which allowed us to update the planning and add modifications.

The programming of the user tests must be done in advance, because if it is done in schools, you will have to do some paperwork that may take some time and the response from the schools is not always immediate. In our case, one day before the user test, the school cancelled the appointment and we had to find an alternative to gather enough children to test. That is why it is necessary to always have resources and initiative to seek solutions even if the A plan fails.

As the Arduino environment was a crucial factor in our project, we made great use of the resources available online. Our recommendation would be that if someone is new to this environment and needs to program within it, instead of creating their own libraries and programs, they should first look at already existing ones as they are usually commented and explained in detail how they work, which can be very helpful for newcomers into the ecosystem.

Going into the hardware aspects of the train, we would recommend the usage of two microcontrollers instead of one. This is due to the fact of lack of space and pins for the components. For us, the train should be divided into a motorized locomotive and a non-motorized wagon both containing a microcontroller. The wagon would contain some of the RFID readers and other components that with clever I2C communication, would be connected to the other microcontroller located in the motorized locomotive.

Conclussions: Concluding our recommendations, our general recommendation would be to spend more time developing the different iteration/prototypes.

On the programming of the app aspect, we would recommend using Android Studio for the actual app and Flinto for the prototyping of the app.

In terms of graphic design, we recommend using online libraries. In them you can find many free icons and content created by professionals, so the appearance and quality are very good.

As the Arduino environment was a crucial factor in our project, we made great use of the resources available online. We would recommend to any newcomer to do this as well.

Finally, we think we should have programmed better and in advance the user tests, so we recommend this to any new projects.

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- "Children need and seek multiple forms of joint involvement with adults, this enables adults to connect with children and provide guidance" (Baumer, 2013)

- "they are someone else and may fantasise about being airplane pilots, police officers, doctors, or teachers" (Marianne Szymanski, president of www.toytips.com)

- "It is usually attributed to processes of social identification, of which gender identity is one of the main aspects and tends to increase as children deepen their understanding of gender differences. In large groups, children of the same gender and age similarity tend to be drawn together to form play subgroups." (Gosso, 2013)

- Ideally, the focus of toys should be towards interactivity and user experience (Socaciu, 2011)

- (H. Bollaert, GGULIVRR: Touching Mobile and Contextual Learning, dec 2012, https://www.openeducationeuropa.eu/en/article/GGULIVRR%3A-Touching-Mobile-and-Contextual-Learning

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APPENDIX A

HOW WE HAVE APPLIED THE EPS COURSES

The European Project Semester is a study program composed of several courses and a project. The courses cover transversal topics that help complement and enrich the project and the assignments of those courses serve as a guideline for the development of it.

The usefulness of the courses and how we have applied what has been learned into the project will be explained in this appendix.

Project Management

This module took place during the first week of the semester. The objective was to help us plan the development of the Project.

In this first module, the project was presented to us and we began to get familiarised with it. This module helped us define some of the basic elements such as the aim, the requirements, the resources, the interested parties, the environment and finally the planning of the workload during the semester. This planning of the semester was done by using the Gant Chart, WBS and Responsibility Matrix.

This course was really useful for getting an overall view of the project, to make us realise all the phases involved in the project, and the times we had to carry them out. It also served us to define the pillars on which our project would be developed.

Team Building

One of the pillars on which the EPS is based is group work. Because the groups are made up of people from different backgrounds and different nationalities, this course focused on laying the foundations for teamwork to be optimal.

We did cooperative activities which helped us to get to know each other better. We learnt about the different roles that people can take when being part of a working team, thanks to the Belbin test. This allowed us to know what the qualities of each member were, and find the strengths and weaknesses of the team. Knowing that, we have been able to distribute tasks more effectively, according to the personalities and inherent behaviours.

Intercultural communication

This module also took place during the first weeks of the semester. As explained before, the team members have different nationalities. Due to this, there are cultural contrasts.

The course was helpful for understanding that in an intercultural setting it is likely that there will be cultural differences however, we are all more similar than we think. The course was very good for helping us let go of stereotypes and preconceptions and it was a great opportunity to bond with our team mates.

Cross Media Communication

This course was useful for helping us create our corporate image and setting some basics of the project. Before this course we did not have a brand name, colour pallet or corporate identity, and during the course we had the chance to brainstorm and focus on this by paying special attention to the meanings of each shape and each colour.

We also had to do a story board about Why, What, How, When, Where and Who our project affected. This encouraged us to think about how to make our product stand out, how to differentiate ourselves, create value and approach the user, and what channels we would use for it.

For this module, the teacher asked us to work on a digital platform called "my sketch drive" where we had to upload the different assignments, and we could see the other groups' assignments to give them feedback and enrich synergistically.

Usability

In the EPS programme we were also provided with more information about usability and how to integrate this information into the project. The goal was to analyse the users of our product in a real time environment and whether the design is right for them or not.

This module was the most crucial for us due to the nature of our project, it being a toy, and since it pushed us to do several user tests with children aged 5 to 6, to check the interaction and whether the game was understandable and playable. From those user tests we obtained feedback, which we implemented as improvements in the next design iterations. Thanks to this, we realised we needed to make drastic changes both in the game as a concept and the physical components. Those observations were essential since they allowed us to re-orientate and remodel the game according to the user's needs, adapting it to their abilities and tastes.

Thanks to this module, our design was made much more interactive, intuitive and attractive for the target group it is aimed at.

Sustainable Design

The sustainable design module was extremely useful for us to achieve our goals during this project. It helped us make clear who the stakeholders of our project were, how to add value to our project in the eyes of these stakeholders and finally, how to involve them with the project.

Additionally, this module helped us see what the current behaviours of our users are and how we should influence these towards our desired one.

English lessons

This module was necessary for this project due to the international aspect of the team. It helped us learn how to do presentations properly, by showing effective and concise ways of transmitting information whilst still drawing the audience's attention. The teacher also gave us personalised recommendations for us to improve our speeches.

This module also showed us how to write a report properly in a formal document. This included useful synonyms of common informal words used, guidelines for the report such as the margins, font... Additionally, it was very useful as our teacher corrected our midterm report, giving us recommendations and improvements, we could make to our writing skills

Designing Electronics

This module was interesting, appropriate and applicable towards our project, it being a hybrid toy train. It helped us condense and make clearer how the electronic components and programming worked together, doing this by the means of a flowchart. It also sparked our interest and curiosity towards electronics as the teacher gave us examples of interesting ways of applying electronics to simple and existing products.

Business Canvas

In this module we learnt more about the different business opportunities, how to create value, which aspects were involved in a business model and therefore had to be taken into account. It helped us decide which kind of business model we wanted to follow. This was a very important decision in the development of the project, since it conditioned the design of the game. We chose to create a basic game kit, which was expandable by means of buying additional add- ons, instead of reusing the same pieces for all the games.

Intellectual Property

This module was useful towards the state of art research, as it showed how to research existing products in the market to assess the novelty of our product

The intellectual property module was also crucial to show us different ways of protecting our product by not only the means of patent rights, but also through less restrictive means that do not require the product to be novel, ground-breaking or distinguished.

APPENDIX B

STAKEHOLDER ANALYSIS

The relevant stakeholders involved in the project are children, parents, schools & teachers, the University of Antwerp, materials companies, toy stores and the government & organizations interested in education. Next, for each of the interested parties, it will be described how we will create value with the project, and how to involve them in it.

* **Children** of both genders are the main stakeholders since these are the users, and therefore the design has to focus on them and has to meet their needs.

- How to create value: The toy provides entertainment to the children, while helping them discover and learn about the environment whilst developing their cognitive and motor skills. By playing, the child will assimilate behaviours such as sharing, reflecting, applying deductive thinking and completion of a task.

- How to involve: We involve them by implicating them in the design process. Going to schools and letting children try and play with the prototypes, so iterations can be made based on the feedback received from them, to improve the product and meet their needs and tastes.

  Another way to involve kids during the game is by designing a brand new product, which appears fascinating, interesting, and challenging so that they will want to play with it.

* **Parents**, close relatives or guardians; they are the buyers as they have the purchasing power.

- How to create value: Offering a quality toy which provides a quality game. Children's playing time is not only used to amuse and entertain, but also to effectively develop and enhance their motor and cognitive skills.

  The materials from which the toy is made are resistant, environmentally responsible and minimize the carbon footprint. Likewise, the philosophy of the project contributes to a sustainable and circular economy that protects the environment for future generations.

  The game provides some autonomy to parents since they do not need to be with the child while they play. However, it is possible to play together, to strengthen the bonds and parent-child relationship.

- How to involve: as with the case of children, involving them in the design process by letting them play with the prototype and turning their feedback into improvements.

Moreover, questionnaires will help gain insight into their needs and preferences. These insights should be implemented into the design so it matches the children's preferences.

In order to make the parents aware of the need and advantages of giving their children a quality toy, not only from the educational standpoint, but also from the perspective of sustainability, as a way to instil in their children the importance of taking care of the environment.

* **Schools and teachers**, as they can also be potential buyers.

- How to create value: Schools may be interested in the toy, since it is an interactive toy that enhances education through play and senses. In addition, several kids can play at the same time, favouring their ability to socialise and create links with their classmates.

- How to involve: Contacting schools and teachers to test the prototypes and with their feedback, improve the design in a next iteration.

  Conducting surveys about the toy since they are the professionals who are in daily contact with the future users of the product and know the needs that have to be covered at each phase of their growth.

*** University of Antwerp**

- How to create value: The project is developed within the framework of the University of Antwerp. The research conducted by PhD student Marieke Van Camp, serves as a starting point. Therefore, our research, designs, prototypes and conclusions are useful to provide feedback, as well as another vision to the PhD enriching it from another perspective.

  The university has (intellectual) rights over the project, meaning there is a clear advantage if the project were to be relevant in the future and it is decided to be patented or produced, since it would provide the university with prestige and make itself more known.

- How to involve: The university is involved since it finances the project.

  The prototypes will be made in the workshops of the university.

  There is a flow of information between the author of the PhD and our project, meaning both parties benefit. The university may have contacts in companies that can be useful for collaboration, development or future manufacturing of the project. When required, expert teachers from the university will be consulted.

* **Sustainable material companies** that respect the environment

- How to create value: It may be beneficial to contact companies that want to implement their materials in a tangible physical product that has the potential to be produced and marketed.

- How to involve: Contacting the enterprises and making prototypes together to check the properties of the materials and see if they adapt to the needs and regulations.

* **Toy stores**, since they are one of the sales channels (looking to the future, if the project should be marketed).

- How to create value: The sale of the product in toy stores can mean an increase in sales, which makes the store gain popularity. Furthermore, because it is a toy that promotes education and sustainability, it can give an image of notoriety and prestige to the store, setting a quality standard.

- How to involve: Giving samples of the toy to the stores and see how they are sold. If the toy is quickly accepted the store will want to acquire more.

  They can also be used to request information about the best-selling products, the most appropriate for the age range of five to six years, the most valued...

* **Government and organizations interested in education**

- Some concrete organizations:

  - Digitale Wolven: organizes workshops on STEM-subject for children

  - STEM-academie: links organizations involved with promoting STEM.

  - Cronos: helps turn research into business solutions, implement new technologies in business models and help start-ups.

  - Levenslang Leren: University of Antwerp offers support to students who want to be involved in entrepreneurial activities and combine studying and working.

- How to create value: It is a long-term investment in the education and training of future generations. It helps prepare youth better towards new challenges and to be stimulated.

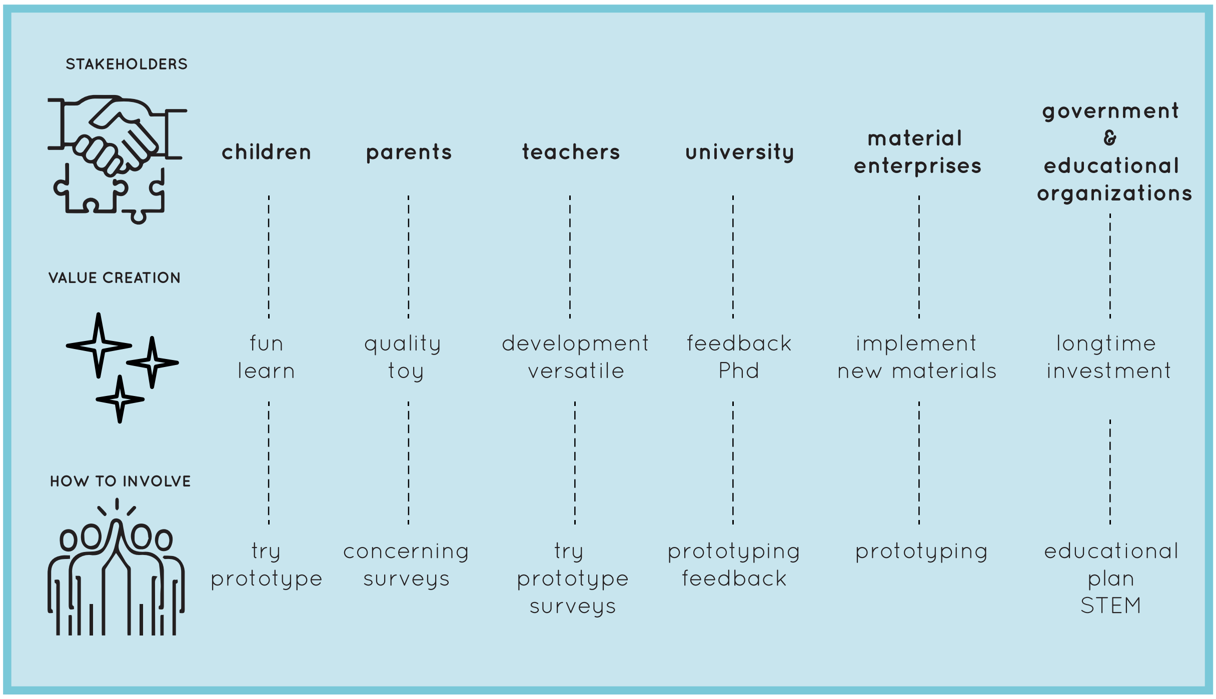
The Flemish government already applies a STEM program. This program "enhances developing scientific, technological and mathematical insights, concepts and practices (S, T & M) and using them to solve complex questions or real-life problems (E)." (STEM Framework for Flemish Schools Principles and Objectives https://onderwijs.vlaanderen.be/sites/default/files/atoms/files/STEM-kader%20%28Engels%29.pdf). This means that for the government, the development of these capacities is something of great importance. Therefore, supporting this hybrid toy can help the development of the values that are intended to be achieved with the STEM program.

It is also a toy that respects the environment which is a relevant fact for responsible and developed countries.

- <u>How to involve</u>: Presenting the product to the government or other interested organizations for financial support and dissemination.

  Also developing hand to hand this toy to adapt it to the educational plans of the future.

  Finally, maintaining a commitment to safety and sustainability that supports environmental measures and a circular economy.



APPENDIX C

MARKET RESEARCH

A market research has been carried out to find out about the current situation of toys, with a view to finding a possible market niche, to see what the main strengths and weaknesses are, and to identify the main competitors.

A collection of toys and images that influenced the progress and development of the project can be found below. These guided us towards the right direction.

The following four categories will be addressed: Trains, complementary games & accessories, tracks and robots & interactive toys.

Trains:

On the market there is a wide variety of toy trains composed by the train itself and some modular tracks that are joined together by tabs, to create the circuit desired by the child. The circuit can be expanded by accessories and complements including traffic signs, bridges, tunnels, stations, traffic lights, elevators, mountains and trees.

A vast majority of the researched trains were "traditional" trains, meaning they are not electronic nor interactive. The child being the one who has to move the train along the circuit and improvise about where to put the other components gives him freedom in the game, however, it can make the toy somewhat monotonous. Within this category of train toys, trains made of wood stand out, as can be seen in the Figure 1. Many brands manufacture with this material since it is a noble, warm, resistant and sustainable material. Some leader brands to highlight are Brio, Janod and Hape.

Figure 1: traditional train toy made in wood

In contrast to conventional trains, there are other toy trains that include electronic and interactive elements such as tokens, which react to certain situations, providing auditory or visual feedback through the emission of sounds or light (Figure 2). The aesthetic aspect of those trains however, is less refined, since they are usually made from glossy plastic materials with bright colours. This attracts children and

stimulates their sense of sight, although they are of poorer quality than those made of wood and therefore less durable.

Figure 2: Plastic interactive toy trains

Some sets include games at different points of the track, as it can be seen in Figure 3. This makes the game more dynamic and entertaining for children since it brings variety. These games tend to enhance and develop fine motor skills, as well as their senses of sight, hearing and touch, so they are interesting as an educational tool that transcends

Figure 3: circuit with complementary games in the tracks

Complementary games and accessories

As previously mentioned, simple challenging games can be integrated into the track and turn the game more interesting, while developing certain skills. These help children explore and experience tactile, visual, auditory and physical movement.

These games (Figure 4) are an inspiration and useful for the development of the project since they serve to lay down concepts that can be applied in the app game.

Figure 4: basic games to enhance skills´ development

Other interesting complements or additions are the proposals of the brand Dusyma (Figure 5). These are implemented in the tracks and serve to make meal time fun. They follow a very minimalist and refined aesthetic, and the use of wood confers quality and warmth.

Figure 5: complements

Tracks

The tracks are an important element since they determine the way of playing. Most games include straight, curved and intersection tracks, (as can be seen in Figure 6) with slits where the wheels of the train settle, and some tabs to join the tracks together. The user can join the tracks to his or her liking and form different circuits.

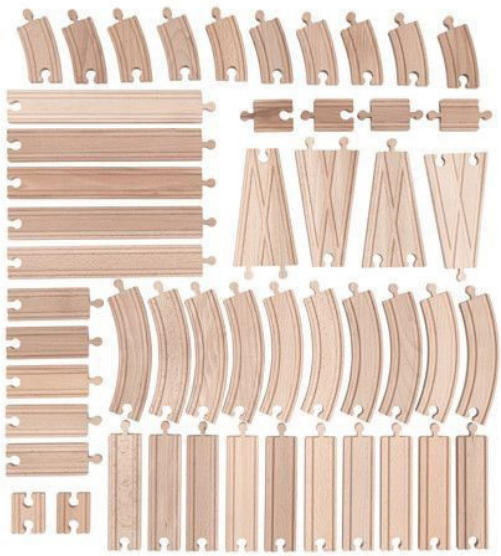


Figure 6 : simple tracks: straight, curved and intersection.

However, the options are still limited compared to other alternatives.These alternatives could be rectangular pieces, flat tokens or cubes, on whose faces several lines that simulate paths are drawn. So the possibilities of combination would be much greater. In this way, multiple labyrinthine paths emerge, which is more challenging for the child, and enhances their spatial and deductive abilities. The Figure 7 serves as an inspiration for the track´s shape.

Figure 7: games based on geometric paths and circuits.

Another alternative is the drawable tracks (Figure 8). The user draws the paths in different colours, a robot with sensors detects them and advances in that direction. This favours creativity and imagination. It is attractive because it is a different type of game that grants greater freedom to the user.

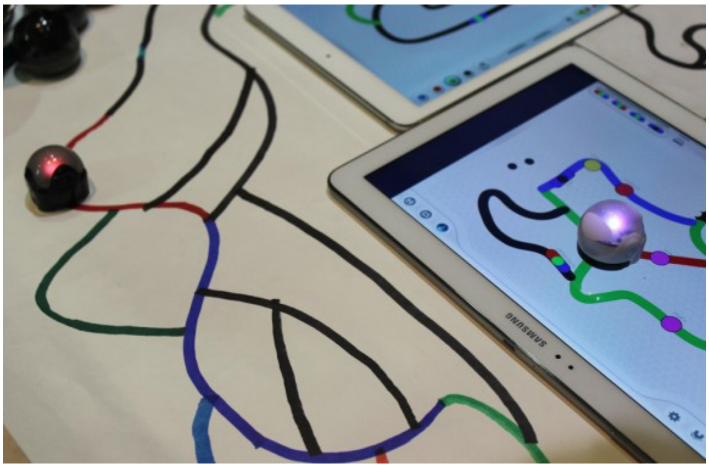


Figure 8: drawable tracks

A train that is very interesting for the concept that applies is the train “musical box”. The tracks have small outgoing points as shown in Figure 9 and the train has a comb that when running into the dots, makes sounds.

Figure 9: musical box train

Robots and interactive toy

There are interactive toys that also consist of a circuit and an element that moves through it. An example is this robot (Figure 10) that teaches coding principles and skills to children. “You do not need any screen device to program this robot; programs are created by simply laying down a sequence of physical code cards that are read by optical scanners. You can program the robot to move in different directions, activate its output gear, light up its LED, play sounds, and respond to different function cards. “ (According to Kid´s First http://www.thamesandkosmos.com/index.php/product/category/science-kits/kids-first-coding-robotics).

Figure 10 : Coding and Robotics

Another game that also applies the principles of technology and programming is the screen free toy, shown in FIGURE 11 , that introduces coding in an easy, friendly way. “This robot can detect and be programmed to go around objects with if / then logic. It can also follow looping commands, follow black lines and have hidden features to unlock! (Learning Resources https://www.learningresources.com/product/botley-the-coding-robot-2936.do?sortby=ourPicksAscend&refType=&from=fn)”

Figure 11 : Botley, the coding robot

These types of games are very interesting because they introduce children to the technology and principles of STEM, developing their logical and deductive thinking.

Nintendo is developing a “Do It Yourself” cardboard toy. This toy is called Nintendo Labo (Figure12), which consists of a new range of interactive experiences “that allow you to play and build, designed to release inventiveness and enjoy playing”.
Starting with some cardboard plates and another series of elements (rope, eyelet, ribbon, stickers) that are included in the Nintendo Labo kits, the user will have to create a series of cardboard structures, which can be objects as diverse as a piano, a robot, a motorcycle or a fishing rod, with which you can then play by combining them with Nintendo Switch and Joy-Con.

These creations can be customized freely, giving free rein to the imagination. Each Nintendo Labo kit will include all the necessary pieces to realize the constructions of cardboard, and a card of game to be able to interact with them in Nintendo Switch.

It is a successful and brand new product since it combines an element such as cardboard with technology, creating a hybrid interaction.

Figure 12 : Nintendo Labo

Lego also presents interactive hybrid game kits, in which the child will have to freely build the figure that he likes the most (Figure 13). The Lego pieces have some sensors and optical
readers that are connected to an application on a Smartphone or Tablet. Through this, the child can control the movements of the toy.

The versatility of Lego´s pieces make possible to build numerous figures, generating a very attractive and versatile product, which enhances the child’s imagination and creativity.

Figure 13 : Lego Boost Robots

To sum up, there are already a large number of toy trains on the market. Most of which are analogue and do not include any interactive electronic components. However, with the development of science and the increasing importance of technology, the development of these skills and concepts is being promoted from an early age, with educational programs such as STEM (Science, Technology, Engineering and Mathematics).

Most of the toy trains have straight, curve and intersection tracks, so a market niche could be to design an alternative train that moves through other types of tracks. The materials most used in the games are wood and plastic. The latter is cheaper but is less responsible with the environment and offers worse quality.

The design challenge is to develop a concept that includes a different track typology, to make the game stand out against competitors, as well as to include elements that interact with the users to stimulate their senses and abilities.

APPENDIX D

INTELLECTUAL PROPERTY

During the research conducted on the intellectual property aspects that apply to our project, we noted that trademark rights, copyright, design rights and patent rights apply to it.

1. Trademark Rights
2. Copyright
3. Design Rights
4. Patent Rights
5. Software Rights
6. Protection of Components

First of all, we will talk about trademark rights and how they apply to our project. In the market scene, names and logs help identify and differentiate different brands and products. To help protect these two, trademark rights exist. In the case that we only wanted to protect the name of our team, we would have to use a word mark and on the other hand, if we wanted to protect the logo, we would need a device mark. Corresponding to our project, we would be able to apply for a word mark and a decide mark. The word mark would protect the name H!TO and the device mark would protect our logo and imagotype.

Now going on to copyright, it concerns an original intellectual creation. Specifically, it protects works of literature, science and art. Additionally, in most countries, graphical elements and concepts fall under the scope of copyright protection. Relating to the duration of a copyright protection, this lasts 70 years after the death of the creator of the item being protected. Another curious feature about copyright is that if a work of copyright that is created looks like another work but it was created independently(for instance when one could have not known that the previous work existed), both works can be protected. In the case of our project, copyright protection could be applied to the concept of our canvas model and also to the different iterations of our game story.

Following this come design rights. With these, the exterior design of an item is protected, including the lines, colours, shape, texture, materials or the ornamentation that was used. To be able to apply for this right, the appearance should be new and it should have its own characteristics. Within design rights there are two branches, registered and unregistered rights. The advantages of registered designs are that the duration of protection is longer, the scope of the protection is broader and finally, that the burden of proof in case of infringement is higher. Also, if the design is unregistered, it has a duration of 3 years, and if its registered, 25 years. Applying these rights to our product, we could protect the aesthetic lines on the tracks that simulate railways, the fake wheels that hold the train on the tracks, the raised tracks, the character design, the design of the tokens and finally but not least, the design of the buildings.

After these rights come the patent rights. Patent law only protects inventions meaning that the aesthetic aspect of toys is not protectable by this area of law. To protect these inventions they must be new, inventive and have an industrial application. From this we saw that patent rights do not apply to our project as we have not invented something novel or discovered anything that makes things easier or more efficient.

As our product includes software, software copyright would be applicable. Software copyright is and extension of copyright law to machine-readable software. The law is used to prevent the unauthorised copying of software. Additionally, free and open source licenses also rely on copyright law. In the case of our project, blocks of free and open source code have been used that in this specific case to not fall under protection along as we credit the original creators.

As our product included many 3rd party components, we had to do some research on the topic. In the case of the Arduino, it does not require any permission for use as long as we do not imply affiliation with Arduino and we do not include their name in our product or the name of the company.

IP right	Trademarks	CopyrightsD	esignsP	atents
Protected features	- Name or logo of the product - Name or logo of the company * if they are used to distinguish the products of that company from those of other companies)	- Design of the toy -Other creative works, such as text, colours, - shapes and drawings	-Designs -External appearance such as lines,contours, colours and shapes.	-Inventions - Discoveries that make certain things easier or more efficient.

During this research, we gathered that the patent CPC classes applicable to our work are:

•A63H 17/00: Toy vehicles.

•A63H 18/00: Highways or trackways for toys.

•A63H 19/00: Model railways.

•A63H 30/00: Remote-control arrangements specially adapted for toys.

•A63H 33/04: Building blocks, strips or similar building blocks.

We also saw that design class applicable to our work (Locarno) is class 21 which includes:

•103343: Constructions sets for children.

•103387: Electronic toys.

•103398: Figurines[toys].

•103361:Toys

•103397:Vehicles

Finally, the trade mark class applicable to our work (Nice) is class which includes class 280163 for toy vehicles.

APPENDIX E

BUSINESS CANVAS MODELS

1. Corporate Image & Branding Model

The first business model we developed was the corporative image & branding model. In this model our target market was business-to-business and companies trying to shift towards a more environmentally sustainable sector, for example, circular economy.

This model's valued propositions include the spreadability of the information about the applicability of the material and to make this known as well as the corporate image and our corporation's values.

The customer relationships pertaining this model would be to create/join a trade fair to advertise our product/material whilst creating stronger and closer bonds with our clients.

Our revenue streams would come from selling our concept for branding purposes, profits from selling the toy if it were produced and finally, from a partnership if the project were to be successful.

Going on to the key facts about this model. The key activities of this model would be the implementation of the material and its development. On to the key resources, these would be the production facilities, computer hardware and software, intellectual property policy and finally, a sustainable circular economy. The final key fact of this model would be our partners which in this case would be the company in charge of the newly developed circular material and possible sponsors.

Finally, on the costs side, these would come from paying the labour hours for establishing and advertising the product, from the rental of production facilities and from the necessary licenses.

This model's canvas can be seen below in Figure 1.

The Business Model Canvas: Corporate Image & Branding

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
Company of the specified newly developed circular material Possible sponsors	Implementing the material into the toy Developing the concept	Expand applicability of the material Make known of the material and corporate image & values to the public and other businesses	Trade fair where the product/ material can be advertised	Target Market: Business-to-business (B2B) Companies trying to shift towards a more environmentally sustainable enterprise (circular economy) Existing Alternatives: Marketing through TV, social platforms, magazines, etc. Develop own applications Hire consulting company
	Key Resources Production facilities Computer hardware & software Intelectual Property Policy Sustainable Design Thinking (Circular Economy)		**Channels**	

Cost Structure	Revenue Streams
Labour hours in order to: Establish the product (Developing the concept and checking feasability) Advertise the product (Renders & visuals showing the concept) Production facilities rental and computer hardware & software licensing	Sell the concept to a company so it can be used for branding purposes In case the product goes into production, obtain a bonus/percentage per toy sold Future partnership and related projects can happen if the project is successful

Achilles' heel:
1. Financing: What part of the company's budget will be spent on a side project like this?
2. For the EPS project it could only be developed a hybrid toy. Depending on the company's core business they might not want to be associated with toys
3. The company's material needs to be suited for use in toys (Demanding regulations & standards)

Figure 1 : Corporate Image & Branding Canvas

2. Hybrid Toy Model

Throughout the research phase of the project, the team had to decide what our business model would be, meaning, we had to describe the rationale of how our "organisation" creates, delivers, and captures value, in economic, social, cultural contexts. Through this research, we decided to continue with the "hybrid toy" business model.

In this model, the buyers would be the parents, grandparents or guardians of the users, since they have the purchasing power. Early adopters of our product could be parents of children with available smartphones that are interested in educational games that enhance their children's motor and cognitive skills by interacting and getting in contact with physical and digital components, or need time for themselves and get it by the means of distracting their children with a fun and educational toy.

Going on to the value propositions, our product would deliver hours of fun and play to our users, whilst developing their skills and imagination and as previously stated, more free time for the parents which in this case are the buyers.

On the side of the revenue streams, our main revenue stream would not be the starter kit but the add-ons/complements to the game. We would sell the starter kit, composed by the basic elements which allow to play the game, with little margin for profit to get as many customers as possible into the ecosystem and once they are in, sell them complements and in-app purchases with a larger margin of benefits.

To calculate the cost structure we would have to include the labour hours, all the infrastructures such as factories, labs…, software licenses, logistics, material costs and finally, transportation.

Whilst developing this business model we had to take into account what our Achilles heel would be, meaning, what disadvantages this model would bring. We saw that due to the nature of our toy, whilst using the app, distraction may occur due to other apps and notifications. Additionally, our product may be more expensive due to its hybrid nature.

The associated canvas can be seen in figure 2

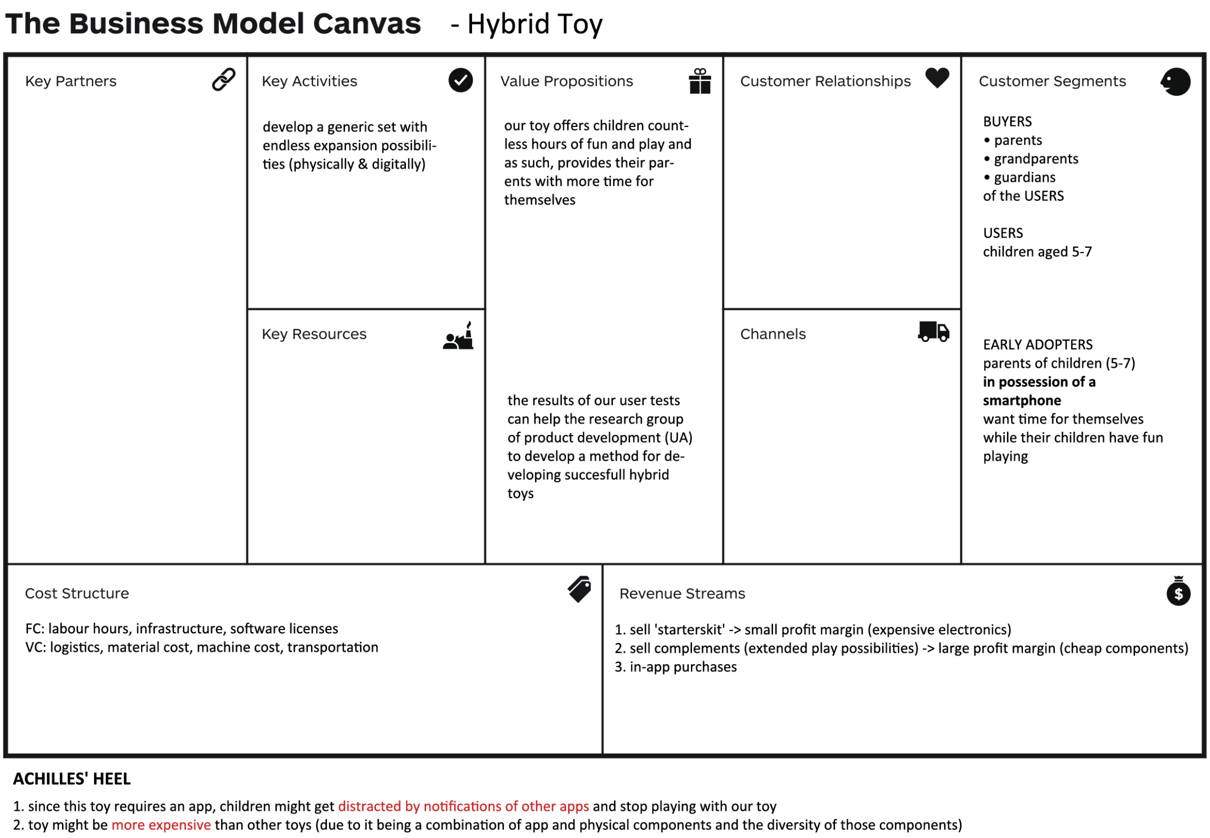


Figure 2 : Hybrid Toy Canvas

3. Educational Game

The last business model we developed was the education game model. In this model due to its educational nature, our clients would be teachers and schools with students aged 5 to 6 years old. Additionally, early adopters of our product could be teachers aged 20 to 40 with a grasp on multimedia devices.

This model's valued propositions include the increase of the duration of attention span and engagement during class. This would be done through the means of multimedia and hybrid toys that keep track of the progress of each child and personalise the difficulty accordingly. This would aid the teacher with large classes as it records the achievements and difficulties each child has. The key actives this product would provide would be the implementation of educational games, regular updates and the possibility for expansion of the game and finally, as previously stated, the track and personalisation of child's progress.

From this value proposition, our revenue streams could either come from sales to teachers or sales to schools and governments once our product is settled in the market. The government would also be a key partner due to its interest in the STEM field. The University of Antwerp would likewise be a partner during the development of the toy.

Finally, the cost structure of this module would come from labour hours, infrastructure and software licenses due to the large importance of apps in this module. Additionally, costs would come from logistics, material costs, machine cost and transportation fees.

This model's canvas can be seen below in figure 3.

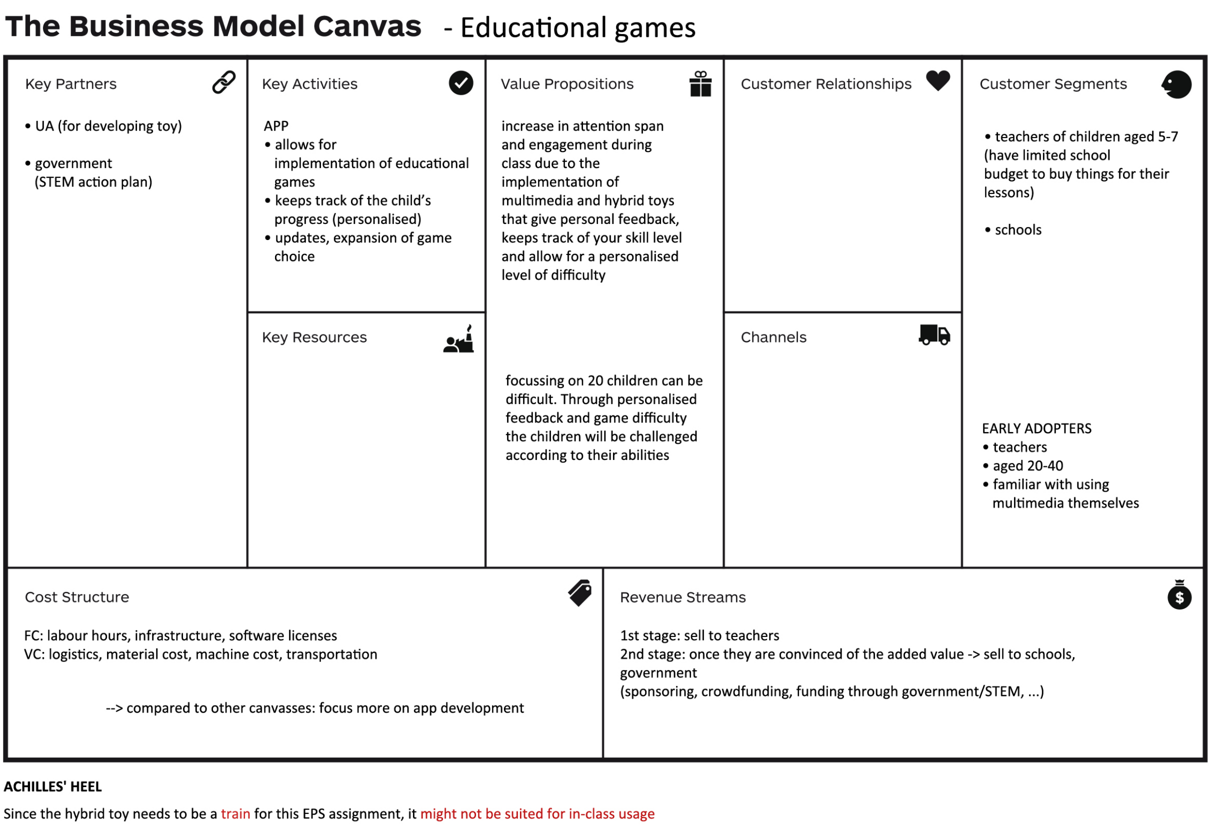


Figure 3 : Educational Game Canvas

APPENDIX F

PROJECT PLAN

1. Project Activities:

Section 1 – Research:

- Market research on existing companies & products
- Determine the type of wireless communication
- Determine in what environments the toy will be used (Context of use)
- Branding and corporate image draft
- Field Research (User Interaction with the product)
- Psychology Research
- Acquire electronic components
- Interview teachers and kids
- Project Plan

Section 2 - Ideation & Development:

- Familiarising with basic app creation
- Familiarising with the electronic components
- Vehicle typology research
- Brainstorm about track type
- Brainstorm about track design
- Brainstorm about track features/extra's (train station, tunnels, bridges, etc.)
- Brainstorm about app interface
- Brainstorm about corporative colours and logo
- Brainstorm about game ideas
- Product sketching (3 concept proposals)
- Low fidelity prototype manufacture
- Flowchart
- Mid-term report

Section 3 – Formalisation:

- App-Product interaction
- Medium fidelity prototype manufacture
- 3D modelling
- Make app function for chosen communication
- Electronic components assembly

- Electronic components programming
- App creation
- App interface design
- Product material research
- Infographics and renders
- Contact with companies
- Final branding and corporate image

Section 4 – Prototyping:

- High fidelity prototype manufacture
- Prototype test
- User test
- Product and App improvements and iterations according to feedback

Section 5 – Production:

- Final user tests
- Brainstorm about the presentation video
- Editing the presentation video
- Final report

Section 6 – Post Production:

- Final Presentation
- Peer Feedback

Section 7 – Weekly Work:

- Other assignments for guest teachers
- Logbook

Section 8 – Holidays:

- Easter Holidays
- Public Holiday
- Free Days

2. Project Scope:

The project extension and limits will be specified during the length of this chapter. The scope will be determined in the duration of the project, what it will and will not include and what preconditions are established at the beginning of the project.

2.1 Project Extent:

The project will encompass the initial research, the second phase of ideation and development, the formalisation of the product and the subsequent prototyping and finally an eventual production of the product and its respective documentation.

1. During the initial research phase, the user and its environment will be determined and a market research will be executed to determine the personal approach of the team towards the project.

2. In the phase of ideation and development, the main features of the product and its functions will be specified together with the development of a mobile application, in addition to the components that will form the whole product and how they will interact with each other.

3. The product will be shaped, and its aesthetics will begin to be determined, and all the internal electronic components will start to be assembled and programmed.

4. In the prototyping phase, an initial product will be manufactured to gain the first feedback from the users, which will be composed of children aged 5 to 6 years old. This will be done to improve and adapt the product to the necessities, tastes and skills of the user. Feedback will be gained from the different iterations, which will then be applied to the product and then again tested until the final and definitive prototype is produced, concluding with a final model of the toy.

5. Finally, in the production phase, the product and the respective mobile application will be finalised and a final interaction with the user will be developed, in addition to concluding the corresponding documentation that will be delivered together with the final product. Therefore, the team will be responsible for executing all the evolution of both the product itself and the mobile application, although in the area corresponding to the acquisition of the elements and electronic components for the product, the team will only be responsible for requesting the desired components to the supervisor who will be in charge of acquiring the components.

2.2 Project Duration:

The project will start the first day of the established planning for the European Project Semester by the University of Antwerp, which is 19th February, 2018 (02/19/2018), and will end with the final presentations on 14th June, 2018 (14/06/2018), although the final report must be submitted on 8th June, 2018 (08/06/2018). Therefore, the official duration of the project, including holidays, will be 17 weeks. The project will be considered finished once all the documentation and designing of the product is completed. This means: the design, specifications, measurements, restrictions, tolerances, materials, aesthetics, finishes; as well as the electronic and digital aspects of the product, which incorporate the different games and programming of the micro-controller.

2.3 Preconditions:

In order to start the project successfully, there are a few matters which need to be considered:

- Hybrid Toy
  The final product must combine a physical and a digital interaction between the train and its external components and mobile application.

- Child Age
  The final user will be children aged from 5 to 6.

- Budget
  There will be a budget ranging from 1000-1500 euros, which will be used to acquire all the elements and electronic components needed to create the electric system. It will also be used to manufacture the possible prototypes and final product.

- Child-Friendly
  The final user will be children, therefore, the product must not contain any hazardous material and be conform with the European Law.

3. Intermediate Products:

In this chapter, it will be determined all the products that will incorporate the project. In this case, it will be understood as a product all the deliverables that will be provided in the final report.

Therefore, the following deliverables, which are well specified in the Project Activities section of this Project Plan, will be defined as a product:

- Project Plan
- Mid-term report
- Final Report
- Product
- Mobile Application
- Previous Prototypes
- Presentation Video

As for the Project Plan and other deliverables that must be provided before the specified date by the University of Antwerp, will already be within the final report, they will not be defined as separate items or products.
The main events will not be considered as products as well because they will also be included in the final report, although they will be contemplated throughout the project to determine the evolution of the project and the team and to analyse how much remaining project is missing and how much has already been done.

4. Quality Control:

During the development of the project, there will be multiple stages to ensure the maximum quality of the product and the project, not only in the theoretical and technical parts but also in the physical components of the toy.

There will be weekly meetings with the supervisor, Marieke, as well as a submission of a mid-term report, to ensure the project is progressing on the right path. The team will be given feedback by the supervisor during these meetings and advise how to continue with the project and which aspects have to be improved and modified, for making the necessary corrections and adjustments to the project. Once the team gains approval from the supervisor, the project will be able to continue and the final report will start being completed, to be submitted in June.

User testing will also be done to gain feedback from the different iterations of the product to understand more what children look for in a toy and what they enjoy playing with. Qualitative analysis will be executed from which the results will be processed and outcomes will be gained to ensure that the quality of the game is optimal to guarantee fun.

For the control of quality at the physical and mechanical level, several simulation programs are available, such as Autodesk Inventor or SolidWorks Simulation.

For the app development, Visual Studio 2017 will be used. Visual Studio gives the programmer feedback any time they make a mistake in their code. This, along with continuously testing and debugging the app using an Android device, most of the coding errors can be found.

Another pillar that will guarantee the quality of the project is the European normative and legislation that pertains to this type of products. This will ensure that everything complies minimum guidelines for a safe product.

5. Project Organisation:

In this chapter, the planning of the project will be determined and the main tasks will be distributed according to the capabilities and skills of each team member.

As within the project team there are well-specified roles due to the different specialisation each member is enrolled in, tasks were divided mainly into the areas where each component of the group felt more comfortable working in, although help of the other members of the team will be provided as well in order to contribute in the work if necessary.

The entire project is supervised by Marieke Van Camp, who is working on a similar project for her PhD. As the project team consists of students with various areas of expertise, team roles were divided to get a better overview of the tasks each team member was going to focus on. Three of the team members were appointed to the role of product designer, as this role corresponded to their education. The product designers are Alicia Alonso, Victor Martinez Nuñez and Tine Vande Verre. The role of an electrical engineer was appointed to Jan Gomez Roberts, and Kevin Schelfer was appointed as the software developer, along with the role of project manager. In Figure 1, a clear overview is given of the team roles. It has been agreed upon that each team member will have slightly more authority when it comes to decisions being made in their area of expertise. This is because said team member(s) will have more experience about the subject and therefore has a more educated opinion. They do not have full authority, however, which means that if the other team members disagree with the chosen approach, a different approach will be required.

Name	Study	Role	Expertise
Alicia Alonso Gil	Industrial Design and Product Development	Product designer	3D modeling, graphic design, simulation & rendering software
Jan Gomez Roberts	Electrical Engineering	Electrical engineer	Circuit designing, low-level programming
Víctor-Marcel Martínez Núñez	Industrial Design	Product designer	3D modeling, rendering software
Kevin Schelfer	Applied Computer Science	Software developer Product manager	High & low-level software development
Tine Vande Verre	Product Design	Product designer	Sketching, 3D modeling, graphic design, rendering software
Marieke Van Camp	Product Design (Major in Interaction Design)	Supervisor	-

Figure 1: Overview of team roles

As according to the provided schedule there are specified hours in order to work in the project, it has been agreed that every team member must be available within these appointed project hours for the entire team convenience.
In accordance with the supervisor preference, a meeting between the team members and the supervisor will be realised each Friday considering the availability of all the members of the project and the supervisor that day.
In order to maintain a constant contact between the team members outside the established team project hours, a chat group will be implemented using either a mobile application or via email and all the project evolution and documentation will be stored in the cloud to be accessible to all the members.

6. Schedule:

In this section, the schedule for the project is shown in a Gantt chart (Figure 2), with a distribution of all the tasks to be developed throughout the project.

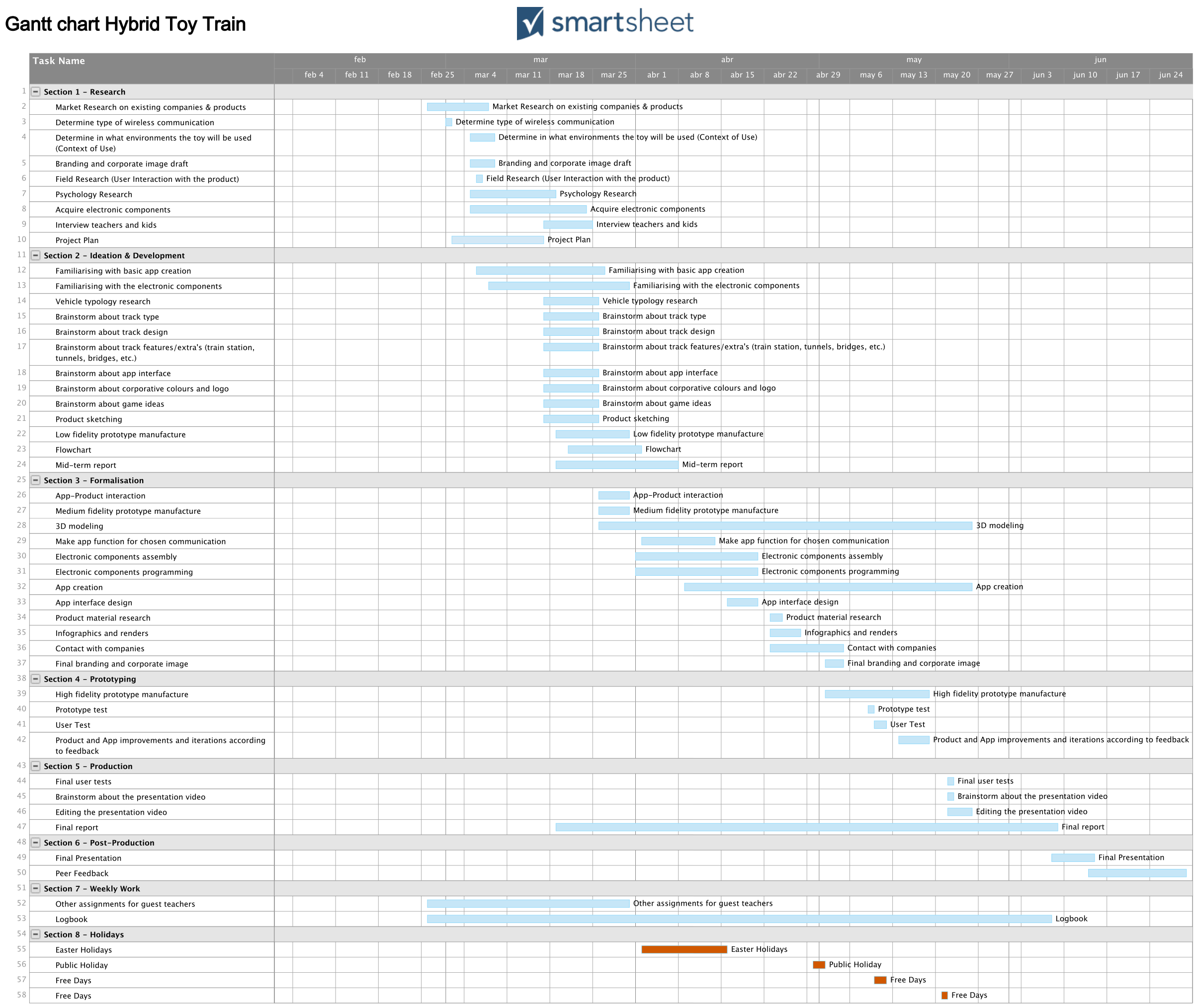


Figure 2: Gantt Chart Schedule

7. Costs & Benefits:

7.1 Working hours:

1. The main cost for this project will be the number of total hours all five team members will invest in this project. These working hours can be split up into two categories. The official amount of hours. These are the working hours the supervisors and coordinators of the EPS-program expect their students to work on the project. The weekly average of these hours differs. In the beginning, they contain about 16 hours due to the obligatory courses that have to be attended by the students during the other hours. Near the end of the project, the average amount contains about 35h/week. In total, the students are expected to work at least 1578 hours on their project (5 students x 315 hours = 1578 hours). This information can be found in the Gantt chart included in Figure 2.

2. The additional amount of hours. These are the hours drawn from the students their spare time. It may be necessary to invest time in this project after the official hours or during the weekend. Preparations, interviews, field research, etc. are activities that

students might be forced to fulfil outside the official time frame. We gauge 3h/week extra will be sufficient. The total amount for all five students is therefore 5 students x 3h/week x 15 weeks = 225 hours.

7.2 Acommodation:

Apart from working hours, there are several other costs to take into account for this project. One of them is the accommodation. The University of Antwerp provides several spaces, three of which we will occupy regularly depending on availability and prototyping needs:

1. Product Development building, 1st floor, "design space": includes tables, chairs, wi-fi-access, power supply, toilet, lighting, computers, Adobe creative cloud, SolidWorks (3D modelling).

   Address: Ambtmanstraat 1, 2000 Antwerpen

2. Product Development building, ground floor, "prototyping lab": includes CNC milling machines, 3D printers (SLS, FDM), Lasercutter (Trotec).

   Address: Ambtmanstraat 1, 2000 Antwerpen

3. Gate 15, co-working space: WIFI-access, power supply, tables, chairs, toilet, lighting.

   Address: Kleine Kauwenberg 15, 2000 Antwerpen

7.3 Accessories:

The accessories are the final cost to take into account. The available budget to spend on these contains 1000-1500 euros. The costs for accessories include but are not limited to:

- Materials for prototyping
- Electronic components
- Software licenses (e.g. Smartsheet for organising the project)

7.4 Benefits:

This project involves a lot of prototyping and user testing. The outcomes and conclusions of these can serve as inspiration for the PhD research that is currently being done by Marieke Van Camp. The end result of this project will be a completely functional prototype. This prototype is to some extent related to the first prototype Van Camp made for her PhD research. She is currently working on a 3rd prototype and our end result can be seen as the 2nd one.

APPENDIX G

CORPORATE IMAGE

To devise the corporate image as well as the name of our brand, we brainstormed concepts and illustrations that we wanted to be present in our image and to communicate the philosophy and spirit of the product. This can be seen in Figure 1.

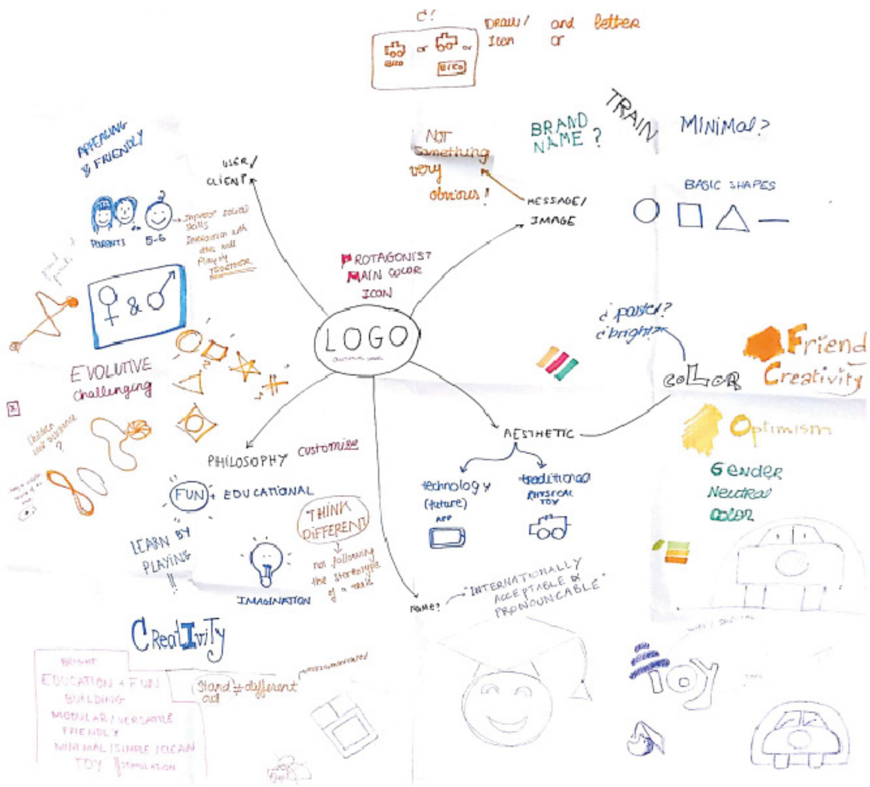


Figure 1: Brainstorming for obtaining ideas for the design of the logo

Some keywords were: dynamism, fun, education, gender neutral, basic figures, skills, friendly... Finally these ideas concurred in the following imagotype (Figure 2):

Figure 2: Imagotype

Colours:

The colours of the logo consists of the three RGB colours with some modifications to make them warmer and enhance among them, plus one extra colour (orange) to balance out the logo. All four colours are cheerful, playful and convey an image of dynamism and vividness. The colours are specified in the Figure 3.

The reason why we choose primary colours was to make it simple and approach to children, since at the age at which our toy is directed (five to six years old), children distinguish these ones better. The colour chosen for the brand name is red considering that it stands out the most and catches the child´s attention.

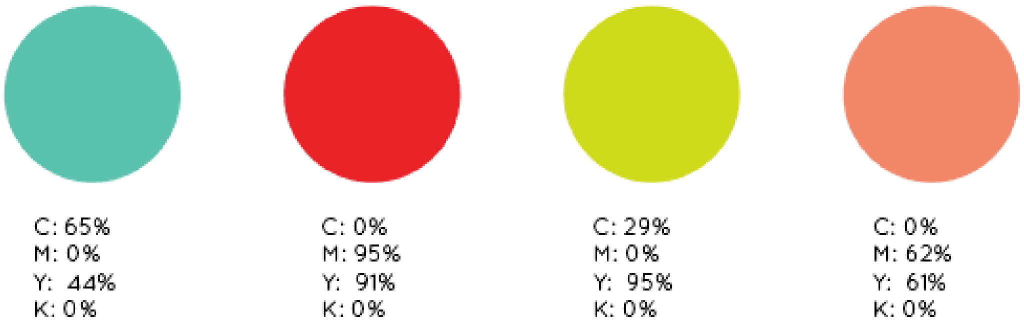


Figure 3: corporative colours

Brand name:

The brand name arises from the combination of the first letters of the project name (Hybrid Interaction Toy) (Figure 4).

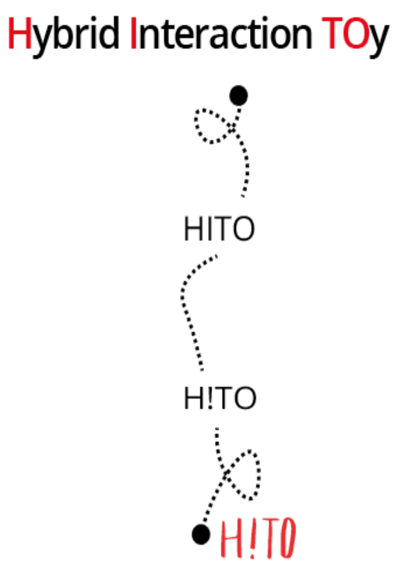


Figure 4: process of the brand name

The combination of the letter H with I creates the word "hi", (greeting), so it seemed an interesting way to approach our product in a cheerful and carefree way as well as capturing attention.
To give more emphasis, we flipped the "I" over and turned it into an exclamation point. This slight change persuades the public and highlights the interaction between the child with the toy. The brand name goes from being a word into a set of letters and characters that can however be read as if they were only letters.

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Logo shape:

The logo shape consists of 3 basic geometrical shapes: rectangle, triangle and circle. As when the election of the colours, the choice to use basic geometrical figures is to create something very simple and minimalist, that is easy to remember.

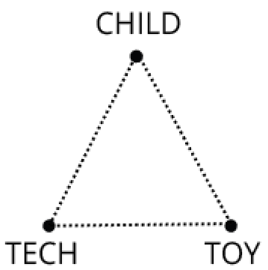


Figure 5: interaction triangle

Being composed of different elements located within a main figure generates the sensation of dynamism and being able to move the components between them to create different combinations or construct larger objects. The logo expresses balance since the visual weights of the parts that make up the logo are compensated.

The triangle is the most dominant shape of the logo, emphasising the harmony in interaction between children – digital technology (app) – physical toy (Figure 5).

Logo + brand name:

Two variations of the position of the logo and the name have being designed, depending on the context and the space where the imagotype will be implemented. The horizontal imagotype fits within a rectangle and expresses reliability and equality. It will be implemented when horizontal space dominates. On the other hand, the imagotype with the name at the top of the logo is more compact, so it will be used for more reduced spaces.

Three variants of the logo are shown in Figure 6, depending on whether the colour scale, grayscale, or laser engraving will be used.

Figure 6: variants of the logo

Other design options:

Figure 7: “PLAY” with the logo

One design alternative is combining the logo in different ways, making some modifications and playing with the elements, to create the letters “PLAY” (Figure 7). It gives the impression of articulated and dynamic components.

Other alternative is to add some shades to the shapes of the logo, it creates more depth and provides a third dimension (Figure 8).

Figure 8: variation with shades

APPENDIX H

TRACK SHAPE EVALUATION

To choose the type of track that we wanted to implement in our game, we made a comparison between 3 types of tracks to decide which was the most appropriate to meet our goals.

Track shape 1: Drawable tracks

Benefits	Omission of physical tracks, which means the final product has a reduced price, as the tracks do not need to be produced, and eliminates the possibility of losing some element from the tracks. Improves the storage of the toy once the child has finished playing with it, as there are no tracks to store. Enhances the use of imagination and versatility to create a circuit for the toy and appeals in major way to childre n of that age due to their tendency to love drawing and painting.
Drawbacks	May not work if the pen provided is not used and in case of paper being the surface determined to draw the tracks, it means a waste of material. Two -dimensional element, which mea ns that the child could find it difficult to interact with it. It would be more complicated as well to include slopes and different heights in the circuit. It provides more freedom to the child regarding the drawing of the tracks, which could be a negative aspect as the child could paint some tracks too challenging or impossible for the toy to detect. Increased difficulty in programming the electronic components of the toy and implementing games and accessories on the playing surface.

Track shape 2 : Tokens

Benefits	Provides the ability to reprogram the tag to perform a different function, which adds an increase in the product's versatility and capability of becoming evolutive and challenging to fit the child's needs. Due to the fact thatthe tag is the interactive element, it can be conveniently inserted in the desiredtrack without disassembling the entire path and can be replaced if lost for a reduced price rather than acquiring the entire track. Reduced dimensions to ease the storage of the toy.
Drawbacks	Due to its reduced dimensions, the tag could get misplaced easily or be swallowed accidentally by the child while playing with the toy. It can be unpleasant and tedious if given the ability to reprogram each tag individually.

Track shape 3 : Conventional tracks

Benefits	Most basic representation of the interaction, making it more comfortable and easier for both the child and the developer of the toy, as it is the closest propos to reality. Provides the ability to reprogram the track, using the colour of each piece, to perform a different function, which adds an increase in the product's versatility and capability of becoming evolutive and challenging to fit the child's needs.
Drawbacks	Requires a large number of tracks to meet the interaction with all the possible games and tasks developed in the app, so it limits the possibilities of the functionality of these tracks. Product's lack of originality due to the large presence of similar products in the current toy market.

Track shape 4: Geometrical / "Tantrix"

Benefits	Due to its unique shape, it provides a new original vision to what is already on market, which gives it a more appealing vision to the consumer. It enhances the creativity and imagination of the child due to the versatility and modular capacity of the product since it acquires an extra functionality of puzzle and construction game.
Drawbacks	Too complicated for the age sector that the product is focused on. Presents difficulty for the toy to interact and detect the various paths located on different tracks, and in case of loss of some piece, it can result in incomplete paths. Hard reprogrammability due to the complexity of the track.

After this evaluation we concluded that the type of tracks that best suited our needs were those that included tokens.

APPENDIX I

MATERIAL RESEARCH

In general, the toys on the market can be categorised by material into four groups: wood, textiles, metal and polymers, also known as plastics. Wooden toys tend to be more expensive than polymer toys, though prices for the latter vary with quality. Lower quality standards equal lower prices, yet comes with an increased health risk when the cheaper toy is being filled up with toxic chemicals such as phthalates in order to cut costs (Korfali et al., 2013).

From an environmental point of view, it is difficult to determine which material is more circular, as those calculations depend on the parameters that have been taken into account and their subjective weighing factors. Wood cannot efficiently be recycled. Therefore it will be burnt at the end of the product's lifecycle. Polymers such as green polythene are claimed to be recyclable for 100% (Braskem, 2017), yet if thrown away with other litter will be burnt nonetheless.

- Korfali, S. I., Sabra, R., Jurdi, M., & Taleb, R. I. (2013). Assessment of Toxic Metals and Phthalates in Children's Toys and Clays. Archives of Environmental Contamination and Toxicology, 65(3), 368–381.
  Retrieved from https://link.springer.com/article/10.1007/s00244-013-9925-1

- Braskem. (2017). I'm green polyethylene: innovation and differentiation for your product.
  Retrieved from https://fkur.com/wp-content/uploads/2017/01/01-Green-PE-Brochure.pdf

Plastic Soup and commonly used polymers in toys:

An important incentive to look into available alternatives for polymers is to avoid further accumulation and fragmentation of plastic debris in the oceans, a phenomena known as the "plastic soup". It is stated that 90% of all toys are made from some form of plastic ('Wasted': Greening the plastics-heavy toy industry, 2018). The pie chart (Figure 1) presents the most common polymers used in toys and their corresponding proportional distribution. Polyethylene and polystyrene are each being used in about a quarter of all plastic toys, respectively for 23% and 25%.

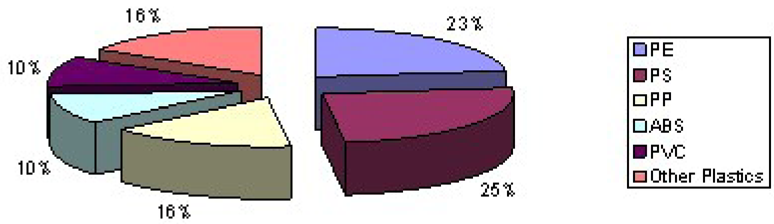


Figure 1: Most common polymers used in toys and their proportional distribution Source: https://knowledge.ulprospector.com/1361/pe-bioplastic-materials-toys/

In order to gain some basic insight into the environmental impact of those commonly used polymers, OVAM's ecolizer has been consulted. The eco-indicators for both the production and waste processing phase of those five polymers – PS, PE, PP, ABS and PVC, and their variants are listed in Figure 2. Addition of those values results in a new indicator that allows comparison. It is important to note that this comparison is rather basic as the environmental impact depends on other parameters as well.

Polymer	Eco-indicator (mPt/kg)		
	Production	Waste processing	Total
PS (GPPS, algemene toepassing)	377	37	414
HDPE High-Density Polyethylene	268	35	303
HDPE High-Density Polyethylene - recycled	74	35	109
LDPE Low-Density Polyethylene	276	35	311
LDPE Low-Density Polyethylene - recycled	73	35	108
LLDPE Linear Low-Density Polyethylene	263	35	298
PP	268	33	301
PP - recycled	73	33	106
ABS	448	42	490
ABS - recycled	79	42	121
PVC (average)	217	32	240
PVC - recycled	69	32	101

Figure 2: Commonly used polymers in toys and their corresponding eco-indicators

- CBC Radio. (2018). 'Wasted': Greening the plastic-heavy toy industry. Retrieved from http://www.cbc.ca/radio/day6/episode-371-iran-nuclear-deal-plastic-toy-waste-kaepernick-bitcoin-bunkers-spotify-vs-composers-and-more-1.4470486/wasted-greening-the-plastics-heavy-toy-industry-1.4470526

Seminar on bioplastic polymers, University of Antwerp:

The so-called bioplastics or biopolymers are included within the "other plastics" portion of the pie chart (Figure 1). In order to expand our knowledge on this topic, we attended a seminar on bioplastic polymers on 5 March, organised by the University of Antwerp. Steven SCHUITEMA, a representative for FKuR Polymers GmbH in Venlo talked about the definition of biopolymers and a 100% recyclable polymer, called green PE.
Bioplastics can be categorised into two groups: bio-based plastics and biodegradable plastics. The latter is commonly referred to as compostable plastics. Typical for these polymers is their ability to break down in carbon dioxide, methane, water, inorganic constituents or biomass through the enzymatic action of microorganisms. They can be derived from either renewable biomass sources such as sugar canes or from fossil-fuel. Bio-based polymers, on the other hand, are solely derived from renewable biomass sources, however, might not be compostable.

Open Biolab ReaGent:

We conducted some more research on the bio-based polymers, more specifically, on the characteristics of mycelium-based materials. Mycelium is the vegetative part of a fungus or fungus-like bacterial colony, consisting of a mass of branching, thread-like hyphae. In short, a mycelium-based product is made by growing fungi on a substrate, such as straw, in a mould and heating it afterwards to stop further growth. In order to feel and see products made from mushroom material up close, we visited the "Open Biolab ReaGent" in Gent, Belgium, as they have been experimenting with the possibilities of this material (Growing materials at home, 2017). Unfortunately, there are some serious drawbacks to using it in our project. The main disadvantages are:

- Time-consuming: it can take up to 20 days to grow a mycelium-based product
- High failure rate: contamination of the bacterial colony leads to failure
- Limited colouring possibilities: the natural colour of this material is a type of white
- Limited styling options: wall thicknesses are at least a couple of centimetres thick
- Limited strength: once the outer layer breaks the product can be ripped apart rather easily
- Risk of swallowing the substrate material once the outer layer has been damaged

- Poncelet, W. (2017) Growing materials at home: Hard Mycelium Materials Manual. BioFab Forum.
  Retrieved from https://biofabforum.org/t/growing-materials-at-home-hard-mycelium-materials-manual/8081

Material Fair XPerience, Ahoy Rotterdam, the Netherlands

A more diverse collection of material samples could be examined on 13 March during the Material Fair "Xperience" in Rotterdam, the Netherlands. The aim of this field research was to gain inspiration for product and game ideas for our toy through material versatility.

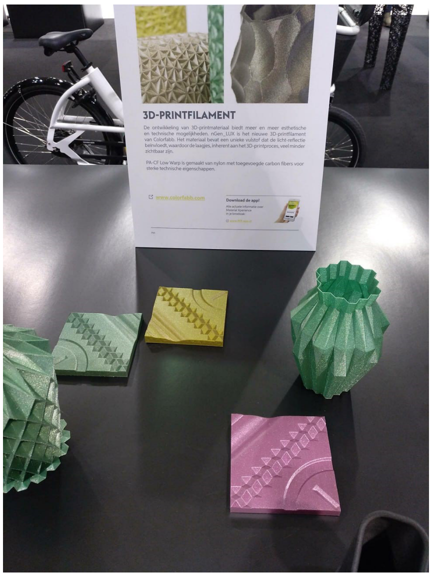


Figure 3: 3D-printed textures

The 3D-printed material expands the aesthetic and technical possibilities of products. Original textures could be implemented into the design of our hybrid toy. Another asset of this production technique is that it allows for products to be personalised. The 3D-filament as shown in Figure 3 is called nGen_LUX and has been developed by Colorfabb.

DRYFLEX (Figure 4) is a "green" material due to its composition. This bio-based polymer consists of over 60% out of renewable biomass resources. Moreover, the addition of TPE grants the material its flexibility, making it an interesting candidate for adding functionality or uniqueness to our hybrid toy.

Figure 4: Flexible bio-polymer

Formcard (Figure 5) is a pocket-sized card made of strong, meltable, biodegradable, non-toxic plastic that can be used to make, fix and modify the world to the child’s imagination. It receives its clay-like characteristics by dropping it in a bowl of hot water. As a result, the material can infinitely be reused.

Figure 5: Formcard - claylike plastic

APPENDIX J

ELECTRONIC COMPONENTS

1. Arduino Genuino Uno

Arduino Uno is a microcontroller board. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button.

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
LED_BUILTIN	13
Length	68.6 mm
Width	53.4 mm
Weight	25 g

1.1 Programming

The programming for the Arduino is done with the Arduino software (IDE). The ATmega328(which is the microcontroller) on the Arduino Uno comes preprogrammed with a boot loader that allows uploading new code to it without the use of an external hardware programmer. Its communications are based on the original STK500 protocol. An alternative way of programming the microcontroller is through the ICSP (In-Circuit Serial Programming) header using Arduino ISP or similar.

1.2 Warnings

The Arduino Uno has a resettable polyfuse that protects the computer's USB ports from shorts and over-current. This is included as an extra layer of protection for the computer. If a current of more than 500 mA is applied to the USB port, the fuse will automatically break the connection until the short or overload is removed.

1.3 Power

The Arduino Uno can either be powered via the USB connection or with an external power supply. The user does not have to worry about setting which power is being used as the Arduino will recognise it automatically. The external power supply can either come from an AC-to-DC adapter or a battery. The adapter can be connected by plugging a 2.1mm plug into power jack available on the board. If a battery is used, the leads can be

inserted in the GND and Vin pin headers. The board can operate on an external supply from 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may become unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts. The power pins are as follows:

- Vin: The input voltage to the Arduino/Genuino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). It can be supplied voltage through this pin, or, if supplying voltage via the power jack, accessing it through this pin.

- 5V:This pin outputs a regulated 5V from the regulator on the board. The board can be supplied with power either from the DC power jack (7 - 12V), the USB connector (5V), or the VIN pin of the board (7-12V). Supplying voltage via the 5V or 3.3V pins bypasses the regulator, and can damage your board. This is not advised.

- **3.3V**: A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.

- **GND**: Ground pins.

- **IOREF**: This pin on the Arduino/Genuino board provides the voltage reference with which the microcontroller operates. A properly configured shield can read the IOREF pin voltage and select the appropriate power source or enable voltage translators on the outputs to work with the 5V or 3.3V.

1.4 Inputs and Outputs

Each of the 14 digital pins on the Uno can be used as an input or output, using pinMode(),digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive 20 mA as recommended operating condition and has an internal pull-up resistor (disconnected by default) of 20-50k ohm. A maximum of 40mA is the value that must not be exceeded on any I/O pin to avoid permanent damage to the microcontroller.

In addition, some pins have specialised functions:

- **Serial**: 0 (RX) and 1 (TX). Used to receive (RX) and transmit (TX) TTL serial data. These pins are connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip.

- **External Interrupts**: 2 and 3. These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt() function for details.

- **PWM**: 3, 5, 6, 9, 10, and 11. Provide 8-bit PWM output with the analogWrite() function.

- **SPI**: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK). These pins support SPI communication using the SPI library.

- **LED**: 13. There is a built-in LED driven by digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.

- **TWI**: A4 or SDA pin and A5 or SCL pin. Support TWI communication using the Wire library.

The Uno has 6 analog inputs, labeled A0 through A5, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and the analogReference() function. There are a couple of other pins on the board:

- **AREF**. Reference voltage for the analog inputs. Used with analogReference().
- **Reset**. Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

1.5 Communication

Arduino/Genuino Uno has a number of facilities for communicating with a computer, another Arduino/Genuino board, or other micro-controllers. The ATmega328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX). An ATmega16U2 on the board channels this serial communication over USB and appears as a virtual com port to software on the computer. The 16U2 firmware uses the standard USB COM drivers, and no external driver is needed. However, on Windows, a .inf file is required. The Arduino Software (IDE) includes a serial monitor which allows simple textual data to be sent to and from the board. The RX and TX LEDs on the board will flash when data is being transmitted via the USB-to-serial chip and USB connection to the computer (but not for serial communication on pins 0 and 1).

A SoftwareSerial library allows serial communication on any of the Uno's digital pins. The ATmega328 also supports I2C (TWI) and SPI communication. The Arduino Software (IDE) includes a Wire library to simplify use of the I2C bus. For SPI communication, using the the SPI library is necessary.

Rather than requiring a physical press of the reset button before an upload, the Arduino/Genuino Uno board is designed in a way that allows it to be reset by software running on a connected computer. One of the hardware flow control lines (DTR) of the ATmega8U2/16U2 is connected to the reset line of the ATmega328 via a 100 nanofarad capacitor. When this line is asserted (taken low), the reset line drops long enough to reset the chip. The Arduino Software (IDE) uses this capability to allow you to upload code by simply pressing the upload button in the interface toolbar. This means that the boot-loader can have a shorter timeout, as the lowering of DTR can be well-coordinated with the start of the upload. This setup has other implications. When the Uno is connected to either a computer running Mac OS X or Linux, it resets each time a connection is made to it from software (via USB). For the following half-second or so, the boot-loader is running on the Uno. While it is programmed to ignore malformed data (i.e. anything besides an upload of new code), it will intercept the first few bytes of data sent to the board after a connection is opened. If a sketch running on the board receives one-time configuration or other data when it first starts, make sure that the software with which it communicates waits a second after opening the connection and before sending this data. The Uno board contains a trace that can be cut to disable the auto-reset. The pads on either side of the trace can be soldered together to re-enable it. It's labeled "RESET-EN". You may also be able to disable the auto-reset by connecting a 110 ohm resistor from 5V to the reset line.

2. RC522 RFID Module

2.1 General Information

The MFRC522 is a highly integrated reader/writer IC for contactless communication at 13.56 MHz. The MFRC522 reader supports ISO/IEC 14443 A/MIFARE and NTAG.

The MFRC522's internal transmitter is able to drive a reader/writer antenna designed to communicate with ISO/IEC 14443 A/MIFARE cards and transponders without additional active circuitry. The receiver module provides a robust and efficient implementation for demodulating and decoding signals from ISO/IEC 14443 A/MIFARE compatible cards and transponders. The digital module manages the complete ISO/IEC 14443 A framing and error detection (parity and CRC) functionality.

The MFRC522 supports MF1xxS20, MF1xxS70 and MF1xxS50 products. The MFRC522 supports contactless communication and uses MIFARE higher transfer speeds up to 848 kBd in both directions.

The following host interfaces are provided:

- Serial Peripheral Interface (SPI)
- Serial UART (similar to RS232 with voltage levels dependant on pin voltage supply)
- I2C-bus interface

2.2 Features and Benefits:

- Highly integrated analog circuitry to demodulate and decode responses
- Buffered output drivers for connecting an antenna with the minimum number of external components
- Supports ISO/IEC 14443 A/MIFARE and NTAG

- Typical operating distance in Read/Write mode up to 50 mm depending on the antenna size and tuning
- Supports MF1xxS20, MF1xxS70 and MF1xxS50 encryption in Read/Write mode
- Supports ISO/IEC 14443 A higher transfer speed communication up to 848 kBd
- Supports MFIN/MFOUT
- Additional internal power supply to the smart card IC connected via MFIN/MFOUT
- Supported host interfaces
- SPI up to 10 Mbit/s
- I2C-bus interface up to 400 kBd in Fast mode, up to 3400 kBd in High-speed mode
- RS232 Serial UART up to 1228.8 kBd, with voltage levels dependant on pin voltage supply
- FIFO buffer handles 64 byte send and receive
- Flexible interrupt modes
- Hard reset with low power function
- Power-down by software mode
- Programmable timer
- Internal oscillator for connection to 27.12 MHz quartz crystal
- 2.5 V to 3.3 V power supply
- CRC coprocessor
- Programmable I/O pins
- Internal self-testing
- Dimensions: 40 x 60 mm

3. 28BYJ-48 – 5V Stepper Motor

A stepper motor is an electromechanical device which converts electrical pulses into discrete mechanical movements. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence, these pulses affecting the direction of the motors rotation. The speed of the motor shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of input pulses applied. One of the most significant advantages of a stepper motor is its ability to be accurately controlled in an open loop system.

3.1 Features:

- The rotation angle of the motor is proportional to the input pulse.
- The motor has full torque at standstill(if the windings are energised)
- Precise positioning and repeatability of movement since good stepper motors have an accuracy of – 5% of a step and this error is non cumulative from one step to the next.
- Excellent response to starting/stopping/reversing.
- Very reliable since there are no contact brushes in the motor. Therefore the life of the motor is simply dependant on the life of the bearing.
- The motors response to digital input pulses provides open-loop control, making the motor simpler and less costly to control.
- It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft.
- A wide range of rotational speeds can be realised as the speed is proportional to the frequency of the input pulses.

3.2 Parameters:

- Model : 28BYJ-48
- Rated voltage : 5VDC Number of Phase : 4
- Speed Variation Ratio : 1/64
- Stride Angle : 5.625° /64
- Frequency : 100Hz
- DC resistance : 50Ω±7%(25°C)
- Idle In-traction Frequency : > 600Hz
- Idle Out-traction Frequency : > 1000Hz In-traction Torque >34.3mN.m(120Hz) Self-positioning Torque >34.3mN.m
- Friction torque : 600-1200 gf.cm
- Pull in torque : 300 gf.cm
- Insulated resistance >10MΩ(500V)

- Insulated electricity power :600VAC/1mA/1s Insulation grade :A
- Rise in Temperature <40K(120Hz)
- Noise <35dB(120Hz,No load,10cm)

3.3 Pin configuration

No:	Pin Name	Wire Color	Description
1	Coil 1	Orange	This Motor has a total of four coils. One end of all the coils are connect to +5V(red) wire and the other end of each coil is pulled out as wire colors Orange, Pink, Yellow and Blue respectively
2	Coil 2	Pink	
3	Coil 3	Yellow	
4	Coil 4	Blue	
5	+5V	Red	We should supply +5Vto this wire, this voltage will appear across the coil that is grounded.

Motor Wire Color	Sequence to Rotate in clockwise Direction							
	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8
Orange	0	0	1	1	1	1	1	0
Yellow	1	0	0	0	1	1	1	1
Pink	1	1	1	0	0	0	1	1
Blue	1	1	1	1	1	0	0	0
Red	1	1	1	1	1	1	1	1

4. ULN2003 Stepper Motor Driver

The ULN2003A contains seven darlington transistor drivers. The ULN2003A can pass up to 500 mA per channel and has an internal voltage drop of about 1V when on. It also contains internal clamp diodes to dissipate voltage spikes when driving inductive loads. Here in Figure 1, is the schematic showing how to interface a unipolar stepper motor to four controller pins using a ULN2003A.

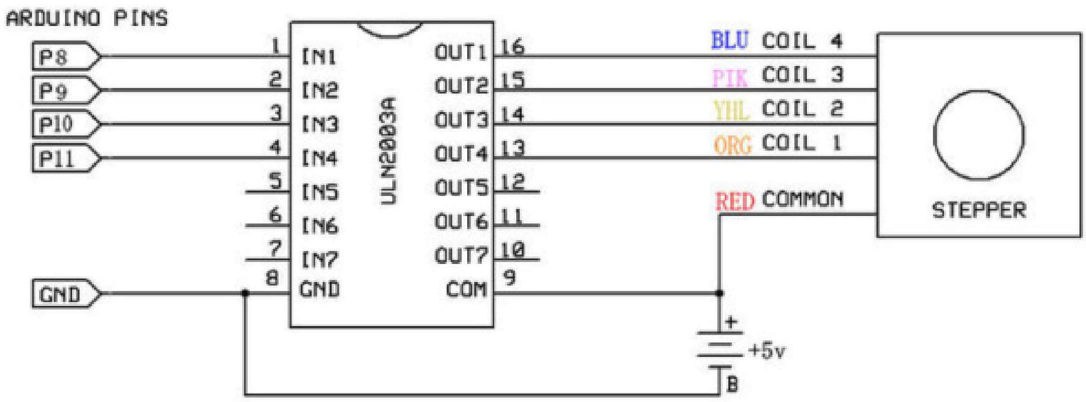


Figure 1: Schematic ULN2003A

4.1 Features:

- The most easy module to learn how to control the Stepper and finish the simple project.
- The logic control voltage:3~5.5V
- Motor Supply Voltage: 5~ 15V
- It can sink 500mA from a 50V supply, but you'd better limit the driver voltage under 15v.
- Operating temperature: -25 degree Celsius ~ +90 degree Celsius

5. HC-05 Bluetooth Module

This bluetooth module works with a 3.3V voltage supply, which has created quite a controversy online because some people think that is necessary to put a voltage divider between it and the Arduino pins. However, this has not resulted in any problems but anyone that does not take these precautions should do it under their own risk.

This module can be configured either in master or slave mode. The AT commands to configure this module can be seen below.

COMMAND	FUNCTION
AT	Test UART Connection
AT+RESET	Reset Device
AT+VERSION	Query firmware version
AT+ORGL	Restore settings to Factory Defaults
AT+ADDR	Query Device Bluetooth Address
AT+NAME	Query/Set Device Name
AT+RNAME	Query Remote Bluetooth Device's
AT+ROLE	Query/Set Device Role
AT+CLASS	Query/Set Class of Device CoD
AT+IAC	Query/Set Inquire Access Code
AT+INQM	Query/Set Inquire Access Mode
AT+PSWDAT+PIN	Query/Set Pairing Passkey
AT+UART	Query/Set UART parameter
AT+CMODE	Query/Set Connection Mode
AT+BIND	Query/Set Binding Bluetooth Address
AT+POLAR	Query/Set LED Output Polarity
AT+PIO	Set/Reset a User I/O pin

APPENDIX K1

USABILITY I

1. Users

Describe/ specify your users

The users for whom our product is intended are boys and girls from the age of 5 to 6 years old.

It is a toy suitable for both genders. In the actual market, toys of this type (vehicles or construction toys) have a more masculine approach that is reflected in the aesthetics of the toy, packaging, advertising ... resulting in the female audience not being attracted or identified. This is why we want to break these barriers and make a neutral gender product.

It is intended for users in "developed countries" or "families with means" since its use requires electricity as well as a mobile phone or a tablet.

It is aimed at children whose parents or tutors see this type of games (Generic Game for Ubiquitous Learning in Interactive Virtual and Real Realities) as an opportunity to discover learning content through interacting and getting in physical contact with it. However, it could also be a suitable toy for children whose parents do not want them to play with electronic devices at such an early age since the app is not required at the time of playing with the analogic game.

General and basic motor and mental skills are required. The kid needs to be able to build the set. For this task the kid may need some spatial intelligence to orientate the pieces into the correct position. Moreover, in order to comprehend the basic operation of the game, the user needs general deductive thinking and logical capabilities.

However, for being able to play the game and set the scenario correctly, the users do not need any specific knowledge or experience, since the game includes several tutorials that explain this step by step, through an intuitive and interactive interface.

Describe/ specify their needs

Toys are a fundamental tool for the development of children. Through toys, the child will learn more effective skills such as body-mind coordination and will develop their logical capacity, attention and observation. Thanks to toys, children progress and are able to accomplish more complex tasks.

Playing has shown strong and consistent relationships between children's playfulness and their cognitive and emotional development, providing a mechanism through which they learn to control aggression. Toys help to enhance imagination and creativity, to develop the fine motor skills of the fingers through manipulating pieces and to stimulate spatial intelligence. That is the reason why it is necessary to provide the children with enough playing time and to guarantee effective toys that stimulate their abilities. That is what we pretend to do with our toy.

Users want to have fun and enjoy the playing time as an explicit goal. Within the range of 5 to 6, children enjoy challenging games and using their imagination to create new realities and make the game dynamic, entertaining and different according to their tastes.

As an implicit goal, children will be able to develop their cognitive and motor skills through the game causing them to feel confident and motivated into learning.

2. Functionality

Describe/ specify the functions of your product

As explained above, the main explicit goal is to provide fun to the child, and the implicit goals are the learning and the development of cognitive and motor skills.

The primary functions are explained below:

- The development of fine and general motor skills is achieved through the movement of the child. He has to build the circuit and the stations, joining and fitting the pieces together, as well as placing the intelligent objects into their correct position. This will help him/her develop his spatial intelligence and motor hand skills. Then, to play with the train, he will have to move it over the lanes, and transport the characters and intelligent objects to different stations. This movement of the train can be done either physically, by manually pushing, or digitally, by controlling it through the application.

- The development of cognitive skills, deductive thinking and logical capacities is achieved through the operation of the game itself. To play the game the user needs to physically get in touch with real objects by scanning an intelligent tag; then the user will get contextual information/feedback about the specific object, which is part of a whole storyline told in the app. This feedback will be expressed through the app and through sounds. The user will have to understand the link between the digital and physical realities, and how the actions committed in one affect the other.

For the user to solve the story in which the game is based, he/she will need to apply deductive skills, in order to obtain the hints that allow him/her to beat the game. For that he will have to travel between stations and do seemingly unrelated favours for the local townspeople, which, after the user has completed them, would come together into one cohesive story that would lead to the solution.

- The empowerment and improvement of creativity and imagination is achieved thanks to the modularity and versatility of the game. The user can play with or without the app's games, creating different circuits and inventing stories surrounding it.

Next, the secondary functions are explained:

- A very interesting feature is to make the game expandable. This meaning, to expand the age range so that it can continue to be used over time. Due to this, the product turns more sustainable since its life cycle is extended, and a reduction of the expenses on the part of the buyers is obtained due to that the same toy covers more needs.

  The difficulty of the game will be adapted to the needs and abilities of the user to always keep the game interesting and challenging, without leading to frustration

3. Interaction - Usability

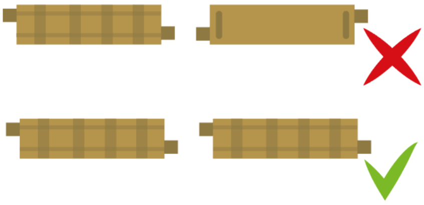
Describe/ specify the interaction requirements of your product

The game has been designed to be very intuitive and easy to use, due to the audience it is aimed at. Not only in the way of building the physical scenario: joining the tracks, building the stations, placing the tags … But also in the app´s interface.

Thanks to several user tests we have been able to identify the design errors we committed. We have made several iterations of the physical and digital parts, modifying and debugging the game to make the user understand easily its assembly and operation.

The user´s previous experience will help him with the understanding of the game since he will already be familiarised with some of the concepts. If he has previously played with building blocks, he will probably know how to join the tracks and build the stations. In the same way, if he has ever played with intelligent tag´s games, he will rapidly know how the link between digital and physical world work.

Below, the main possible errors and comments on how to solve them are shown.

ERROR	SOLUTIONS
Incorrectly connecting tracks 	The design of the tracks is such that the union system can be made from both sides of the tracks. Moreover, to indicate which face is the upper face, some drawings imitating the rails are included in the top part, and the bottom part incl udes some ledges to elevate the track from the floor, so if the user tries to join the tracks in the reverse side, he will realise that the train cannot move forward due to those ledges.
Swallowed parts	The pieces have been designed with a sufficient size (in accordance with European regulations) so that they cannot be swallowed and do not pose a danger for the user.
Lost or broken parts	Thanks to the versatility and modularity of the game, the pieces that compound the set can be easily supplied by buying them separately through the company´s webpage.
Forget to turn on/off	Through a light or auditory system, the set will give feedback. After a period of non -use, the device switches off automatically.
Incorrectly building the stations	The pieces of the stations are joint with means of grooves. To make the stations' set modular and versatile all the pieces have been designed with the same size of groove, so they can be joint between any of them.
Incorrectly placing the objects in the trai n	By means of curved surfaces, we can avoid that the user places the characters or the intelligent objects in the wrong places. To stand out where they have to be located, objects and characters have a hole on the low part (female parts), and the train an d wagon have a ledge (male parts).

Misunderstanding of the functioning of some parts of the game	The parts that make up the whole set will be explained through very simple tutorials in the app.
Misunderstanding of the app	We have designed a very intuitive and synthetical app that directs the centre of attention in a limited number of elements so that the user has no problem identifying with which he/she is interacting. To increase the efficiency of the game, this is explained and illustrated with icons easily understood by children and sound, replacing the text. In the first contact with the game, only the first tutorial is available, so that in order to unlock the next ones, it is necessary that the child has achieved and understood the previous. This will be attractive to the child since he will see that his achievements have a reward that makes the game challenging and encourages him to continue exploring and learning to reason.
Misunderstanding of the connection betwe en the physical and digital reality	By means of sounds we will provide feedback when the actions committed in the digital reality have an effect in the physical and vice versa.
Electrical problems	To avoid the kid having access to the electronic components or, all the train is closed. To have access to the battery, there is a lid that needs to be taken out with screw.

As previously mentioned, the child needs to have a basic and general knowledge to be able to interact with the game, such as recognizing sounds, colours, shapes, and associating the results that occur with the actions performed (deductive thinking).

4. Expression and emotion

Describe/ specify the expressive requirements of your product

The inherent feelings linked to the word "play" are fun and positive emotions such as happiness, curiosity, enthusiasm, fascination, stimulation, encouragement, competence, pleasure. While playing and achieving the several challenges, the user will acquire more body-mind coordination, so the child will feel more mature, smart and confident with himself/herself.
This type of games that link the physical world with the digital one arises from the user´s curiosity towards technology and stimulate his/her deductive capacity since the child will

be amazed by this connection.

On the other hand, it is also possible that the game leads to negative emotions, such as tension and frustration, for example, if the child is not able to overcome the levels of the game. In this way, if the game is too complex and takes the user too much time to find the hints and overcome the challenges, the child will probably become impatient and frustrated. This frustration can lead to anger.

Another emotion that can occur is boredom or the feeling of repetitiveness. A game too defined, limited or specific can end up being boring for the child if it always consists of the same and is not challenging enough.

If the building of the scene and set up of the game take too long, the user may get bored and may lose interest in the game, so he could give up before having started playing with the train.

In the event that there is more than one player, it is possible that competitiveness and rivalry among users arises. However, they can also develop their capacity to share and strengthen feelings of solidarity and camaraderie.

5. Context – Environment

Describe/ specify the context requirements of your product

For the correct interaction between user-product, a space where to place the toy is needed. Usually, it is expected to be set on the ground although it could also be set on another type of flat surface. It is intended to be used indoors, in rooms with enough space to mount the circuit and play comfortably.

Due to the fact that it includes electronic and digital components, it is necessary to take some measures so that there is no damage to the systems such as avoiding contact with water. In order for listening the sounds emitted by the train, a quiet room is also convenient. Due to the Bluetooth connectivity between the app and the train, the Bluetooth must be on and the child must be located at a reasonable distance so the communication between physical and digital does not fail. The game is designed to be played individually, also being possible several players (3-4 players maximum). During the day, depending on the family, the child will have different time periods to play. This is why the time restriction depends on the time that parents consider appropriate. In a user test we saw that the average duration of the game was 40 minutes.

APPENDIX K2

USABILITY I I: REPORT ON VERIFICATION THROUGH USER TEST

1. Short description on design project

This project consists of a Hybrid Toy Construction for children aged 5 to 6. The toy contains both physical play elements in the form of a train toy, tracks, modular building blocks to create the stations and intelligent tagged objects; as well as digital play elements in the form of an app with a Graphic User Interface. To play the game the user needs to travel through the different stations and physically get in touch with real objects that contain an intelligent tag, by scanning them. After that, the user will get contextual information about the specific object which is part of a whole storyline.

The toy is aimed to stimulate the children's senses and to encourage their development by using fun and educational games.

2. Argumentation on the tool you selected (user test). Why did we chose this one?

The tool selected for executing the user test is one that would allow us to verify the interaction between the child, the app and the train. This type of user test, through observation, also allows us to identify possible unforeseen uses that the user makes of the elements.

We wanted to observe the behaviour of the child with the toy. Verify what kind of problems the user had when playing with both the physical and the digital realities, to identify aspects of design that had not been correctly approached or taken into account and that with the help of the feedback that we would obtain, correct the errors for the next iteration of the project.

Due to the novelty of this game concept that connects the physical and the digital reality, it was essential to check if the user was able to understand the link between both of them, and to realise that the actions undertaken in one reality affect the other. For example, when choosing a station in the app, the train moves to that station physically in reality or whenever an intelligent object (such as an apple) is scanned, the application was updated and showed that element within the Wagon.

In the user test we wanted to check the level of intuitiveness of all the parties that make up the game. Is the graphic user interface of the application intuitive enough so that child can navigate correctly in it? Does he/she understand the logic of the story and how do all clues lead to the solution of story? Is the way of building the scenario and the circuit obvious enough so that they can make it without errors? Is the correct use of our product conditioned by the previous play experience with apps and / or trains and construction toys?

Apart from checking the difficulties of the game, we also wanted to see if the game was fun and attractive enough for our target group or if the tutorials created were not sufficiently challenging or dynamic. We wanted to prove as well, if the toy could maintain the child´s attention over the course of the game or if he/she gave up prematurely if he/she got stuck at some point.

3. Method: how, when, where, with whom?

3.1.How:

At the beginning of the test the children were asked the following questions in order to gain some insight on their previous play experience with both apps and trains (construction games):

- Do you have a smartphone or tablet at home on which you can play games?
- How many days in a week do you play games on these smart devices?
- Do you have a toy train at home?

We did not ask them any questions after the actual user test. As the whole test has been recorded their emotions and level of interest can be verified there.

After the questions on their previous play experience, the user test was divided into three phases of about ten minutes. During the first phase the children were asked to complete Tutorial 1, 2, 3 in the app. Those tutorials all focus on becoming familiar with the tracks, the station tokens and building open or closed circuits. If they had time left upon completion they could start on the fourth tutorial. The aim was to verify if doing it digitally first, would make the building process easier, as they had already been shown how the pieces interact with one another.

During the second phase they were asked to construct two stations: the tree station, and either the bakery or windmill station. Since Tutorial 6, which contains instructions for correctly assembling the stations, had not been developed yet, we could not test if delivering them instructions would speed up the build process compared to not providing them with any clues. Instead, we handed them only those parts that made up the station together with the name of the station they had to build. As such, we wanted to observe if they were able to complete this task without further hints. We chose this option because it would not make sense to compare the speed and errors made in phase 1 with the speed and errors made in phase 2, as building tracks without build manual is likely to be easier than building stations without one.

The third phase was meant for testing if the interaction between the app and train was clear to the child. They were asked to complete Tutorial 5 which requires them to scan the driver and navigate the train to the desired station.

The whole test has been recorded by two cameras, provided by the University of Antwerp's Department for Design Sciences. One camera recorded the whole scene from a front view perspective. The other camera was placed behind the participants and slightly to the left or right in order to record their gestures made while playing the app games.

3.2 When:

Monday 28 May 2018, from 08:30 until 15:30

3.3 Where:

Opperstraat 32, 1770 Liedekerke, Belgium

3.4 With whom:

Our sample consisted of 8 children from the same school, Sint Antonius, in Liedekerke which is a small village near Brussels. Half of them were boys, the other half girls. Their native language is Dutch. At the moment of testing all of them were 6 years old. None of them had foreign roots.

4. Results user test: conclusions + how did we implement these new insights into our design

4.1 Suggested design adjustments for future iterations

1. We designed the curved tracks to be narrower in order to prevent the train from getting stuck. However, during the user test it became clear that these altered tracks sometimes cause the train to go off track in the middle of a turn.

2. Include more audio stimuli so that the user can explicitly perceive the feedback when an action done in one reality matches the other reality.

3. To avoid the incorrect positioning of the characters within the train, make the surfaces curved so that the user cannot lay the characters there and realises that their correct place is another.

4. To make more evident some actions that need to be commited, a video tutorial could explicitly teach the user how to do it.

4.2 App

During the user tests, we noticed several problems with the interaction between the children and the app. The first of these problems is that the vocabulary used in order to explain the tutorials was too complex. For example: The children knew words such as “tablet” and “game”, but had difficulty understanding words such as “swipe”, “touch screen”, “scan” or “app”. Furthermore, the children found the wording of ‘stations’ to be

confusing, as they have a very typical idea of what a train station is supposed to look like. A future solution could be to hand teachers and parents a list of the most important terms used in our tutorials and ask them if there are words which the children might not understand. Moreover, the written parts in the app should be replaced by audio.

Secondly, the children did not notice many of the interactions between the app and the train, and vice versa. An example of this is that the children do not realise when they have scanned an object correctly. A solution to this problem could be to add auditory feedback in both the app and the train in order to draw the children’s attention towards the specific changes (e.g. a sound in the app that notifies the child after an item has been scanned).

Next, in the first two tutorials, the user would have to slide one track towards the other in order to connect both pieces. One of these two pieces is fixed in place, in order to simplify the programming process and due to time constraints. The problem with this, however, is that as a result the children would assume both pieces were fixed in place if they tried to move the incorrect one first. A solution to this problem would be to either manage to make both pieces moveable, or to give visual feedback to the user of which track piece can be moved.

Another problem during the user tests, was that in the 5th and 7th tutorials, the children had to scan the driver character in order to open the map with the stations. While the children remembered that they had to open the map, they did not understand that scanning the driver was directly related to opening the map. On a related note, the children did not seem to understand the purpose of the ‘example’ screens in the 5th tutorial, which could have contributed to this confusion.

Finally, despite giving the children instructions on how to play the tutorials, they did not always understand what they had to do while playing. An example of this is in the 3rd tutorial, where the user would have to assemble a train circuit by moving tracks over to the

indicated locations. The users would not understand where to place the tracks or what the objective was. A solution could be to add an automated example of the tutorial which shows the user what actions are required.

4.3 App illustrations

The aim of the second tutorial was to introduce the children to the tokens by displaying both tracks and a token. However, none of the children noticed the icon of the token by themselves. This could be due to the fact that they are new elements, as well as quite small and light in comparison to the larger, darker tracks. Another explanation might be that the colours of the token in the app and the ones used for the physical part were inconsistent. Keep coherence between the app´s graphics and the physical elements to evidence the connection between both. A simple solution to this problem could be to introduce the tokens properly beforehand by explaining what they are and what their function is.

4.4 Physical prototype

Finally, there were also some problems with the interactions with the train itself. Firstly, as the top part of the train to scan RFID tags is a flat surface, children tended to leave tokens up there once it had been scanned. Since there is enough space for multiple tokens, they often placed a second item next to the one they had scanned before. Unfortunately, this would cause errors with the RFID reader, as it can only read one tag at a time. To solve this problem, the top of the train could have a three-dimensional surface, instead of a flat one. While implementing this, however, it should be noted that the RFID reader should still be able to read the tags.

The second problem with the train was that the children did not fully understand how to scan the driver properly. While they understood that the driver had to be scanned on top of the train, the presence of the physical pin in the front of the train suggested that that was the only location the driver could be placed.

The last problem which was noted during the user tests is that when attempting to connect a wagon to the main train, the children would often forget the necessary connector piece, and thus be unable to connect the two. A solution could be to integrate the connector piece with the wagon, although this could become a structural weakness as the connector piece is long and flat, which could cause it to break easily.

USABILITY I I: USER TEST SINT ANTONIUS

The user test videos have been sent to our supervisor.
The permission papers signed by the parents have been stored into a separate file.

Child 1 Lotte

In tutorial 1 she was not asked to collect the pieces she recognised in the app (error test leader).

Joins the tracks physically, then digitally.

Tries to drag the track which is fixed in place. Does not try to move the other one.

Attempts to join digital tracks by putting her thumb on one track and her index finger on the other and making a pinch movement.

Tries to turn track by making a rotating movement.

Does not notice the illustration of the token (thinks she only needs the tracks).

Does not now how to drag the token into the track (app).

Hesitates when assembling the tree. Starts correctly but stops and asks how to do it.

Assembles bakery with the façade pointing inwards.

Does not look at the bakery as a whole when building it.

The standardised grooves do not entirely allow just any combination: when joining the two side walls of the bakery together the pieces will not line up perfectly.

Positions the stations near the right tokens.

Positions grandma on top of the train on the RFID as their was no wagon attached to the train.

Tries to swipe the driver in the app instead of manually placing him on top of the train.

Does not know scan the right character (seems to think the driver needs to stay on his pin).

Is able to select a station.

Train does not stop at station (token needs to be held to its bottom manually in order for it to stop).

Attempts to connect the wagon to the train directly (without using connector piece).

Seemed really shy. Not sure if she liked the game.

Child 2 Yarne

Tries to drag the track which is fixed in place. Is confused it does not move.

Uses typical gestures for interacting with touchscreen (e.g. use to finger and rotate, rather then clicking as he was told to do).

Does not notice the illustration of the token (thinks she only needs the tracks).
Has experience with apps

Seems genuinely interested in the game. (remarks: “Maar hoe rijdt die?” “Hoe kan dat?” “Mag ik nog eens met de trein?”

Child 3 Leon

Was asked to do the 3rd tutorial about building open and closed circuits.

Child 4 Lucas

He has an eye for detail and positions all tracks as displayed by the app (even though this is not necessary).

Clicks white hand (with arrows) instead of the tracks.

He was handed a track upside down and he attempted to attach it to the other ones as such. Once he realised it was upside down he managed to join them correctly.

Thinks moving the tracks physically will trigger changes in the app.

Does not notice the icon of the white token (tutorial 2).

Tutorial 4: is shown how to drag the map into the backpack and open it. Afterwards he does not have trouble collecting items by dragging them into his backpack, nor does he have trouble navigating within the backpack.

Does not know he has to click the cat to unite her with grandmother.

Has been given red and yellow tokens together with the two pieces to build the tree. He puts the tokens into place before sliding both parts that make up the tree into one another.

Realises the coloured side of the façade of the bakery should be visible on the outside.

Attempts to connect the wagon to the train without the connector piece.

Says he enjoyed the game, because it went well. (He likes trains in general)

Seems genuinely interested in the game.

Child 5 Mara

Inserted the façade of the bakery with the coloured parts facing inwards.

Doesn't realise you need to scan the driver on the roof. Puts him on the pin in the front instead.

Train seems to drive faster than before. Probably because the battery had just been replaced.

Train does not derail (but did not need to take turns).

Train stops at proper station.

Does Tutorial 7 too. When first attempting to scan an apple the app does not react. However, the next time it does.

She remembers the driver needs to be scanned on top of the train, which pops up the map, allowing her to chose the station she prefers.

Train gets stuck on straight tracks.

Train stops at proper station.

Seems genuinely interested in the game.

Maybe train a bit to slow ("Dat gaat nog wel even duren").

Child 6 Mats

Connects the tracks first, then swipes them together in the app.

Clicks on the illustration of the hand instead of clicking the tracks.

Tutorial 2: Does not notice the difference between the illustrations of tracks without holes and the ones with holes spontaneously.

Did not notice the illustration of the windmill token. So he thought he needed two pieces instead of three.

He points at the windmill station when asked to collect the item seen in the illustration of the white windmill token.

Asks at least twice what he needs to do. Does not seem to understand the purpose of swiping the tracks together in the second tutorial.

He rotates the token by clicking it, but does not drag it towards the track.

Does not struggle with moving small icons in the app.

Physically assembled several tracks together in the second tutorial, therefore already creating an open circuit as would be taught in the third tutorial.

Asks if the third tutorial also requires him to join the tracks together as shown in the app. **Says the tutorial is different from the physical world, as there are no illustrations of tokens included within the tutorial for creating open or closed circuits.**

Asks if he needs to drag the tracks on top of the example circuit.

Phase 2: no difficulty assembling the tree.

Asks if we lost some apples and lemons as there are more holes in the tree than there are tokens.

Placed the stick with wings upwards into the windmill station instead of using the holes in façade and back wall.

When asked to position the stations he did not use the tokens in the tracks to determine their position.

Doubts the function of the wagon. Attempts to connect it directly to the train.

Attempts to swipe the driver onto the train in the app, even though he was told this would not work.

Puts the driver on the pin when shown the instruction for scanning it onto the train.

Tutorial 7: recognises the illustrations about the grandmother and apples and collects the according physical equivalents.

Thinks he needs to swipe or touch things in the app because this was the case in all previous tutorials.

When scanning apples or wheat onto the train their pin should point upwards, as this ensures the tag inside is as close to the RFID reader as possible.

Forgot the driver needs to be placed onto the train in order to let the map pop up.

He wants to bring the apple to the bakery, as they can make apple pie.

The train did not stop at the bakery. For some reason it did not read the tag.
Suggests to push the train forward.

Looks bored at the end of the test.

Yawned during game

Constantly asked what he should do next without trying anything, even after giving him tips he did not seem to get the point

Tutorial 4: drags map into backpack

Understands the ladder is needed to help grandma. Realises the ladder is in the backpack after having been given a hint.

Clicks the cat to unite her with grandma.

Child 7 Sanne

She did not notice the token in the app drawing.

She saw the link between app and physical components

She struggled to build the windmill (if part gets stuck halfway she thinks it is wrong and tries something else)

She put the stick with wings immediately in the right position.

She thought she did it wrong when she attempted to move a track and ...?????

She put 2 people on top of the train (would cause interference -> make sure rfid has an angle so you can not put things on top of it permanently)

Very fast, completed all the available tutorials.

Recognises patterns, knows what to do because she did it before

Said she liked the game because you have to build things

Seems genuinely interested in the game.

Child 8 Hannah

See video user test.

Frequenties calculated in SPSS

join_tracks

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	unable	1	12.5	12.5	12.5
	able	7	87.5	87.5	100.0
	Total	8	100.0	100.0	

place_ token_in_track

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	able	8	100.0	100.0	100.0

construct _tree _station

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	unable	1	12.5	12.5	12.5
	able	7	87.5	87.5	100.0
	Total	8	100.0	100.0	

station_near_token

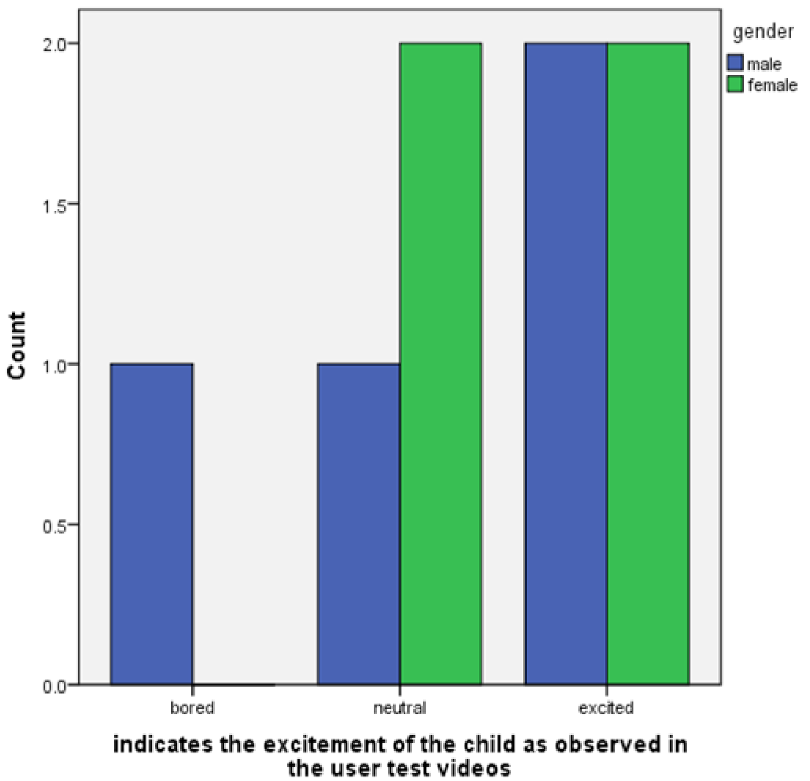
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	unable	3	37.5	37.5	37.5
	able	5	62.5	62.5	100.0
	Total	8	100.0	100.0	

scan_driver

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	unable	3	37.5	37.5	37.5
	able	5	62.5	62.5	100.0
	Total	8	100.0	100.0	

choose_station

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	able	8	100.0	100.0	100.0



APPENDIX K4

PERMISSION DOCUMENT FOR USER TEST

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toestemmingsformulier
goedkeuring ouders/voogd deelname gebruikstest

Onderzoek	:	onderzoek EPS (European Project Semester)
Onderzoekers/studenten	:	Alicia Alsonso Gil, Victor Martiñez, Jan Roberts-Gomez, Kevin Schelfer, Tine Vande Verre
Onderzoeksbegeleider	:	Marieke Van Camp
Departement	:	Ontwerpwetenschappen - Productontwikkeling
E-mail	:	marieke.vancamp@uantwerpen.be

OMSCHRIJVING VRAAG

Voor een onderzoek naar "hybride speelgoed", zullen binnenkort enkele gebruikstesten doorgaan in Hof ter Bekestraat 1. Tijdens deze gebruikstest mogen de deelnemers (5-6 jaar, Nederlandstalig) met het prototype van een door ons ontworpen spel spelen. De gebruikstesten zullen maximum 30 minuten duren en zullen gefilmd worden. Het beeldmateriaal zal enkel gebruikt worden voor onderzoeksdoeleinden. Indien we achteraf beeldmateriaal wensen te publiceren, zal hiervoor via mail goedkeuring gevraagd worden.
Alvast bedankt.

VAK VOOR DE OUDER/VOOGD

Gegevens zoon/dochter

Naam	~~GIELEN~~ LAURENS
Voornaam	ARNE
Geslacht	☐ V - ☒ M
Geboortedatum	04-10-2012

Gegevens ouder/voogd

Naam	GIELEN
Voornaam	ISABELLE
Geeft toestemming om zijn/haar zoon/dochter deel te laten nemen aan de gebruikstest.	☒ ja - ☐ neen
Mail (zal enkel worden gebruikt indien achteraf een goedkeuring nodig is voor het publiceren van beeldmateriaal)	isabellegielen@hotmail.com

Datum: 24-05-2018

Handtekening onderzoeksbegeleider:

Datum: 24-05-2018

Handtekening ouder/voogd:

1.

Universiteit Antwerpen

toestemmingsformulier
goedkeuring ouders/voogd deelname gebruikstest

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Onderzoeksbegeleider	:	Marieke Van Camp
Departement	:	Ontwerpwetenschappen - Productontwikkeling
E-mail	:	marieke.vancamp@uantwerpen.be

OMSCHRIJVING VRAAG

Voor een onderzoek naar "hybride speelgoed", zullen binnenkort enkele gebruikstesten doorgaan in kleuter- en lagere school Sint Antonius. De kinderen van de derde kleuterklas of het eerste leerjaar, mogen tijdens deze gebruikstesten met het prototype van een door ons ontworpen spel spelen. De gebruikstesten zullen maximum 30 minuten duren en zullen gefilmd worden. Het beeldmateriaal zal enkel gebruikt worden voor onderzoeksdoeleinden. Indien we achteraf beeldmateriaal wensen te publiceren, zal hiervoor via mail goedkeuring gevraagd worden. Graag zouden wij u vragen om onderstaand formulier in te vullen en terug te bezorgen aan de juf. Dan weten wij of uw zoon/dochter al dan niet kan deelnemen aan het gebruiksonderzoek. Alvast bedankt.

VAK VOOR DE OUDER/VOOGD

Gegevens zoon/dochter

Naam	DE LEEUW
Voornaam	LOTTE
Geslacht	☒ V - ☐ M
Geboortedatum	26.12.2011

Gegevens ouder/voogd

Naam	DE LEEUW
Voornaam	[illegible]
Geeft toestemming om zijn/haar zoon/dochter deel te laten nemen aan de gebruikstest.	☒ ja - ☐ neen
Mail (zal enkel worden gebruikt indien achteraf een goedkeuring nodig is voor het publiceren van beeldmateriaal)	deleeuwdavid@yahoo.com.

Datum: 17-05-2018

Handtekening onderzoeksbegeleider:

Datum: 25/5/18

Handtekening ouder/voogd:

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Onderzoeksbegeleider : Marieke Van Camp
Departement : Ontwerpwetenschappen - Productontwikkeling
E-mail : marieke.vancamp@uantwerpen.be

OMSCHRIJVING VRAAG

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VAK VOOR DE OUDER/VOOGD

Gegevens zoon/dochter

Naam	HUYSMANS
Voornaam	YARNE
Geslacht	☐ V - ☒ M
Geboortedatum	15/5/2012

Gegevens ouder/voogd

Naam	HUYSMANS
Voornaam	KATYA
Geeft toestemming om zijn/haar zoon/dochter deel te laten nemen aan de gebruikstest.	☒ ja - ☐ neen
Mail (zal enkel worden gebruikt indien achteraf een goedkeuring nodig is voor het publiceren van beeldmateriaal)	katyahuysmans1975@hotmail.com

Datum: 17-05-2018

Handtekening onderzoeksbegeleider:

Datum: 27/5/2018

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Onderzoeksbegeleider	:	Marieke Van Camp
Departement	:	Ontwerpwetenschappen - Productontwikkeling
E-mail	:	marieke.vancamp@uantwerpen.be

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VAK VOOR DE OUDER/VOOGD

Gegevens zoon/dochter

Naam	Steinhauer
Voornaam	Leon
Geslacht	☐ V - ☒ M
Geboortedatum	14/9/2011

Gegevens ouder/voogd

Naam	Van Damme
Voornaam	Sofie
Geeft toestemming om zijn/haar zoon/dochter deel te laten nemen aan de gebruikstest.	☒ ja - ☐ neen
Mail (zal enkel worden gebruikt indien achteraf een goedkeuring nodig is voor het publiceren van beeldmateriaal)	vandammesofie@gmail.com

Datum: 17-05-2018

Handtekening onderzoeksbegeleider:

Datum: 25/5/'18

Handtekening ouder/voogd:

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Onderzoeksbegeleider	:	Marieke Van Camp
Departement	:	Ontwerpwetenschappen - Productontwikkeling
E-mail	:	marieke.vancamp@uantwerpen.be

OMSCHRIJVING VRAAG

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VAK VOOR DE OUDER/VOOGD

Gegevens zoon/dochter

Naam	Timmermans
Voornaam	Lucas
Geslacht	☐ V - ☒ M
Geboortedatum	5 / 4/11 /

Gegevens ouder/voogd

Naam	Gavaert
Voornaam	Melissa
Geeft toestemming om zijn/haar zoon/dochter deel te laten nemen aan de gebruikstest.	☒ ja - ☐ neen
Mail (zal enkel worden gebruikt indien achteraf een goedkeuring nodig is voor het publiceren van beeldmateriaal)	MELISGOVA @ YAHOO . COM

Datum: 17-05-2018

Handtekening onderzoeksbegeleider:

Datum: 24/5/ 18

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Onderzoeksbegeleider	:	Marieke Van Camp
Departement	:	Ontwerpwetenschappen - Productontwikkeling
E-mail	:	marieke.vancamp@uantwerpen.be

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VAK VOOR DE OUDER/VOOGD

Gegevens zoon/dochter

Naam	HANOT ~~[illegible]~~
Voornaam	MARA
Geslacht	☒ V - ☐ M
Geboortedatum	14/07/2011

Gegevens ouder/voogd

Naam	DE PAUW
Voornaam	Veerle
Geeft toestemming om zijn/haar zoon/dochter deel te laten nemen aan de gebruikstest.	☒ ja - ☐ neen
Mail (zal enkel worden gebruikt indien achteraf een goedkeuring nodig is voor het publiceren van beeldmateriaal)	veerledepauw@yahoo.fr

Datum: 17-05-2018

Handtekening onderzoeksbegeleider:

Datum: 28/5/2018

Handtekening ouder/voogd:

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Onderzoeksbegeleider	:	Marieke Van Camp
Departement	:	Ontwerpwetenschappen - Productontwikkeling
E-mail	:	marieke.vancamp@uantwerpen.be

OMSCHRIJVING VRAAG

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VAK VOOR DE OUDER/VOOGD

Gegevens zoon/dochter

Naam	Steppe
Voornaam	Amats
Geslacht	☐ V - ☒ M
Geboortedatum	12/7/'11

Gegevens ouder/voogd

Naam	Timmermans
Voornaam	Sarah
Geeft toestemming om zijn/haar zoon/dochter deel te laten nemen aan de gebruikstest.	☒ ja - ☐ neen
Mail (zal enkel worden gebruikt indien achteraf een goedkeuring nodig is voor het publiceren van beeldmateriaal)	saraatje@hotmail.com

Datum: 17-05-2018

Handtekening onderzoeksbegeleider:

Datum: 27/5/'18

Handtekening ouder/voogd:

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Onderzoeksbegeleider	:	Marieke Van Camp
Departement	:	Ontwerpwetenschappen - Productontwikkeling
E-mail	:	marieke.vancamp@uantwerpen.be

OMSCHRIJVING VRAAG

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VAK VOOR DE OUDER/VOOGD

Gegevens zoon/dochter

Naam	Schockaert
Voornaam	SANNE
Geslacht	☒ V - ☐ M
Geboortedatum	2/12/'11

Gegevens ouder/voogd

Naam	Schockaert
Voornaam	Steven
Geeft toestemming om zijn/haar zoon/dochter deel te laten nemen aan de gebruikstest.	☒ ja - ☐ neen
Mail (zal enkel worden gebruikt indien achteraf een goedkeuring nodig is voor het publiceren van beeldmateriaal)	Steven.Schockaert78@gmail.com

Datum: 17-05-2018

Handtekening onderzoeksbegeleider:

Datum: 28/5/'18

Handtekening ouder/voogd:

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Onderzoeksbegeleider	: Marieke Van Camp
Departement	: Ontwerpwetenschappen - Productontwikkeling
E-mail	: marieke.vancamp@uantwerpen.be

OMSCHRIJVING VRAAG

Voor een onderzoek naar "hybride speelgoed", zullen binnenkort enkele gebruikstesten doorgaan in kleuter- en lagere school Sint Antonius. De kinderen van de derde kleuterklas of het eerste leerjaar, mogen tijdens deze gebruikstesten met het prototype van een door ons ontworpen spel spelen. De gebruikstesten zullen maximum 30 minuten duren en zullen gefilmd worden. Het beeldmateriaal zal enkel gebruikt worden voor onderzoeksdoeleinden. Indien we achteraf beeldmateriaal wensen te publiceren, zal hiervoor via mail goedkeuring gevraagd worden. Graag zouden wij u vragen om onderstaand formulier in te vullen en terug te bezorgen aan de juf. Dan weten wij of uw zoon/dochter al dan niet kan deelnemen aan het gebruiksonderzoek. Alvast bedankt.

VAK VOOR DE OUDER/VOOGD

Gegevens zoon/dochter

Naam	MOONENS
Voornaam	HANNAH
Geslacht	☒ V - ☐ M
Geboortedatum	26 / 11 / 2011

Gegevens ouder/~~voogd~~

Naam	MIROIR
Voornaam	KIMBERLEY
Geeft toestemming om zijn/haar zoon/dochter deel te laten nemen aan de gebruikstest.	☒ ja - ☐ neen
Mail (zal enkel worden gebruikt indien achteraf een goedkeuring nodig is voor het publiceren van beeldmateriaal)	

Datum: 17-05-2018

Handtekening onderzoeksbegeleider:

Datum: 28/05/2018

Handtekening ouder/~~voogd~~.

APPENDIX M

PERSONAL REFLECTIONS

1. Jan Gomez Roberts

During this personal reflection, I address what I think I have gained from the EPS project and in what areas there could have been room for improvement.

At the onset of this project we were presented with the courses and classes we would experience during the semester. During this period I was slightly reticent towards all these modules as I thought they were not really necessary or relevant for the main project itself. However, I soon realised that all these modules in one way or the other were used. An example for me was the English writing and English Presentation modules. When I saw that I had to attend these modules I thought to myself that it would be a waste of time as I am a native English speaker. In spite of this, I found that these modules were pretty useful and helped me improve my presentation and writing skills.

Throughout the course of the project, I have been in charge of the electronic aspects of the toy, due to my field of studies being Electrical and Electronic Engineering. Due to this involving as previously stated, the electronic aspects of the toy, my participation was essential on almost every aspect of the toy itself, such as the design and the programming for the app. However, on my part, I left some parts of the electronics, such as the soldering, late, this affecting other parts of the project.

Going on to the project communication, at some points in time I played a major role in it due to my bilingualism in Spanish and English, using this to help my fellow Spanish teammates at times when they were not able to express themselves or had trouble finding an equivalent Spanish word in English. However, I feel I could have done better in communicating some of my ideas and problems, as I sometimes expect people to understand me without having to pause or going deeper into detail. I also sometimes kept quiet my opinions as I would rather do that than create a disturbance or be judged. This also reflected itself in the project work process, as I would keep some of my opinions quiet. However, I feel that more than only me miss-communicating, it was the team as a whole that lacked communication skills. From this, I consider there could have been room for improvement in that aspect.

This project has helped me improve my circuit designing. I also improved my use and programming of Arduino micro-controllers, which I had not used very often in the past. In comparison to other peoples specialities, I feel I have learnt a lot from my fellow teammates in the aspect of designing and conceptualising.

In terms of the project results we have achieved, we have done a good job within the timeframe and resources available to us, however, we fell behind on schedule in multiple occasions, many times due to external factors. This was due in part to a large number of classes and reports to be submitted externally to the main project, leaving little time to continue on the main project. Now that we have finished the project though, I realise that most of these modules were necessary and have had a positive impact on our project, such as the Usability module and the Designing Electronic Products module.

In the aspect of the team building, as I have previously mentioned, we could have improved our communication skills as a whole, communicating our problems, ideas and what we had done up until that point in time. Despite this, I have developed my team skills, further refining them.

Within the team context, we could have set more defined weekly goals to keep us on track, as I feel that we did not keep up with our promises and goals, in particular, me, in some aspects of the electronic components. Personally, as I stated before, I would like to improve some of my team communication skills. I also want to improve my working hours and energy, as due to the large amounts of classes and reports, I was always feeling tired.

In conclusion, even if we have had our ups and downs during the course of this project, I have enjoyed it and I think we have done a good job.

2. Víctor Martínez Núñez

Once completed the entire period of the programme and having entirely developed the project, this personal reflection is aimed at the evaluation, both personal and of the team, of the progress made regarding the assigned project. In this reflection, I outline the evolution of the team and possible aspects of both the project and the programme to be taken into account and improve for future students and programmes.

I define myself as someone multidisciplinary, entrepreneur and hard-worker, who loves to see my ideas turn into something tangible and real, always having my own opinion but also willing to hear external ideas to improve my work. Therefore, this programme has helped me for personal development, enhancing my knowledge and broadening my horizons, and to be able to evolve as an industrial designer, since it has granted me the ability to work on a real-life project that has allowed me to observe from a closer point of view the problems and difficulties that a real company has to confront.

Thanks to the different courses that have taken place throughout the project, I have been able to observe the project from different points of view to determine in detail aspects that had not been contemplated yet or that were difficult to develop, due to the little or non-existent experience and knowledge in that specific area. This has allowed me to discover and analyse more in-depth the project and learn to take into account all these factors that have been addressed in each course for future projects.

Throughout the project, together with the help of the courses that have taken place during the program, the different roles have been established for each member of the group in a natural way, since each individual has adapted to their environment and has provided his knowledge and experience in a progressive manner so that in the end the group already knew in which areas each of the members could help and get involved.

In my case, as a current student of Engineering in Industrial Design, my knowledge and experience ended up helping the group in the field of ideation and product development, although I could also provide another point of view in the field of programming and

electronics, since throughout the career I have also acquired some basic knowledge in these two areas. This helped in a clear way to the interaction and communication within the group between the side more focused on the development of all the internal electronic part of the product and the side more focused on the formalization of the idea of the product itself. Therefore, there was an easy and precise understanding between what was possible to achieve on both sides of the team group, both on the group of designers and product developers and on the group of programmers and electronic engineers.

Despite the fact that the evolution of the project has been positive and the team has worked in a regular and progressive way, in the first part of the programme before Easter holidays the progress was very slow and interrupted due to a large number of hours focused on the courses. Although most of them were useful for the project in order to have new ways to deal with the different problems and doubts, sometimes certain project information was treated in a similar way but from different points of view, and it was not possible to progress since there were inconsistencies and disagreements between these that complicated the progress of the project. Therefore, during the first part of the programme, the project was more focused on trying to meet all the established requirements and we did not spend as much time as desired to build the ideas in a clear and precise way about how to orientate the product. Due to that, the available time for the complete development of the project was less than expected and there were areas of the product that we would have liked to have developed more in depth, but the time constraint forced us to make decisions at a faster pace.

In conclusion, from my point of view, although there may have been certain differences between the different members of the group regarding how to approach the project, in general, the evolution has been positive and there has been a visible progression.

However, it should be noted that, although most courses have been useful for the project, too much time has been devoted to them, which has not allowed an adequate approach to the project, that has resulted in a very slow evolution of it. Therefore, the evolution of the project had to be at an accelerated pace that meant paying less attention to certain areas due to lack of time.

3. Kevin Schelfer

In this document, I will reflect on my experiences, contributions and results during the European Project Semester (EPS) project, which took place between 19 February (2018) and 14 June (2018) in Antwerp. During the EPS project, I worked on the 'Hybrid Toy Construction' project. In this document, I will first discuss the courses of the EPS, after which I will talk about my contribution to the project and I will discuss my communication.

- The courses

During the semester, a variety of courses was provided by the university, including: Project management, sustainability, usability, business canvas, and more. However, I personally felt that these courses were of little-to-no use to me on a professional level. This is mainly due to the classes being aimed at designers (which is, admittedly, 80% of the students in the EPS group), and due to us only receiving 1-3 classes per subject, forcing the teachers to provide very general information, instead of any in-depth knowledge, which might have been more useful in understanding the design process.

- Contribution

My personal contribution to the Hybrid Toy Construction project was the creation of the app that would be used alongside the toy train. This role helped me develop my skills as a programmer, as before this project I had never created an app before. The app for the project went through multiple iterations, but eventually consisted of 7 tutorials to help the user understand the basics of the games we had planned. Two of these tutorials are able to interact with the toy train through the use of a Bluetooth connection.

In general, I think that the final result of the project, the toy train with the corresponding app, were of decent quality considering the inexperience of the project group. Due to the quantity of the tutorials, I do feel that the overall quality suffered somewhat, as considerable amount of work had to be completed in a reasonably short timeframe.

- Communication & Development

During the course of the project, I made sure to communicate whenever I was unable to implement certain features due to them being too difficult for me to implement within a reasonable timeframe. Additionally, when I would run into major problems, I made sure to notify the team as then they would be aware that my progress would be delayed.

After the midterm report we had significantly more time to work on our EPS project than before. This meant that we could make considerable amounts of progress each week, as there were no classes or assignments which could distract us from our work.

During the project, I tried to give the other team members directions on what our next objective should be and, at times, tried to help if there were problems with their parts of the project. However, I tried not to involve myself with the other production processes in the group as much, as I knew I would need all the time I had available to develop a properly working app.

I realised during the project that, especially compared to other disciplines, programming takes up a considerable amount of time without any visible results. At times it could take me up to two days to resolve a particular error in the code, while in the meantime sketches, graphics and other designs were made.

- Conclusion

In the end, I am glad to have been a part of this project as it allowed (or forced) me to learn about app development. With experience in this area of expertise, I can more easily apply for jobs revolving around app development. Other than the development of personal skills, this project also enabled me to gain experience with working in a multidisciplinary team.

4. Tine Vande Verre

In this reflection I look back upon the two months following Easter break up until the delivery of our final report on 9 June. The first half covers my contribution to the team's performance, while the second half focusses on the intended points for improvement on both team and individual level.

This project required a diverse range of knowledge fields such as app development, graphic design, electronics and programming, 3D modelling and rapid prototyping. The latter was my greatest input in terms of providing physical designs which could be used to verify ideas, usability, aesthetics and dimensions. A secondary benefit of this tangible work was that it helped visualise our goal and, therefore, tended to motivate people, which was highly needed after our midterm report. Every week the prototypes would evolve towards a more high fidelity stage, up until the creation of the final prototype which was cut by laser, glued, sanded, coloured and varnished, thus ready to be used in a user test.

My second asset is related to the fact that I was the only local in our group. As a result, I could provide additional resources or knew where to find them, yet the most significant benefit was speaking the native language. This eased the search for participants for our user tests, and was necessary for conducting them, as the children had to be addressed in their native language. As the only other Dutch speaker in our group happened to be our only programmer for the app I took responsibility for arranging, executing and analysing the user tests.

In my view, the most difficult aspect of this project was management, since many different actions had to be executed simultaneously, influenced one another, needed to be compatible, finished by the deadline, and look coherent. Alicia and I took care of this in slightly different ways. She would constantly check in on team members to know what they were working on and remind them of pending tasks and deadlines, which is something I find energy draining and time consuming to do, especially as this would be yet another item on my to do list. Instead, I kept our final goal in mind, which was the creation of a hybrid toy verified through a user test, and attempted to reduce weaknesses and risks.

As we were on a tight schedule, one way I attempted to reduce risks was by providing our only app developer and our only electronics expert the maximum amount of time possible by relieving them of all other tasks. As such, they could solely focus on their expertise while the three designers took care of additional assignments. However, after a couple of weeks it became apparent that our electronics expert would not meet our final deadline for the user test, as he did not show much progress, nor commitment, nor initiative to seek help. Any attempts to make him work harder looked in vein, and sitting next to someone in order for them to keep working distracts you from executing your own work. Eventually, I requested help from a friend of mine in order to have a backup for the user test.

This backup plan caused a lot of extra pressure and stress as I chose to bear responsibility for something that would not have been mine to bear if this team member had proven to be reliable. In the end the backup train was used as the one provided by my team member was unsuited for children to play with. What I have learnt from this is that, next time, I will communicate this kind of issue to our supervisor in an earlier stage, when intervention is still possible. The second lesson I have learnt is to be more careful when it comes to mixing your work life with your personal life, since this puts pressure on close relationships.

As for the intended points for improvement on team level, we did regard proofreading as a proper task which is time consuming when executed well. Moreover, we had less long and unproductive discussions, as we worked on a more individual basis on our tasks. However, the backside of this is that it became more difficult to keep track of each other's progress. Thus, I believe a good understanding, sense of reliability and trust is necessary, as well as a brief and daily update on your progress.

As for the intended points for improvement on an individual level, I belief I did take much more initiative compared to the midterm report. My other good intention was to communicate better, which I partly succeed in. I communicated very easily and to the point with Kevin and told Jan he was not making enough progress. I put a list with distribution of tasks online, yet it became clear getting everyone to update this was the difficult part. Looking back, I should have informed Alicia and Victor about the backup, as they might have felt excluded and kept in the dark.