Designing a Toolkit Based on Playful Learning Aspects to be Used in a Puzzle Route

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July 7, 2023

Abstract

Playful learning is a very effective form of education. It can be used to teach children the basics in electronics and programming. For this project, a toolkit has been developed that uses playful learning aspects to let children pick and assemble their own components, changing the behaviour of the toolkit fitted to a changeable story and difficulty. With this toolkit, users can go and solve puzzles spread out a park.

Acknowledgement

I'm extremely grateful to Marcello ('Maro') A. Gómez-Maureira and Marcus Gerhold for filling the role of supervisor and critical observer respectively. Their feedback and support were of invaluable help. I am also gratefull to Don Blaauw of Señor Sensor for trusting me with this assignment and helping by supplying components.

Contents

1 Introduction

Teaching the basics of technical subjects to primary school children can be challenging. Programming itself consists just out of text and might not draw the curiosity of the engineers of the future. Playful learning, an interactive methodology for teaching, might prove useful in these more technical subjects. Playful learning is a method in which a certain subject is taught in a playful manner. This methodology is even theorised to be the future of education due to it's seaming effectiveness (Natriello, 2007; Sawyer, 2006; Tuomi, 2007). By centering electronics and programming around game-creation, you can more easily peak and keep interest, resulting in a more effective learning session. Hand's on building experience can make abstract or technical ideas really tangible and understandable.

Señor Sensor, 2023 is a project by NoMoMo (Studio-No-More-Mondays, 2023) that focuses on do-it-yourself escape-room kits. Their goal is to create puzzles by using electronics in a playful and exciting manner. They for example have their EscapeVRoom project, which allows secondary school children to build kits based on the sustainability goals (United-Nations, 2023).

As a company, they require a product that can draw sales, and that peaks interest. Every product Señor Sensor sells has certain design aspects that make them stand out, these aspects should be carried over to any new products that they develop. The client has been playing with the idea of bringing their current product concept (diy playful learning escape puzzle boxes) outside, into nature. This will add the secondary goal of getting kids to play outside.

The client has suggested a puzzle route to expand their current product line. The project proposal revolves around a toolkit that is needed to solve and interact with the puzzles. This toolkit has to rely on playful learning elements concerning electronics and/or programming. The toolkit is assembled by the participants with the goal of creating more immersion and establishing a connection to the tools they just created with their own hands. The route will be an outdoor experience in which children (ages 8 to 12) walk through for example parks, zoo's or bungalow parks. This route is mainly targeted at families, so difficulty level should be fit for all ages and may be adjustable.

For this purpose a toolkit prototype was designed which is able to house three different types of components simultaneously. This allows for these components to be switched out and thus change the behaviour of the toolkit. There will always be one actuator, one passive and one feedback component present. The actual components will be selected based on what story and difficulty the participants choose. The toolkit does not look out of place when placed together with other señor sensor products, but is built in a more reliable way, introducing plastic 3D printed parts and core.

Throughout this document the design process will be explained. The first chapter is background. Here more information will be provided about relevant competing products and companies, potential ethical issues and a foundation will be laid in playful learning methods. Based on this background research and discussions with the client, a list of requirements was set up. This list encapsulates a framework within which the eventual design has to fit. Then after ideation, a lot of sketches and brainstorming sessions, a design can be specified. In the specification chapter design decisions will be made and argued. In the realisation chapter the prototype development process will be explained. The evaluation serves as a point of reflection, what did the prototype accomplish, what was good, what has to be improved, where is more research needed.

2 Background Research

Within the background research more background information will be reviewed and processed to serve as a basis for the ideation phase. An important subject within the background would be playful learning methods and their proven implementations. A set of relevant researches regarding these methods will be reviewed and compared. Both Señor Sensor, 2023 and a competitor, KiwiCo, 2023, will also have their product lines reviewed.

2.1 Implementation of Playful Learning Methods

Research has to be performed into the field of playful learning in electronics and programming to be able to design a solution that successfully incorporates relevant playful learning methods. This paper goes into the implementation of methods in playful learning in different fields and the advantages and disadvantages of those methods. Focus will be on methods concerning creation and education, aligning with building and using the toolkit respectively. A priority is given to studies concerning playful learning for ages below 15, since this matches the target group set for the puzzle route. The reviewed methods will then be compared and evaluated.

2.1.1 Creation Using Playful Learning

Co-creation is a playful learning method that revolves around groups creating a certain project by trail and error, learning based on experience, and is an import aspect of the proposed project. Laakso et al., 2021 performed a study concerning co-creation in game development, which shows the actual usability of co-creation as it relates to playful learning. The study used a nationwide game design competition to examine how students the experienced game design project and how it influenced their personal interests, collaboration skills and digital competences. The students were free to create any game they wanted; not tied to a set subject or style.

Benefits Students who participated in collaborative game design showed clear professional growth. Participants were able to set up life-like development team structures, reported an increase in confidence in their digital- and artistic competences and were able to recognize the usefulness of the learned skills in other school subjects. In addition, Camacho-Sánchez et al., 2022 found that students working in groups experienced a growth in their technical vocabulary and groups naturally fell into a certain role division similar to professional settings; students gained new knowledge and more confidence.

Drawbacks However, the methodology is also not universally effective. Laakso et al., 2021 concludes that there is a difference in progress made by different students. For a group the digital competences remained unchanged, while others reported significant improvements in the development of these competences. This difference is reckoned to "likely be related to the design roles that participants played in the game design projects" (p. 11), since the competences tend to develop more "through effortful problem solving" (p. 11).

Other issues holding these programming lessons back are the lack of computer science courses and the lacking progress in implementation (Heininger, Seifert, et al., 2017). Teachers who did not follow such a course themselves, are less able to assist their students in these kinds of projects. This leaves the students to have to figure everything out by themselves, without the needed assistance.

2.1.2 Teaching Using Playful Learning

Playful learning can also be used as a way of communicating new information. A pre-made playful learning environment be can be used as an educational tool. Kangas, 2010 and Randolph et al., 2013 test the viability playful learning environments as part of the educational system, reviewing the effectiveness of such a method. The participating students, ages 6 to 12, had to plan out and program their own games into an interactive playground. The game developing and playing were included in the curriculum of a certain course, chosen independently by each teacher. The method was thus tested for a range of different subjects.

Benefits Both studies were able to prove an statistically significant academic improvement in participating students. Students performed overall better on the post test compared to the pretest. Randolph et al., 2013 found that these test scores increased by 25.60%. This improvement was shown to be "regardless of their gender, age, satisfaction with schooling, or country" (p. 10). Next to providing academic improvement, the playful learning environment encourages students to be more creative and innovative, and they train their media skills by building the games for the playground.

Drawbacks Using new technologies means that teachers have to be (re)educated to be able to utilize them (Kangas, 2010, Randolph et al., 2013). This increases the effort needed to implement the playful learning environments as proposed.

On the other hand, incompleteness of the reviewed studies cast some doubts concerning the validity of the results. Randolph et al., 2013 notes that not being able to test against a control group limits the reliability of the study, “making the experiment susceptible to threats to internal validity” (p. 10). The study also does not test repeated use, so any influence of novelty bias is not accounted for. The study only focuses on initial results; however, novelty is heavily suggested to impact the effectiveness of reward-based learning methods (Houillon et al., 2013), like playful learning.

2.1.3 Comparison

Randolph et al., 2013, Kangas, 2010, Laakso et al., 2021 and Camacho-Sánchez et al., 2022 all show that playful learning is a very effective way of engaging curiosity in children. The implementation however, varied considerably. Where Randolph et al., 2013 reports on the creation of games tied to subjects, and learning from playing these games, Laakso et al., 2021 only considers the game creation process. For any of these playful learning methods to be effective, the content needs to be adapted for the right age group to get good integration and involvement from students, noted as one of the success factors in playful learning methods by Heininger, Prifti, et al., 2017.

All four studies report an increase in digital competences, which students will use to learn, communicate, access new information and grow as a professional (Baggia et al., 2016). The proposed methodologies also encourage collaboration between students. The playful learning environments shown by Kangas, 2010 and Randolph et al., 2013 focus more on playing together by creating and trying games. The method proposed by Laakso et al., 2021 is more structured, best explained as a group project, in which groups are assembled and tasked with creating and developing a game. The interactions (success factor) between students are very important for the growth of the students involved. They are able to grow through the discussions that they have in the classroom.

The teacher also plays an important part, having student-teacher interactions also be part of the interactions success factor. Teachers need to be able to give sound feedback to students, to help them progress and improve, and the teacher should also be able to guide the classroom discussions to be productive and provocative. For this, teachers need to understand the material, in the studies by Randolph et al., 2013 and Laakso et al., 2021 teachers received some additional education. The teachers were educated on the playful learning environment and how to use it, to guide students in in their efforts, for “the network trained the teachers to master the computational methods needed for designing digital games” (Randolph et al., 2013 p. 4). Teachers were thought to program, so that they could help students build story lines, visuals and functions Laakso et al., 2021.

2.1.4 Discussion and Conclusion

Playful learning is a valuable asset in the modern educational system. Test scores on a targeted subject are significantly higher after exposure to playful learning (Randolph et al., 2013) and students were even able to replicate development team structures on their own accord (Laakso et al., 2021), making them more prepared for when they eventually start working. All studies covered in this review report positive results, but with some minor drawbacks that can be solved with investment in certain stakeholders, for example, (re-)educating the teachers where needed would allow them to give sound feedback to the students.

Both implementations show game creation as an important factor of the tested playful learning method, certain elements, such as the game creation around a certain subject (Randolph et al., 2013) and letting students work together to create (Laakso et al., 2021) are valuable for the further development of the given problem statement. Another important part to take away from this review into the further development of the previously mentioned proposed project is the success factors as explained by Heininger, Prifti, et al., 2017. These factors allow a proposed playful learning method to be planned out in a structured manner. Not all success factors have been flashed out in this literature review, but will be considered in full for the execution of the project.

None of the reviewed studies include a control group, they all show significant educational gains, but doing similar tests with an included control group will give the conclusions more viability. So for further research, similar studies, but with control groups are recommended. Implementation over longer period of time would also allow researchers to evaluate the longevity of playful learning environments, this would eliminate any novelty bias, which is suggested to influence reward-related learning (Houillon et al., 2013).

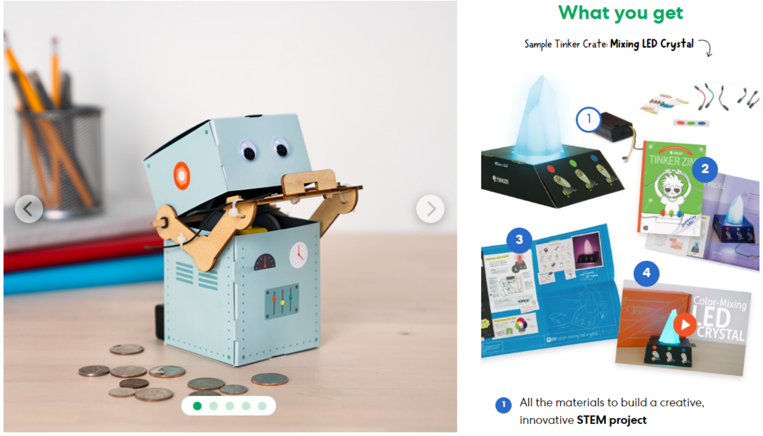
2.2 Relevant Companies

Señor Sensor, 2023 and KiwiCo, 2023 are the companies being reviewed. KiwiCo was chosen as an international competitor that develops and sells monthly changing do-it-yourself boxes targeted at different age groups. Where Señor Sensor works just in the Netherlands, KiwiCo has been successful in increasing their export countries. Señor Sensor is relevant to review, since this allows the project to match their current product-line in aesthetics.

2.2.1 KiwiCo

KiwiCo is a company that focuses on STEAM (Science, Technology, Engineering, Art, Math) projects for kids. They have monthly changing boxes for five different age ranges that contain interesting projects. They note on their homepage that "KiwiCo was founded by a mom AND engineer, with a mission to inspire the next generation of innovators and problem solvers through seriously fun hands-on projects. Since 2011, KiwiCo has delivered over 40 million crates to kids of different ages, interests, and abilities, all around the world" KiwiCo, 2023.

The Kits In the age range 9 to 12, KiwiCo offers boxes with the following themes: Atlas (geography & culture), Yummy (science of cooking) and Tinker (science & engineering). The tinker crate is most fitting to the problem statement, a snip of the website can be found in *figure 2*. This create contains an engineering project, made out of simple electronics and simple materials, such as wood and cardboard. Assembly does not require soldering or any form of power tools. Most boxes seem to go together with just friction and few tie wraps. This allows for easy assembly, which is required when working with the intended target group. The kits also interesting, all bearing printed cardboard parts that give the kit personality. The kit in *figure 2* has eyes, making a simple square piggy bank suddenly a box with character.



1 All the materials to build a creative, innovative STEM project

Figure 2: Tinker Crate as advertised on the KiwiCo website (KiwiCo, 2023)

2.2.2 Señor Sensor, A Project By NoMoMo

Señor sensor (Señor Sensor, 2023) is a project by NoMoMo (Studio-No-More-Mondays, 2023) that focuses on do it yourself escape-room kits. Their goal is to create puzzles by using electronics in a playful and exciting manner. They for example have their EscapeVRoom project, which allows secondary school children to build kits based on the sustainability goals (United-Nations, 2023).

The Kits They have a set amount of kits to choose from, all with different puzzles and interactions. *Figure 3* shows a selection of their available kits. All kits are based on laser-cut boxes, which go together with a few drops of glue. The electronics are all powered by an ESP32, attached to a custom printed circuit board with a set amount of quick connectors. All the sensors and actuators can be attached via these quick connectors, allowing the electronics to be easily assembled. Most puzzles also have a large customization component. The ”kantel box” (tilt box) and the ”master memo” both us voice recording modules to allow users to add their own sounds to the puzzle. The ”schat box” (treasure box) and the ”volgorde box” (sequence box) use NFC modules, with blank cards or stickers included, so that users can customize their own solutions.

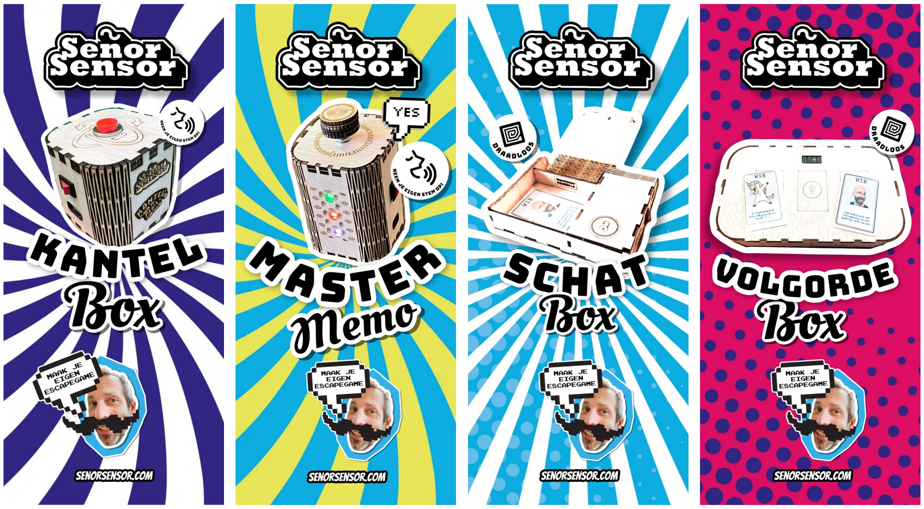


Figure 3: Part of the selection kits promoted on Señor Sensor, 2023

2.3 Ethical Review Subjects

A few relevant ethical topics to this project will be discussed in the following section. Ethical issues are easily overlooked, but are important to keep track of. Since they can help create informed designs. This is even more prominent when designing for children, since they are not able to give consent for participation in user tests. When designing for children, relevant subjects include beneficence and non-maleficence. These are relevant since with the design goal of entertaining with playful learning children, a certain beneficence would be necessary. Non-maleficence is very important, since the prototype, and even more-so the final product, should be fully safe to use for children. Creative design can greatly benefit the experience.

2.3.1 Beneficence

The product should benefit the user. A product should be safe, easy to use and improve the quality of life. An important factor is ease of use. The whole project is centered around playful learning and solving puzzles, so there should be some challenge in assembling the toolkit and solving the puzzles. However, this challenge should only be in the designed playful learning part., any other interactions that are not designed as such, need to be easily understandable and usable. This is a fine line to keep track of, when is something an appropriate challenge, when is something an annoyance.

2.3.2 Non-Maleficence

The product should be designed to avoid harming the user (rule 3, IEEE, 2014). A product should be designed in such a way that hurting yourself by using it is a difficult as it could possibly be. Safety is an import factor for this project, since children, ages 8 to 12, will be working with electronics. They should not be able to shock themselves by connecting two wrong wires, the design should be adapted in such a way to prevent this situation. Parent supervision is expected of course, but the children should be able to built the toolkit by themselves. Currently, the kit is expected to need a mere 5 volts, which is not harmful. Any of the mechanical parts of the puzzle should have the necessary safety precautions, like resistance detection to avoid squeezing curious fingers, to avoid any possible way of harming the user.

2.3.3 Personal Data

Personal data should not be easily accessible by anyone, no information is needed, so no personal data should be collected (rule 1, IEEE, 2014). The current concept does not utilize IOT elements, and will strictly communicate via contact between the toolkit and the puzzles. This to avoid any of the insecurities surrounding IOT, you cannot hack into the data stream, unless you have the physical toolkit. Avoiding safety risks and creating a more reliable communication method in the process. By not using IOT the puzzles do not need to have an "always on" function, but they can be activated by the switch, saving power and adding to the sustainability of the system.

3 Methods and Requirements

This section explains the methodologies used during the design process of this project. Afterwards all the requirements will be laid out and explained. These requirements are also put in a table and will be used in the evaluation of this project.

3.1 Research Methods

Creative Technology Design Process The project was worked out using the creative technology design process. This process is based on idea iteration via three distinct phases: ideation, specification and realisation. In the first phase, ideation; a concept will be developed via sketches and discussions, these will then be filtered and worked out further in the specification phase. In this phase, details will be given to the concept, low fidelity prototypes will be made to test out the concept. Through validation from the client a more developed mid fidelity prototype will be developed. This prototype should be mostly functional and fit for user testing. After these user tests, the results will be processed, shortcomings will be noted. Based on the improvements, another round of ideation, specification and realisation will be performed.

User Research Setup Two user tests are performed, the first of which is a proof of concept. This test is executed with fellow students as participants. A paper prototype is used in this test, to allow for flexibility and quick changes where needed. This test will also be used to validate the test method. The test will consist of participants following a dimmed down version of the assembly process, using the paper prototypes. Having participants select a story and difficulty and assemble their toolkit with parts. During the test they will be observed, and afterwards they will be asked to fill in a survey consisting of eight Likert scale questions. The questions and answers to this survey can be found in *appendix A*. The second test will be executed with the actual target group as participants, children ages 8 to 12. Since these kids are not able to give consent, a parents consent will be requested. The parent or guardian is also invited to be present during the test, since having a guardian present will allow the child to have a comfortable person present, increasing the likeliness that they will use their right to quit, if needed. The test itself will follow the same process as the proof of concept test, but will now utilize the actual prototype. Participants will be asked to assemble the prototype toolkit and use the provided interface. During the test participants will be observed. Afterwards participants will be asked to fill out a visual survey with similar questions as the first test. This survey can also be carried out verbally if the written survey proves to be too difficult or in-comprehensive.

3.2 Research Requirements

As discovered in the literature research chapter, co-creation can be seen as a valuable aspect of playful learning, as shown by Laakso et al., 2021 and Heininger, Seifert, et al., 2017. So the toolkit should be designed to encourage collaboration between participants in a single group.

Balancing creativity and user needs. As a designer it is very easy to make elaborate and beautiful designs. But it is important for this project that the toolkit is simple and manageable by the participants. Usability has more importance than the looks. Since the toolkit needs to be assembled by the participants, the function needs to be clear. The form follows the function (Pelzel, 2023).

The flowchart in *figure 4*, as highlighted in Fleddermann, 2012, mainly touches on important factors when designing for children. With kids you need to be sure that the product is very save, a simple warning sign might be enough for adults, but not for children. Difficulty and accessibility also play an important role, since children are still developing both in skills and in size. Putting the solution or physical puzzle out of reach can make children unable to actually use the product.

The puzzles shall have an activation and deactivation moment, which locks to a certain user. This means that once a group start their interaction with that puzzle, no other participants can use said puzzle. It should not be possible for other groups to interfere with the active group their progress, and neither should any answers that the active group finds, impact the experience of the waiting groups.

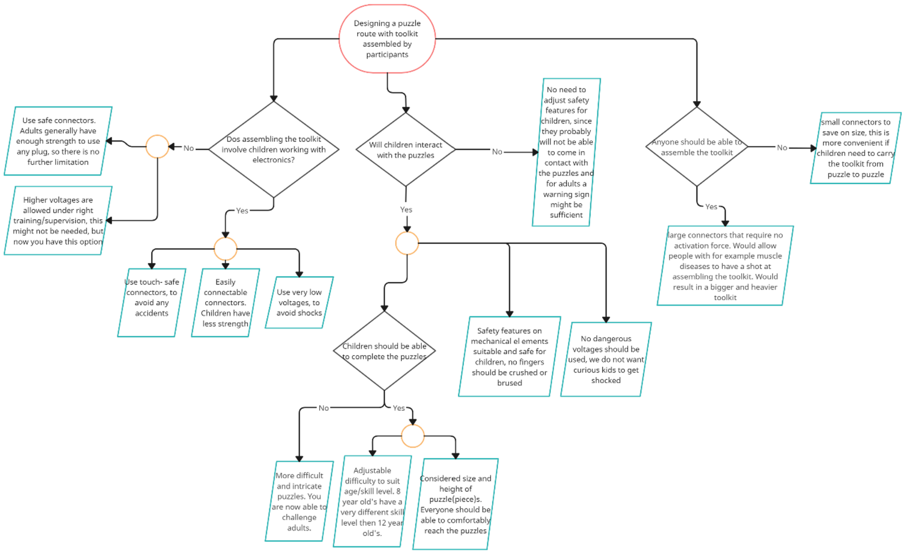

Designing a puzzle route with toolkit assembled by participants
Dos assembling the toolkit involve children working with electronics?
No
Use safe connectors. Adults generally have enough strength to use any plug, so there is no further limitation
Higher voltages are allowed under right training/supervision, this might not be needed, but now you have this option
Yes
Use touch- safe connectors, to avoid any accidents
Easily connectable connectors. Children have less strength
Use very low voltages, to avoid shocks
Will children interact with the puzzles
No
No need to adjust safety features for children, since they probably will not be able to come in contact with the puzzles and for adults a warning sign might be sufficient
Yes
Children should be able to complete the puzzles
No
More difficult and intricate puzzles. You are now able to challenge adults.
Yes
Adjustable difficulty to suit age/skill level. 8 year old's have a very different skill level then 12 year old's.
Considered size and height of puzzle(piece)s. Everyone should be able to comfortably reach the puzzles
Safety features on mechanical el ements suitable and safe for children, no fingers should be crushed or brused
No dangerous voltages should be used, we do not want curious kids to get shocked
Anyone should be able to assemble the toolkit
No
small connectors to save on size, this is more convenient if children need to carry the toolkit from puzzle to puzzle
Yes
large connectors that require no activation force. Would allow people with for example muscle diseases to have a shot at assembling the toolkit. Would result in a bigger and heavier toolkit

Figure 4: Flowchart showing relevant ethical issues

A design decision which was made in cooperation with the company, is that the puzzles stay in a set location, whilst the toolkit moves around with the participants. This allows the toolkit to be the brains of the experience and for it to influence the puzzles behaviour.

The client required the use of certain electronics and software. The current setup of the company revolves mainly about a set list of libraries, that can be used in different projects. They have developed general libraries for different sensors, printed circuit boards and use cases. These libraries have been made accessible for the development of this project, however, these files cannot be shared as for a non-disclosure agreement with the company. The company currently uses almost exclusively ESP32 micro computers for their products, so this project will also be based on a ESP32, to fit with their current infrastructure and libraries.

All of these requirements, and more, have been put in a concise table. Some relevant puzzle requirements can be found in *table 1* and a more elaborate toolkit requirement list can be found in *table 2*.

Conflict of Interest This project is executed for both a company and the University. Both parties have a stake in the project and set requirements. To make sure these requirements do not collide proper communication is necessary. Regular discussions with client and supervisors are needed to ensure logical progression of the development of the project. In the case of conflicting opinions from both groups, the opinion of the supervisor from the university will be taken to move forward with. There is a contract in place that states that this

		Method of Validation
1. Technical Requirements		
1.1	The puzzles shall be powered based on usage	Technical test
1.2	Puzzles shall be operable without a need for a manual reset	Technical test
2. Appearance Requirements		
2.1	The puzzles shall have a clear place to connect the toolkit to	User test
3. Functional Requirements		
3.1	The puzzles shall be used by a single user at a time	User test
3.2	The puzzles shall be able to withstand rain	Technical Test
4. Safety Requirements		
4.1	The puzzles shall not have any potentially sharp edges	Technical Test
4.2	The puzzles shall be able to withstand unintended usage	Technical Test

Table 1: Puzzle Requirements

		Method of Validation
1. Technical Requirements		
1.1	The toolkit shall be based on the esp32 platform	Visual test
1.2	The toolkit shall be able to communicate with the puzzles	Technical test
1.3	The toolkit shall be easily transportable	User test
1.4	The toolkit shall consist of multiple parts	Technical test
2. Appearance Requirements		
2.1	The toolkit shall be appropriately sized for children	User test
2.2	The toolkit shall have visual progression trackers	User test
2.3	The toolkit shall have clear attachment point for toolkit-puzzle communication	User test
2.4	The toolkit shall have clear indications of where parts need to be connected	User test
2.5	The toolkit shall fit the current design language in use by the client	Visual test
3. Functional Requirements		
3.1	The toolkit shall be based on the esp32 platform	Visual test
3.2	The toolkit shall be build-able by children ages 8 to 12	User test
3.3	The toolkit shall be usable for multiple sessions	User test
3.4	The toolkit shall trigger different solutions based on part selection	Technical test
4. Safety Requirements		
4.1	The toolkit shall not use a potentially dangerous power supply	Technical Test
4.2	It shall not be possible to assemble the toolkit in a incorrect manner	User test
4.3	The toolkit shall have no mechanical potential of harming user during assembly	Technical Test

Table 2: Toolkit Requirements

assignment is for my education, so the university has final say in any disputes. This is because this study is done as a graduation assignment, and is thus in the first place an assignment done for the university.

Intellectual Property Rule 5e of the IEEE, 2014 code of conduct targets the misuse or infringement of intellectual property, which is relevant for this project. Since I work with libraries made by the client company, I do come into contact with their intellectual property. I had to sign a non-disclosure agreement (NDA) before I was allowed to work with these libraries. I am not allowed to share the inner workings, the code, of these libraries. It is however allow to describe the logic on a surface level, but this description will be checked by the company before it can be published.

4 Ideation

Based on the requirements set together with a client, new concepts can be generated. In the ideation phase, multiple solutions will be brought up and discussed. The goal of the ideation phase is to generate a few possible solutions and to evaluate on possible benefits and drawbacks. A decision can then be made together with the client on which way to move forward.

4.1 Sequence

The order of completion influences the design of the toolkit. Participants can either be expected to go through the puzzles in order, or random, see *Figure 5* for a visual representation. The toolkit can be simplified if the participants solve the puzzles in order, since there is a set sequence, the toolkit ”knows” what puzzle will be next. This setup would also allow the puzzles to build on each other, making the progression more coherent. If the puzzles are set up as non-linear, to toolkit has to be able to track puzzle completion even if the order is completely random. The progression should still make sense, even though you cannot expect participants to have picked up certain knowledge at a previous puzzle.

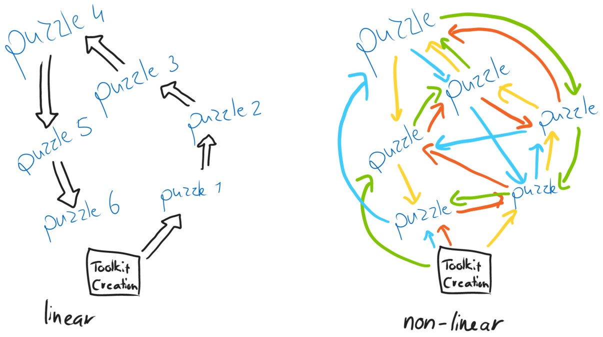


Figure 5: Linear setup compared to parallel setup

4.2 Difficulty

The target group is set to encapsulate the ages 8 up to 12. You cannot expect every 8 year old to have the same competences as a 12 year old, and both could still play together. The puzzles have to be designed so that they challenge all targeted participants. This can either be done by step-wise or continues scale. Step-wise (ease, medium, hard) would allow for easier development, since there are set difficulties that participants will activate at the start. Continues is more difficult, since there is not a clear division between difficulties, this make the development more complicated.

All participants need to be engaged and challenged. A family with one 8- and one 12 year old will probably set the difficulty to accommodate the 8 year old, this might be too easy for the 12 year old. Both can be challenged by having two difficulty variables, one min, one max. This would allow a group to set two levels. Both difficulties will then be present in the puzzles, parallel to, or alternating each other.

4.3 Colliding Groups

If two groups reach a puzzle at the same time, one can block the other from solving the puzzle. Puzzles have an activation/deactivation moment, which locks to a certain user. A participant needs to activate the puzzle by placing their toolkit on top of the puzzle, the puzzle gets deactivated once the toolkit is removed, allowing a next participant to repeat the sequence. By having the puzzles set up to be non-linear, participant will be able to move on the another puzzle and come back later to complete a previously occupied one. Another solution would be to have duplicate puzzles at each location, allowing for multiple group to work on the same puzzle parallel to each other. The amount of puzzles at each location would then be based on the amount of participants a certain host location draws.

4.4 Toolkit

The participants are required to partially assemble the toolkit themselves. This is done to encourage co-creation which will activate playful learning (Laakso et al., 2021). A base will be supplied to which a set amount of components need to be added. Firstly, a difficulty level has to be chosen, the sketch in *Figure 6* shows an implementation with a step-wise level system. Secondly, the participants can choose the story, this part will influence the framing of the puzzles. These stories are deemed out of the scope of this project, and will be developed later in the production process. Lastly, the battery can be connected, the participants can watch their toolkit come alive.

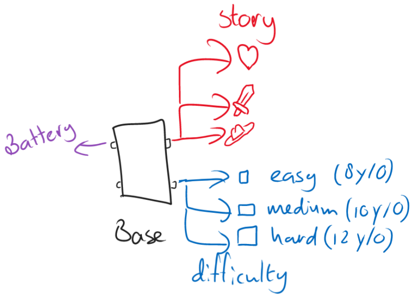
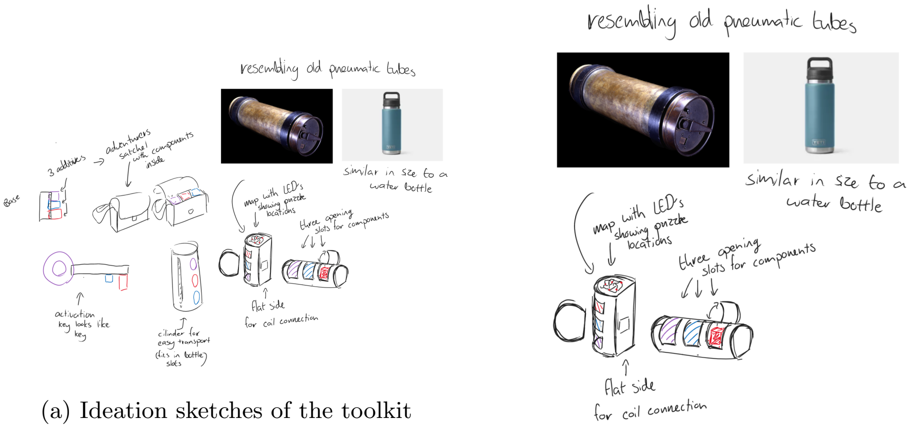


Figure 6: Schematic drawing of the toolkit assembly

A portion of the ideation sketches can be seen in the *Figure 7a*. The sketches all contain the same setup as the schematic in *Figure 6*. After trying different shapes and assembly methods, the sketch in *Figure 7b* was chosen to use as a base. Reason being that this design was made to resemble both a water bottle in size and a pneumatic tube in aesthetics. The size of a water bottle allows it to be easily carry-able, and most bags have designated pockets for water bottles, allowing for easy storage when moving from one puzzle to the other. The flat side is needed to allow for easy assembly and to allow for secure positioning on the puzzles, which is needed to activate said puzzles. There are three latches in the design, each latch houses one of the previously discussed components. Since these components are detachable, extra protection via a closing latch might prove necessary. During the ideation phase, the idea was thought up of including a map on one of the sides of the tube. This map is designed to look like the park the puzzles are in, and each puzzle is indicated on the map with an LED, which will light up, or turn off, upon completion.


resembling old pneumatic tubes
similar in size to a water bottle
Base
3 additives
adventurers satchel with components inside
map with LED's showing puzzle locations
three opening slots for components
activation key looks like key
cilinder for easy transport (fits in bottle slots)
flat side for coil connection
resembling old pneumatic tubes
similar in size to a water bottle
map with LED's showing puzzle locations
three opening slots for components
flat side for coil connection

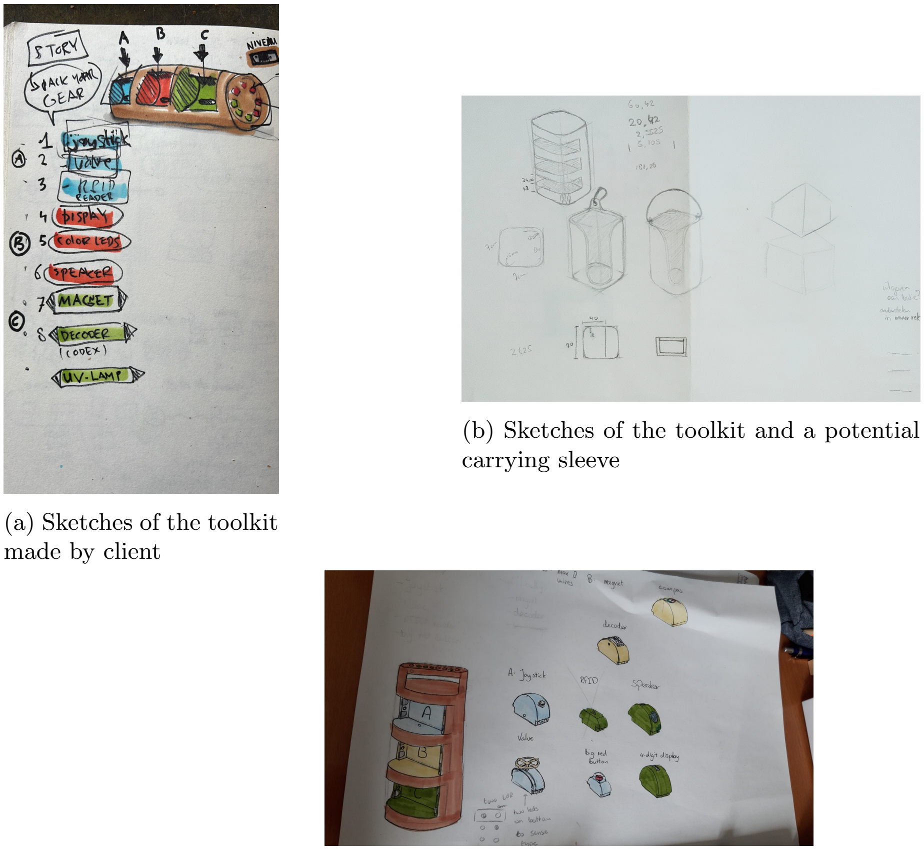
(a) Ideation sketches of the toolkit

(b) Sketches of the toolkit

Figure 7: Ideation sketches

4.4.1 Parts

After having a clear idea of what the toolkit housing will look like, designs for the separate parts can be made. Based on the toolkit design, resembling a water bottle, a footprint of 7cm by 7cm was decided on. The parts, as seen in *figure 8c*, will follow the general shape of the toolkit, they are designed to fit snugly into the slots in the toolkit. As the geometry of the toolkit changes through iterations, the shape of the parts will change accordingly. The parts are around 4cm by 7cm in footprint. Each part will house a different component, in *figure 8c* examples can be found for a few components. The parts will be sorted based on characteristics. The first group will contain actuators, the second group will contain passive components and the third will be used for feedback. The setup with examples can be found in *table 3*. The different sorted groups will be color coded, just as the slots on the toolkit. This is done to ensure that the parts will be properly connected and no extra logic has to be added to make every part suit every slot. Each slot will likely use a different connection method, to ensure that parts cannot be connected in a slot they are not supposed to. Parts will be held in using magnets and the addition of a sleeve will secure them even more.



(a) Sketches of the toolkit made by client

(b) Sketches of the toolkit and a potential carrying sleeve

(c) Sketches of the toolkit and a set of parts

Figure 8: More ideation sketches

4.4.2 Interactions

In discussion with the client, to possible assembly flows were discussed. The first option is that the components are chosen by the participant, so that they can influence the behaviour of the toolkit. This would require a clear overview

Group	**Purpose**	**Color coding**	**Example parts**
1	Actuator	Red	Joystick, Button, Valve
2	Passive	Green	Compass, Cipher
3	Feedback	Blue	Screen, Buzzer, Indicator LED

Table 3: Division of parts in groups with examples

of what influence certain components have, to make sure that participants can make an educated decision. The second option would be to let the participant choose their story and difficulty in a companion program, which then will point them to what parts they need for their toolkit. The second approach would allow the assembly of the toolkit to already be part of the story line.

A detailed interaction flowchart of the first setup can be found in *figure 9*. This chart shows interactions the user has and a global communication setup between the toolkit and the puzzles. This flowchart considers the parts to influence the story and difficulty, instead of the story choice deciding the part. This was changed to the latter option later on.

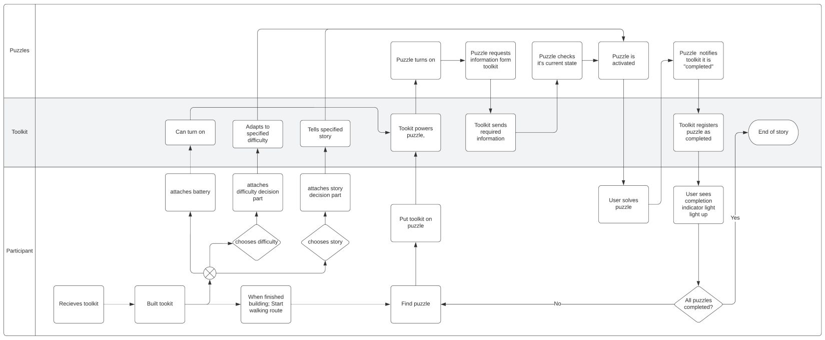

Puzzles
Toolkit
Participant
Recieves toolkit
Built tookit
When finished building; Start walking route
attaches battery
chooses difficulty
chooses story
attaches difficulty decision part
attaches story decision part
Can turn on
Adapts to specified difficulty
Tells specified story
Find puzzle
Put toolkit on puzzle
Tookit powers puzzle,
Puzzle turns on
Puzzle requests information form toolkit
Toolkit sends required information
Puzzle checks it's current state
Puzzle is activated
User solves puzzle
Puzzle notifies toolkit it is "completed"
Toolkit registers puzzle as completed
User sees completion indicator light light up
All puzzles completed?
No
Yes
End of story

Figure 9: Flowchart showing interactions between users, the toolkit and the puzzles

4.5 Toolkit-Puzzle Communication

The communication between the toolkit and the puzzle only has to activate once the toolkit comes into contact with the puzzle. There is no need to have permanent communication running. The communication can be handled over WiFi, in a similar setup as smart home systems. But this would mean that the toolkit would have to host it's own network, since there is no feasible way of setting up a WiFi network in a park. This would add more expenses and complexity to the product, which makes other solutions more attractive. A very basic solution would be to just have a serial cable (USB-A for example) hanging from the toolkit, which you can plug into a puzzle to start interacting with it. This, however, would add a very breakable part, the cable, to something that has to go outside and be moved around a lot. In addition, ports can fail due to collected dust and debris blocking of connection points. Another solution would be to use pads on the bottom of the toolkit, that connect to pads on the puzzle. This does again suffer from possible breaking due to debris. But since this is just a flat area, it is easier to keep clean, and an automated cover can be implemented to keep the puzzle pads clean in between uses. This cover would then be spring loaded, you push it aside with the toolkit when you want to activate the puzzle and it slides over the pad when the puzzle is removed. The best solution would be a full wireless connection, using a combination of magnetic relays, a wireless charging pad and NFC, the whole communication range should be covered. This is also the most complex and time consuming solution to implement, so it might be necessary to leave this as a possible future development.

4.6 Education

The educational portion has taken a back seat during ideation. Participants should not spend too much time on building, since the assembly of this toolkit is just a small part of the whole experience. So it was decided to have simple assembly parts which can be assembled in around half an hour. This leaves enough room for the actual adventure; finding and solving puzzles. Participants will need to pick the right components from a selection, via the story they can be thought about the influence certain parts have. In a discussion with the client a setup was prompted that entailed an inventor asking the participant for help. He made some mistakes with his time machine meaning that certain things were transported to a time they are not supposed to be. Depending on when they choose to investigate, the part-choice will change. By having this inventor as a guide, the story can contain educational elements about the behaviour and functionality of the parts. But the assembly process has mainly been reduced to an opportunity to create a bond with the toolkit, since it is something that they built by themselves.

4.7 Story Implementation

Studio-No-More-Mondays, 2023 uses a story application for some of their products already. This application allows for story progression via certain checks. This allows it to be perfectly suited for an application in this project. Each puzzle will then output a certain code that they can fill in on their story app which will advance the story. The application has to be slightly adapted to be suited to the non-linear setup of the project, but a simple duplicate check should ensure that participants do not repeatedly enter the same code.

The story can be used to guide participants during the assembly of the toolkit, next to the logical advancement of the story based on puzzle completion. Having the assembly be part of the story will create a more complete experience, instead of assembly and puzzles be completely different parts, having the overarching story will make it feel like a singular complete experience.

4.8 General Flow

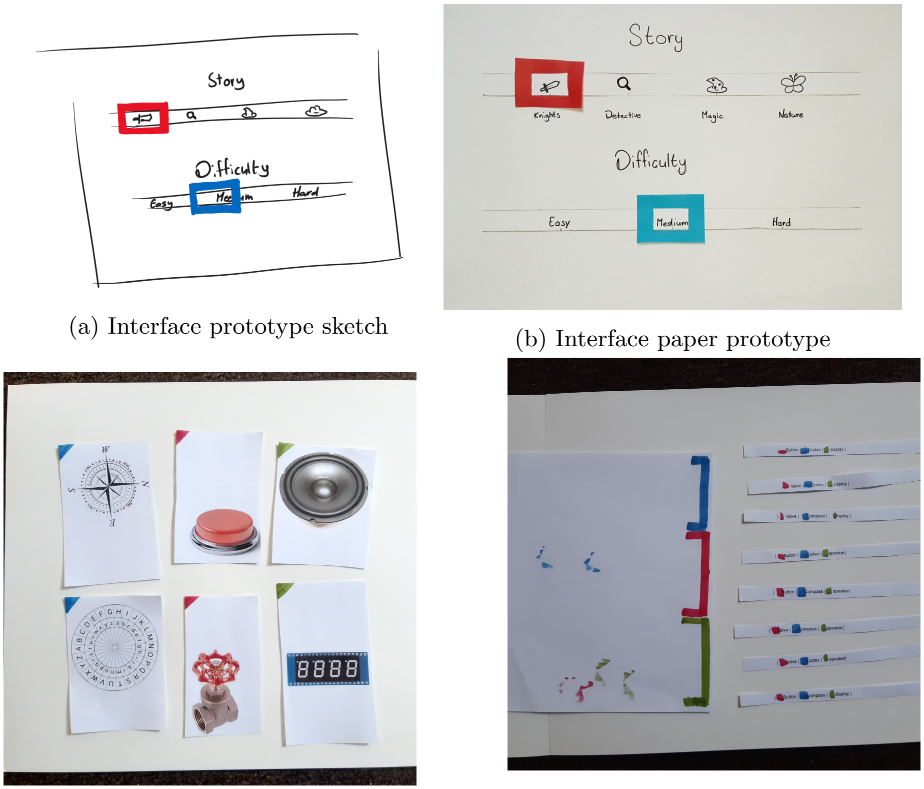
The general flow of the experience shows the steps participants have to take to go from purchase to puzzle. Firstly, participants will order a ticket, either online on at the counter, probably depending on host. With that ticket they will be able to start a story and receive a toolkit at the counter of their chosen host. They can then follow the story application to fill in their desired story theme and difficulty. This will produce a unique code which they can hand in at the counter to receive their desired parts. They can then assemble the toolkit by connecting the parts in the right slots. It would be nice to have a first "check" station present in the assembly room for participants to check the toolkit before they progress with the story, to see if it functions as expected. After a pass for this check they are free to go search for puzzles.

5 Specification

5.1 User Test - Proof of Concept

The goal of this first user test is to validate the concept and test-setup. The concept has to be validated to ensure that all design decisions seem to work as they are expected to work. The test-setup has to be validated to check if everything is clear and works accordingly, since everything has to be as clear as possible for when the prototype is eventually tested on children (ages 8 to 12).

Test Setup Since the main goal of the first user test is to validate the concept, it is not necessary to test with the target group. This test is performed on university students to get a feel for the flow of the activity. It will be performed by utilizing a "pen and paper" prototype. This method allows the prototype to be quickly adapted in between tests if the need arises. The test will focus on the interface, in which users will decide what story and difficulty their experience will contain. The sketch and pen and paper prototype can be found in *figure 10*. The red and blue borders can slide back and forth between the different selection options. After the user has made their selection, this paper will be traded for a corresponding list of components which they then have to collect. The components are be represented by paper print-outs of the parts **??**, these parts are be color coded, so this is also represented in the print-outs. The will be no physical assembly performed with the participants at this stage. The main points of interest at this stage are the flow of the activity; is everything clear and logical, and the overall experience. The flow was measured by observations during the test. The experience is reviewed via a survey consisting of 8 Likert scale questions (see *appendix A*). Consent is asked orally, since the data will not be traceable to the participants, and overview of the relevant notes given to the participants before they are asked to consent can be found in *appendix B*.



(a) Interface prototype sketch

(b) Interface paper prototype

(c) Parts paper prototypes

(d) Toolkit and prompts from the paper prototype

Figure 10: Paper prototype for the interface used in proof of concept user test

Results The user test was performed on fellow students. Participants received a short project introduction and were then asked to start the mock-up assembly process, as shown in *figure 11*. Everyone understood the interface immediately, sliding around the sliders to their desired selection. An interesting note is that everyone chose ”magic” as story theme, so it might be good to test story themes with children before developing the stories, would be a waste of resources to develop a story that no-one eventually chooses. After showing the interface to the researcher and receiving their part prompt back, participants set out the collect their parts in the toolkit. 60% of the participants picked the wrong place for the first part. The order of the prompts was intentionally different than the order in the toolkit. Since you cannot control the orientation they assemble the toolkit in. The first part was always put on the left side of the toolkit. When picking the second part they would notice that the first part was in the wrong color box, and move it over. One participant assembled the toolkit with the wrong parts, but with the colors in the matching location. Later admitting to be curious to see what would happen.

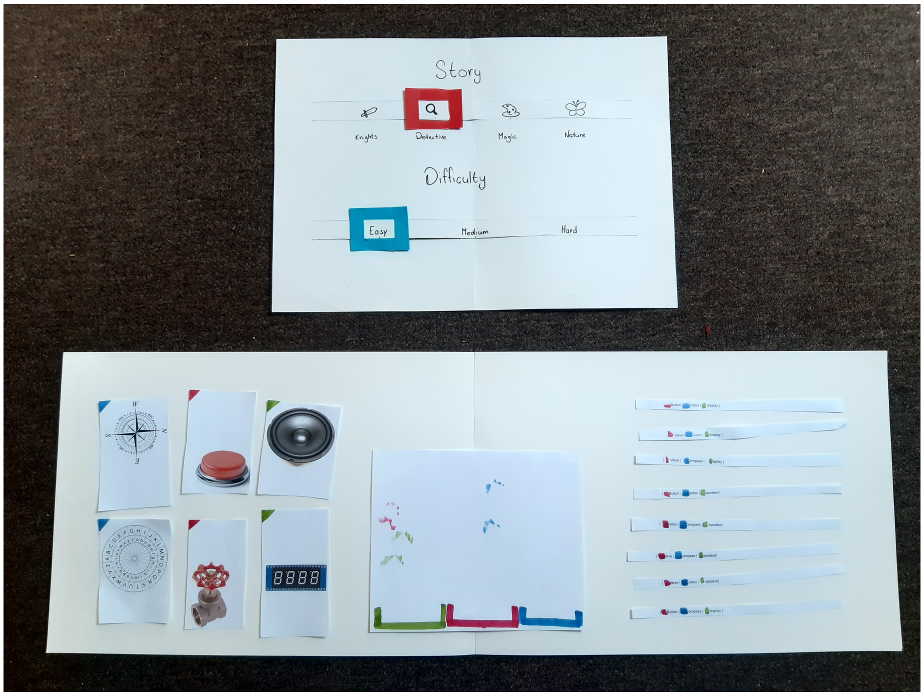


Figure 11: User test setup

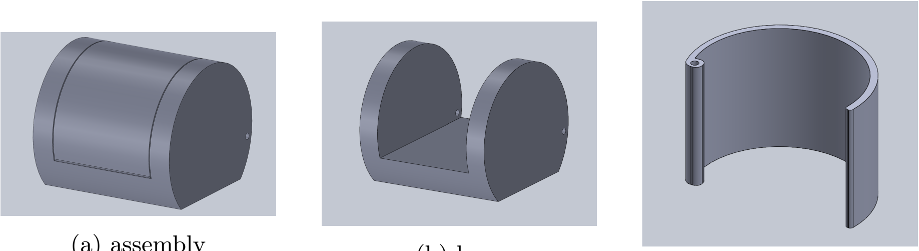
Based on the survey participants filled in after completing the test (*Appendix A*), a few conclusions can be made. Participants generally understood what was expected of them and felt like they understood the interface. Not everyone understood why they had to pick certain parts, but having this story guided should bring more motivational elements to the assembly. Not everyone expected different parts to change the behaviour of the toolkit, but this questions had to be clarified to a few participants, so the more average answers could be caused by an unclear question, most people did however expect the parts to have influences beyond just a different look. Participants felt it was clear where they had to put the parts in the toolkit. All of the participants expected the target group to be able to complete this assembly process and would have enjoyed such an activity when they were target group age. A few extra notes that were given enforced earlier observed elements, with one participant noting that it would be helpful to have the order of the prompt be the same as the order of the toolkit slots, and another participant noted that they felt that there was no direct impact of their choices in the current setup.

5.1.1 Improvements To Be Made Based On The User Test

Based on the user test, it was found that the color need to be clearly present for people to instantly match parts to it. In the test the colors were just given by lines and colored corners. For the actual prototype, the parts will be fully colored in their reference color. The toolkit will have the slots fully colored, but also a line around the slots. This is to ensure that you can still see the slot color, even when there is a part inserted in that slot. The inclusion of a story will be able to improve the parts with the lowest scores. Having a story to guide users though the assembly process allows the user to gain more insight on the functionality of the different parts they have in their toolkit. This will help expectations around behaviour of the toolkit and give reasoning about why these parts are important.

5.2 Prototype 0.1

The first prototype was based on the sketch shown in *figure 7b*. This model was made to be cylindrical with a flat bottom, *figure 12* shows pictures of the 3D models and *figure 13* shows the 3D printed prototype. Since this was a first try of the mechanism, just one section was printed where the eventual product will have more. The hinge was designed to rotate around a piece of PLA filament which was molten to the base. The hinge mechanism would allow the parts to be placed inside of the tube and secured by closing the hinge. This would prevent the parts from falling out during play. In discussions with the client, it was decided to not further develop the hinged system, since this would add more possible points of failure to the design, with the hinge being a possible weak point.



(a) assembly

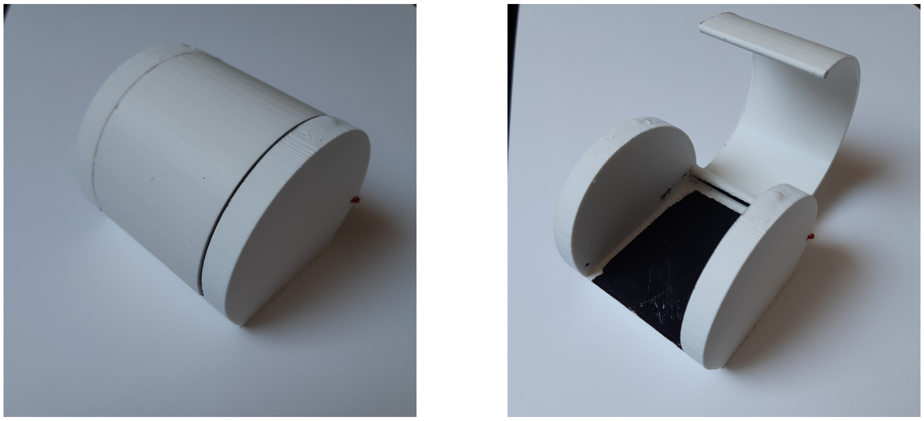
(b) base

(c) lid

Figure 12: 3D model of the hinged protoype

5.3 Prototype 0.2

In discussions with client it was decided to leave out the hinge, and to change the design of the box to match the current product line of Señor Sensor, 2023. A new 3D model (*figure 14*) was made and produced. This resulted in the prototype as seen in *figure 15*. The living hinge went through three iterations



(a) Closed

(b) Open

Figure 13: 3D printed prototype with hinge

before it worked as designed. The first file had the cut lines way to far apart, resulting in immediately breaking, this mistake was noticed by the technician preparing the files for production. Then a second setup opened up the slots a bit more, to allow the wood to move inward, instead of use itself as a hinge to break itself. This version was able to bend, but it was not able to reach the desired 90 degrees before breaking. The third version, as seen in *figure 15* worked according to plan. This is still a third of the actual size of the product. This one element houses a single part. This element three times stacked on top of each other will be able to house three parts and should be close to the final outer enclosure of the product.

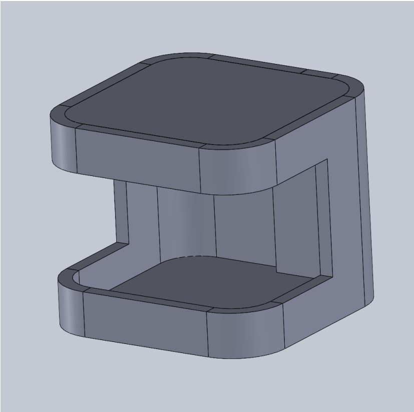


Figure 14: 3D model prototype 0.2

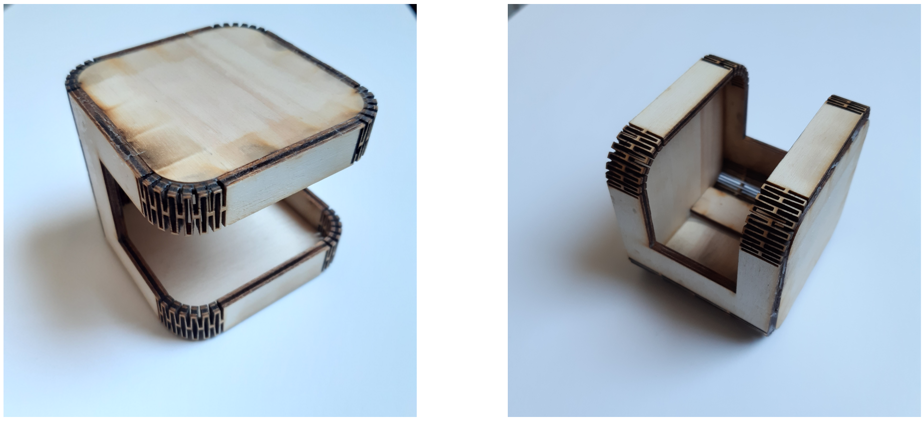


Figure 15: Laser cut prototype

5.4 Prototype 1.0

Based on the model shown in prototype 0.2 a larger version has been made. This new complete model has a footprint of 7cm by 7cm and stands 23 cm tall (as seen in *figure 16* which fits in a standard water bottle holder. The dimensions of the slot separators have been slightly altered when compared to the smaller design to give them a bit more strength. Even though not visible in the 3D model, some structural braces have been added to ensure the strength of the bent corners. Each component consists of a bottom shell and a cap. The insides are adapted to suit the different designs.

Each of the parts has a dedicated resistor that can be used to read out what part is connected. Based on this resister value, a distinction can be made between different components, and new components can easily be added. This results in a more flexible setup than having a physical distinction. An actuator part (red) will have five connections (GND, +5V, ID, D1, D2). With GND being ground, +5V the positive line, ID the identification signal and D1 the input data line. A passive part will have just two connections (+5V, ID) since these components are passive in functionality, the only connections needed are for part recognition. The feedback part will have 5 connections (GND, +5V, ID, D1, D2), this slot will thus allow for elements that need two data channels to work. All parts will be able to share their respective GND and +5V connections, but the ID and data connections will be connected to unique pins on the ESP.

Actuators The actuators chosen to develop into the prototype are a button and a rotary encoder (valve). The red button will be used to trigger certain events that otherwise might need a more complicated input. This button can also be used to input Morse code or can be used to count when paired with the 7 segment display. This part will need 5V to power the button and the recognition signal. The outputs will include the trigger output (D1) of the button, and the

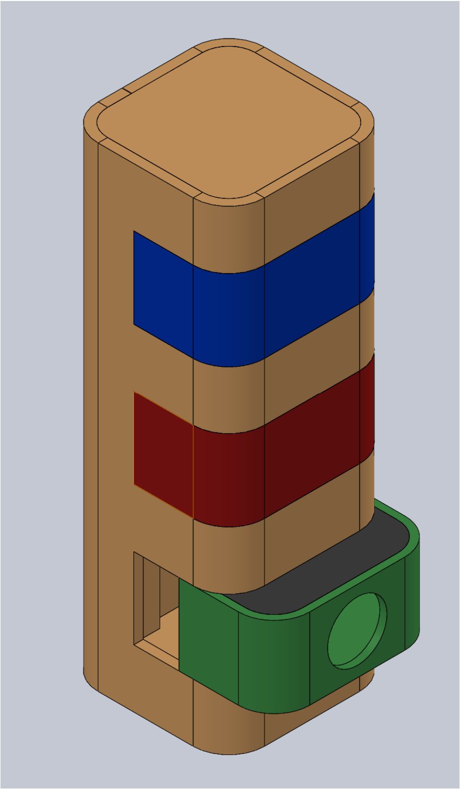


Figure 16: Solid Works model of the toolkit with color coded empty parts

identification signal (ID) of the part. The rotary encoder will use the same setup, but it needs more pins, since a rotary encoder needs two outputs. On of these outputs will be guided to D2, D1 will be used for the other encoder signal. The other connections are utilized in the same way as for the button. The rotary encoder can be used as valve, as a safe lock and even as a directional controller.

Passive The passive parts need just two connections, to be able to identify which part is connected. The parts chosen to be developed are the compass and the cipher. The compass will be an element with a compass embedded into it. It can be used to determine the direction in regard to the horizon, or can be used to check for magnets. The cipher will include a movable ring with the alphabet on it, with a numbered ring on the inside. This will allow participants to solve certain riddles more easily with this part. You can write a number code that can then easily be translated into letters. The cipher can also be used to read out scrambled letters into a code.

Feedback The feedback elements will include a part with a 4 digit 7-segment display one with a buzzer. The buzzer needs just one data pin, so using just D1 will be enough to provide sufficient control. The other pins will be the standard 5V for power, GND to ground the circuit and ID to identify the part. The buzzer can be used to give audible feedback to certain tasks. When paired with the rotary encoder it can give feedback on positioning, it can also be used as a motivational element. Playing a happy tune each time a puzzle is completed. The 7-segment display will probably need more pins, but there are LED driver boards available that allow such a display to be controller with just one data pin. The standard +5V, GND and ID will be used as in the other parts. For now, it is expected that the display will need just one data pin. The display can be used to display codes, hints and feedback, and it can also be used to keep previously solved puzzle segments available.

Circuitry Setup The circuitry is centered around an ESP32. This esp needs to be able to connect and interface different parts, so the circuitry needs to be suitable to accept these different possible connections. This was accomplished by designating a distinct ”ID” connection for each of the three parts (ID_A (actuators), ID_P (passive), ID_F (feedback)). Based on the input received on these pins the relevant code will be activated. Each component also needs a +5V and GND (ground) connection, even the passive components, since these connections are needed to generate the ID value. The ID value is controlled via a voltage divider inside the part. The maximum needed data connections is 2, for the 7 segment display and for the rotary encoder. So both the actuator and the feedback slots need to be suitable for two data connections. A schematic can be found in *figure 17.*

Programming Structure The programming structure will be centered around a main class, in which functions to check what components are present are called. Based on this information certain functional classed for the targeted parts are activated or de-activated. When interacting with a puzzle, the identifications of the parts will be shared with the puzzle, based on which the puzzle will be able to control the parts. This communication is done via a separate class that gets activated once puzzle contact is established. The puzzle then activate a part in a certain display mode for the feedback elements, or wait for feedback from the actuator elements.

6 Realisation

After ideation and specification, it is now finally time to delve into the realisation. This chapter will go into the design process of the eventual prototype as it was used in the final user test shown in the evaluation chapter. Each of the different components' design philosophies will be explained and visualized via snapshots of relevant 3D models and physical prototypes.

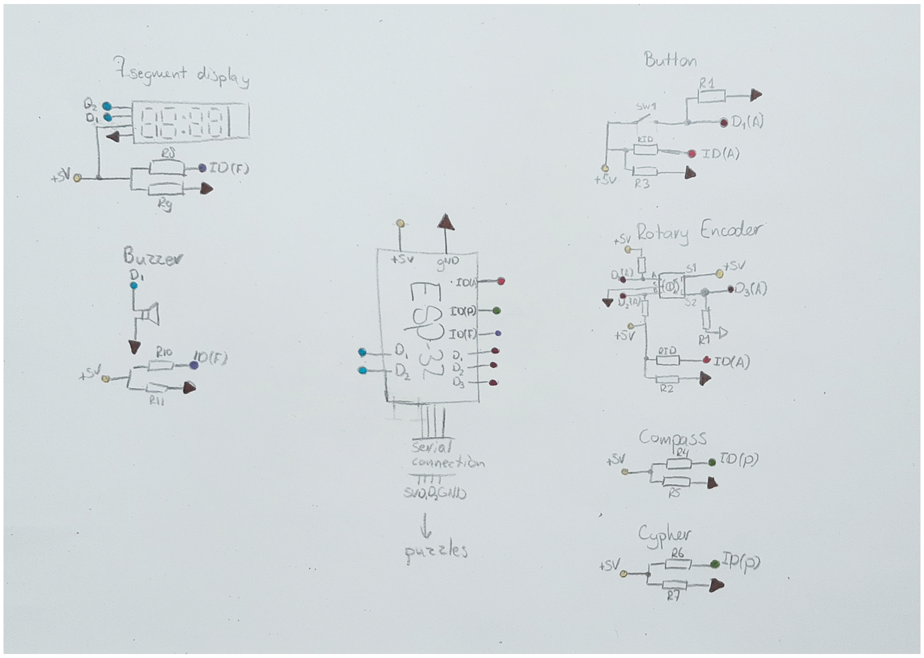
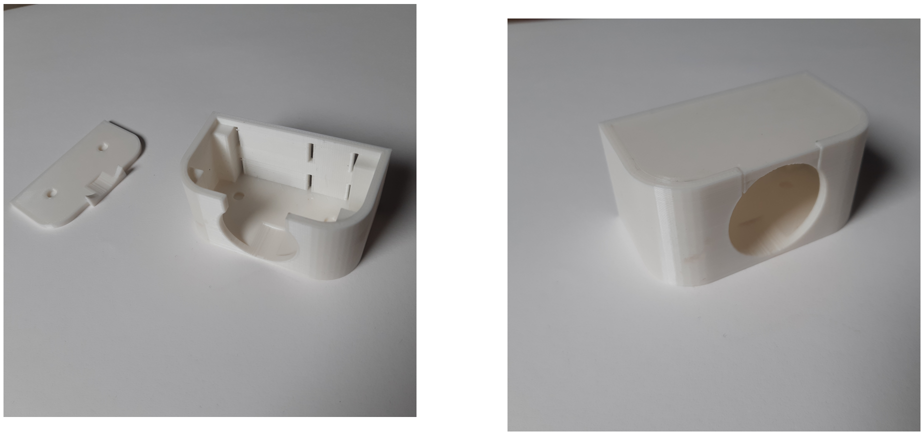


Figure 17: Schematic representation of the circuit

6.1 General Element Construction

All elements consist of a ”base” and a ”cap”, as can be seen in *figure 18a*. The cap is pushed into the base and snaps into place. No screws are needed to keep the cap in place. Holes were created in both the base and the cap where magnets will be pushed in, these magnets are again fastened through force. The back of the base has slots through which connections can be made towards the connection points that will be placed on the back of the base. There is also a guiding slot, which is visible in *figure 19*. This slot in the bottom of the element is there to help guide the part in place. The insert (*chapter 6.2*) has the male version of this same slot. Every part has their own design features to keep the designated electronics securely in place, these will be elaborated upon later on in this chapter. The element used in *figure 18* is an early prototype of the button element, this version did not fit the button correctly and the guiding slot was too small, so it had to be redesigned. Since there are just two elements developed per classification for this prototype, no voltage dividers were implemented in the identification circuit. One element connect straight to 5V, the other to GND.

Button Element The 3D model for the button element can be found in *figure 19*. The button element was designed around an arcade button which was 3cm in diameter. The hole in the front of the casing is large enough to push the button in and have it sit tightly in place without the need for any



(a) Cap (left) and base (right) of an element

(b) Assembled element

Figure 18: Button element first prototype

other fasteners. The button was however slightly too large to fit inside with the standard wall thickness, so the circular cutout had to be extended into the bottom and top walls. The slots on the back of the element are meant for connecting the connection points through to the electronics inside the element.

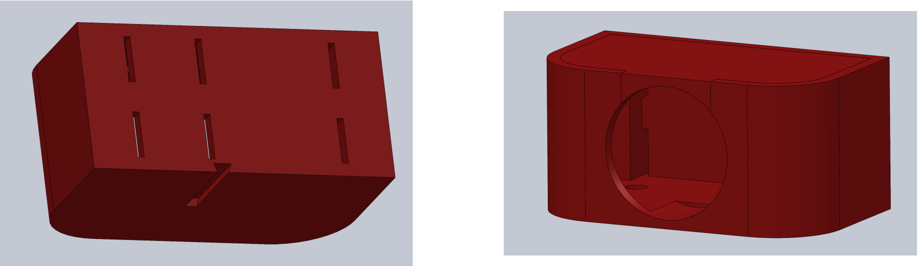


Figure 19: Button element final 3D model

The eventual physical prototype (*figure 20*) was 3D printed and painted red. For paint a generic spray lacquer was used. The inside of the element can be found in *figure 21*. The button was pushed into the bottom part and is held in by two compliant springs built into the button. There is a physical pull-up resistor soldered in between the button signal and 5V. All wires are connected to the corresponding pads on the back of the element.

Rotary Encoder Element The rotary encoder element (model in *figure 22a*) was designed to fit a EC16E20-24P24C switch encoder. This encoder has a locator tab for which a cutout was designed into the cap. This made the cap too thin and it broke. So for a re-design this locator pin cutout should be moved

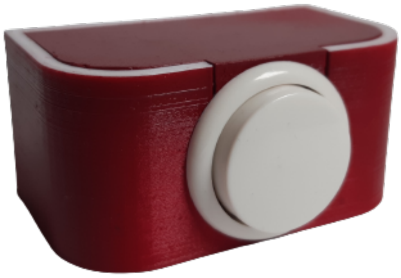


Figure 20: Final button element

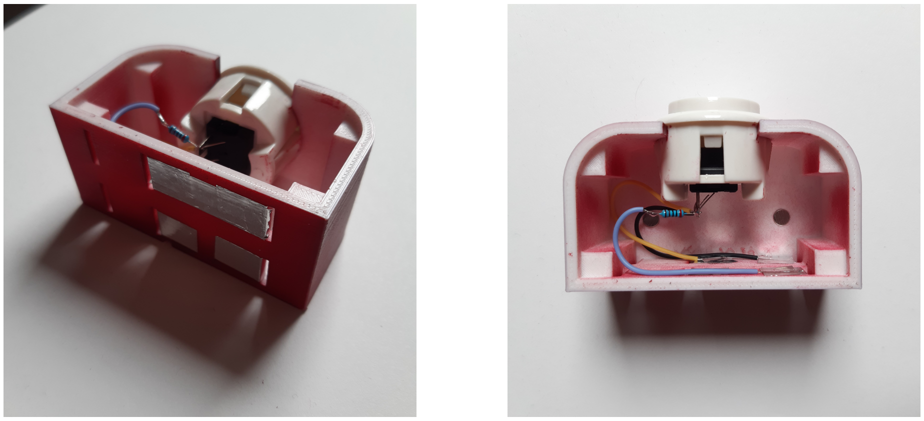
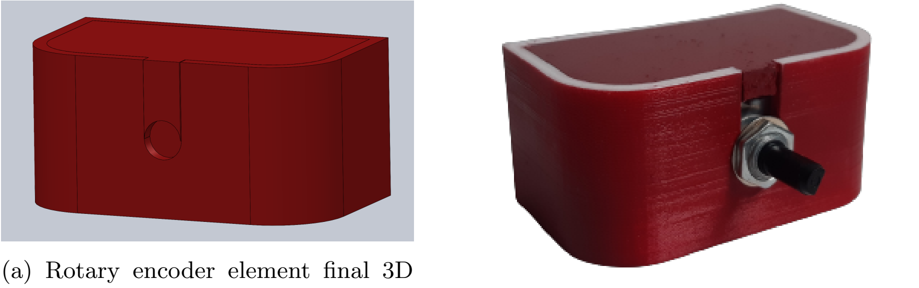


Figure 21: Button element opened

to the base, since this part has more structural integrity. The encoder was attached by tightening a nut and washer on the threaded shaft of the encoder. In every other physical aspect this element is the same as the one used for the button, since only the front of the element need to be adapted to fit a new part. The model was painted using the same paint as the button element. The corresponding connection points were connected (*figure 23*) to the rotary encoder according to the schematic provided in *figure 17*.



(a) Rotary encoder element final 3D model

(b) Final physical rotary encoder element

Figure 22: Final rotary encoder

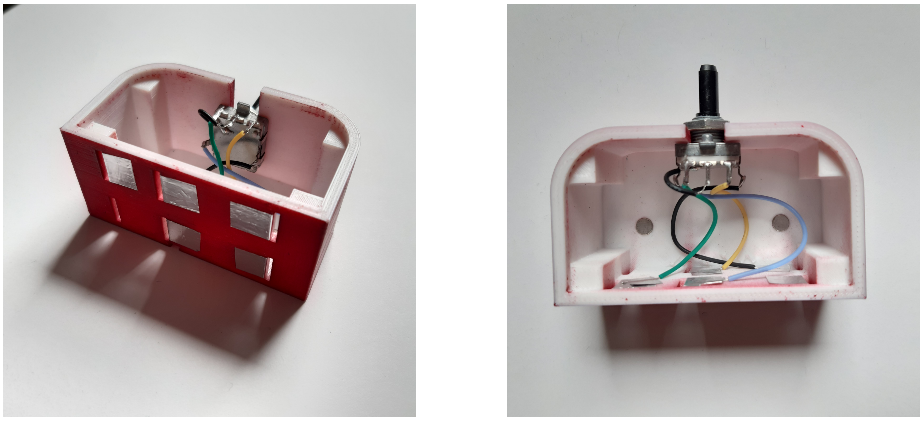
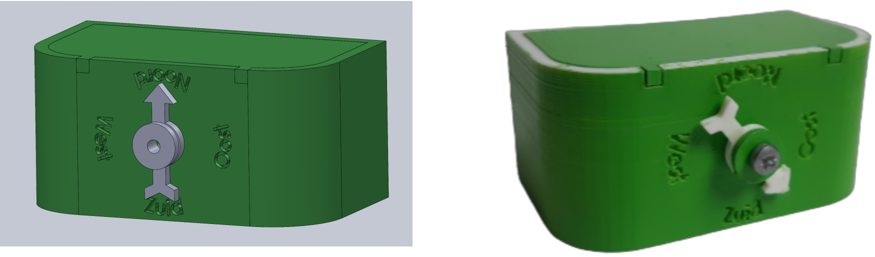


Figure 23: Rotary encoder element opened

Compass Element The compass element was meant to house a real working compass, but due to shipping issues and tight deadlines, this idea was put on hold. An alternative was designed using an arrow that can be moved by the user. The base has indentations spelling out ”noord” (north), ”oost” (east), ”zuid” (south) and ”west” (west), as can be seen in both the 3D model (*figure 24a*) and the physical prototype (*figure 24b*). The text is in dutch, since this product is being developed for a dutch company who’s target group is dutch children. The arrow extension consists of two 3D printed parts. A bushing, and the arrow itself. The busing is tightened to the base using a 3M bolt and nut while the arrow is fitted around the bushing. The busing has a varying diameter, the smaller side allows the arrow to spin, whilst the larger side is big enough to hold the arrow assembly together. When looking at *figure 25* it is clearly an empty box. Since this is a passive component, the only electronics needed would be for identification purposes. As earlier discussed, in the current prototyping setup, there is no need to use voltage dividers in the identification circuit, since only two parts will be developed per segment. This allows the identification to work with just 5V and GND.



(a) Compass element final 3D model

(b) Final physical compass element

Figure 24: Final compass

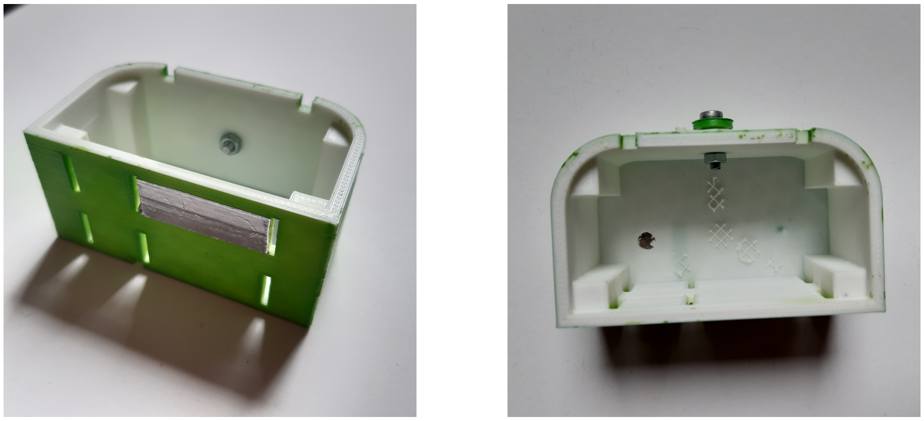
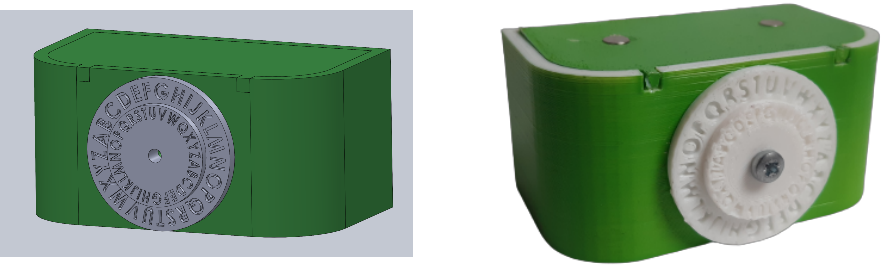


Figure 25: Compass element opened

Cipher Element The cipher element (*figure 26b*) was constructed using the same methods as the compass. The cap and base are the exact same design. The outer wheel is attached using the same method. The smaller wheel is bolted to the base using a M3 bolt and nut, and the bigger wheel spins around this smaller wheel, and is held in place by it. The wheel was inspired on a Caesar wheel, but the design is not fully functional. The spacing between the letters is not equal, the ”W” takes up more space than the ”I”. Every two letters need to have the same spacing between their center points. So this requires some redesign to be fully functional, but it is sufficient for the purpose of this prototype. There were also some printing issues with this part, that is why this is the only constructed element to show magnets on the outside. The 3D model (*figure 26a*) does have the magnet holes constructed on the inside. This element is empty, no connections or electronics, as can be seen in *figure 27*. The same reasoning as given for the compass element holds here. The passive components do not need any connections, and due to the setup of the prototype, no voltage divider was needed to get the identification resolution high enough.



(a) Cipher element final 3D model

(b) Final cipher element

Figure 26: Cipher element

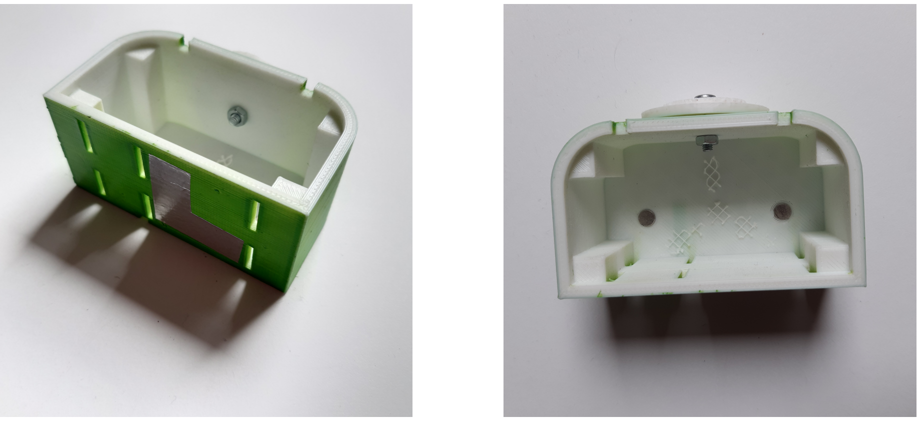
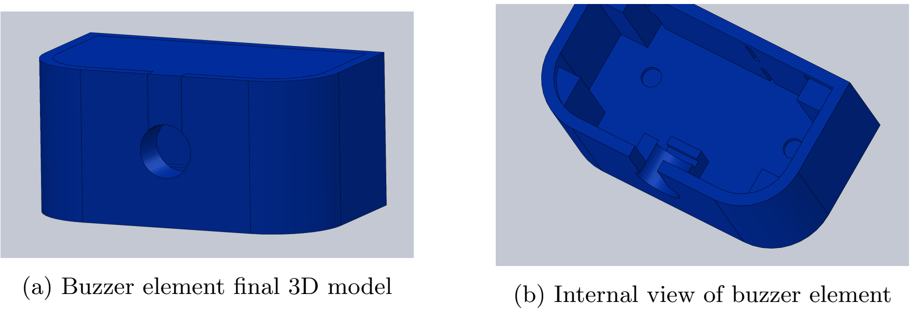


Figure 27: Cipher element opened

Buzzer Element The buzzer element was designed to fit a generic buzzer board. Geometry was added on the inside of the element to be able to snap the board in. This extra geometry can be seen in *figure 28b* and in *figure 30*. This allowed the buzzer to be attached to the base without the need for any assisting fasteners. The The part itself was again wired up with each pin from the buzzer connected to the corresponding connection pad. The board that is attached to the side in *figure 30* is a ground and positive bus. Both the buzzer and the identification signal share ground and +5V via this board. The final buzzer element is displayed in *figure 29*



(a) Buzzer element final 3D model

(b) Internal view of buzzer element

Figure 28: Buzzer element final model

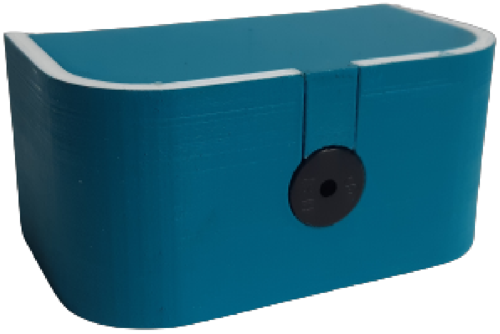


Figure 29: Final buzzer element

7-Segment Display Element The 7-segment display element was designed to fit a 4 digit LED display with an embedded TM1637. This chip allows the ESP to control the display through just two data lines, instead of having to control each LED individually. This also allows this element to connect just like all the others, since if it needed (4 digit x 7 segments) 28 individual connections

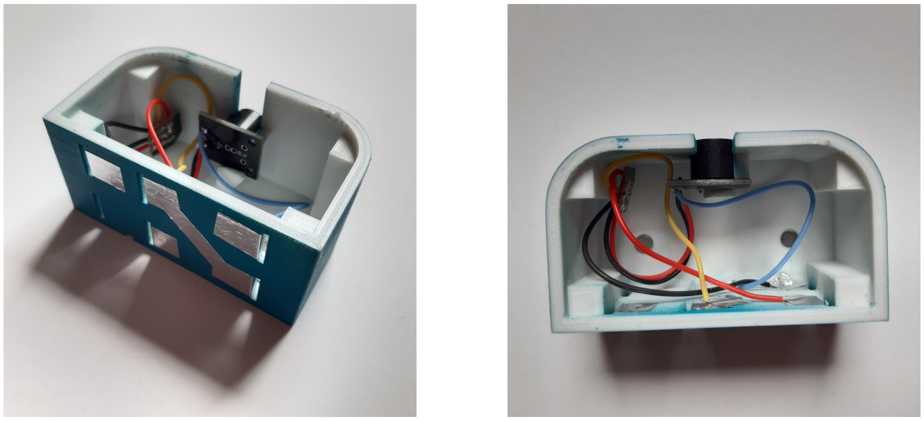
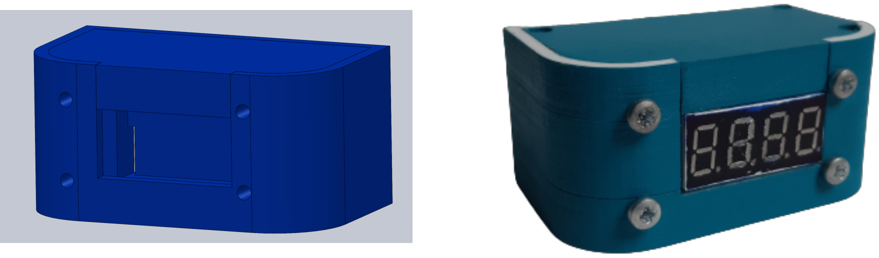


Figure 30: Buzzer element opened

it would not have fit within the current modular connection setup. This was the first model (*figure 31a*) to be designed, so this is the only element that needs bolts to attach the component. Redesigning this element in such a way that the screen is held in through geometry is recommended, since then it would fit the aesthetics of the other elements better. The top view (*figure 32*) also shows some screw holes, these were removed for all the other elements, since the cap was held in perfectly without these screws.



(a) 7-segment display final 3D model

(b) Final 7-segment display element

Figure 31: 7-segment display element

6.2 Insert

The different elements all have a designated slider slot, this geometric is hard to match with a wooden piece, so a 3D printable insert for inside of the wooden enclosure was designed. This insert would give the wooden outside some extra structural integrity, and allow the components to have a smooth surface to

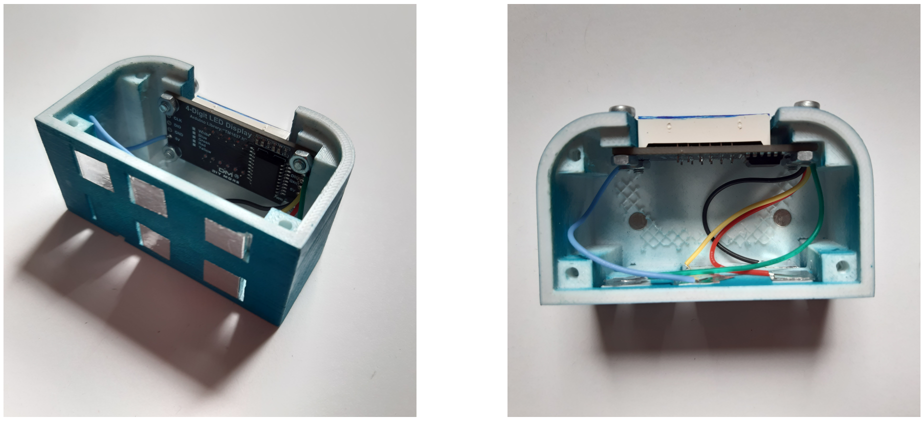


Figure 32: 7-segment display element opened

slide against. Having this 3D printed insert also allows for the slider slot to be matched. In *figure 33* the first trail for this part can be viewed. This print showed some weaknesses in the design. The gaps where the element would slide in were slightly too small and the infill was too low, this caused the walls to be too weak and break when trying to insert an element. For the final version (*figure 34*) the gaps where the elements should fit were increased by 1mm, so that inserting a part would not put stress on the walls, and the infill was increased from 10% to 20%. The slots were perpendicular to the walls in the first version, matching the slots on the elements. These were changed to parallel (*figure 35* since this would be easier to construct a spring mechanism around. Other additions in the final version were the removal of one of the end walls, since this gap would fit a 9volt battery perfectly, a little notch was added to accommodate for the wiring. On the other end, a circular cutout was added where a led-ring will be embedded into the 3D print, this cutout did accommodate for the wiring needed to make the LED-ring work. The gaps in between the walls where no part would be inserted were made to decrease material usage. Every wall has two holes where magnets can be pushed in, these magnets align with the magnets embedded inside the elements and should help the elements stay in place. The guiding rails shirt 5mm for each slot, this is matched on the parts. Through this 5mm shift, parts do not fit properly into slots of a different color.

6.3 Wooden Structure

The wooden enclosure is made up out of three parts. The top , the surrounding walls and the bottom. The top (*figure 36b*) is a wooden piece of 6.4 by 6.4 cm with rounded corners and a ring of cutouts for the LED's of the LED ring that will be attached right under. The bottom is the same piece as the top, but then without the cutouts for the LED's. The surrounding walls are made from a flat

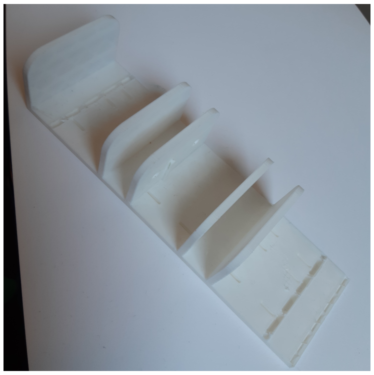


Figure 33: Insert first 3D print

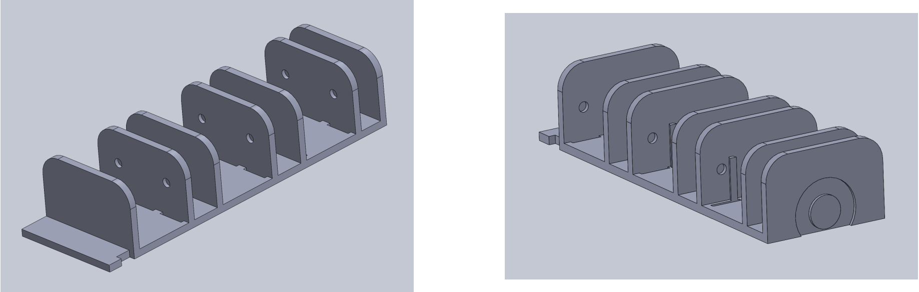


Figure 34: Insert final 3D model

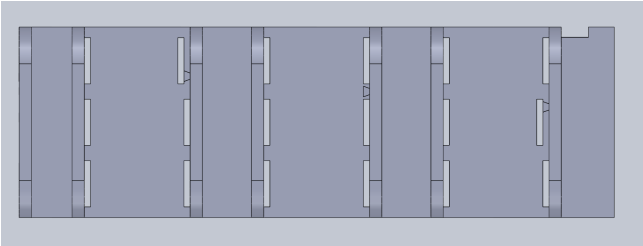
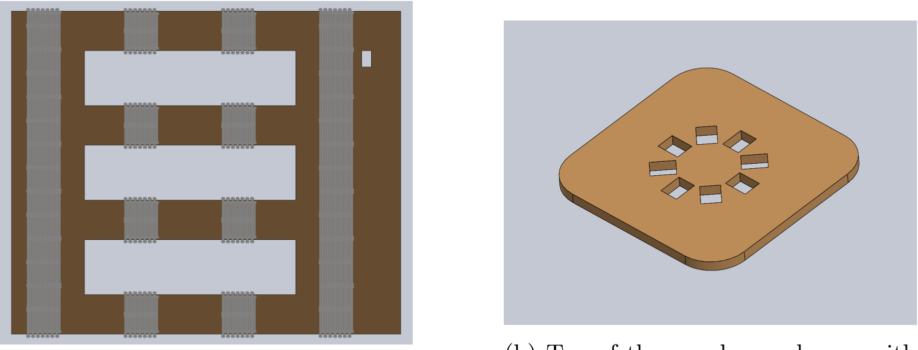


Figure 35: Insert final 3D model face view

piece of plywood that is cut is such way that it can bend. The cutting pattern can be seen in the flattened model in *figure 36a*. The scored (grey) parts of the flattened model will be able to bent into the shape displayed in *figure 37*. Since the walls next to the opening for the elements to slide in proved too weak in the smaller scale test of this prototype, the walls were increased in size for this prototype. There is one more cutout on the back of the enclosure, this will house a small on/off dip-switch to be used for prototyping purposes and to turn on/off battery power.



(a) Flattened model of the wooden enclosure

(b) Top of the wooden enclosure with holes for LED ring

Figure 36: Wooden enclosure models

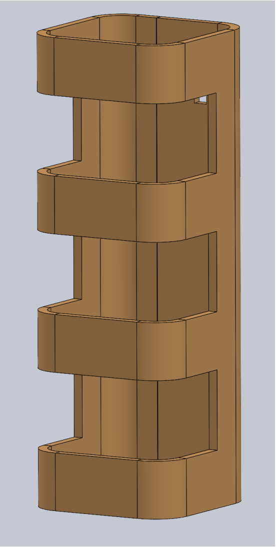


Figure 37: Folded 3D model of the wooden enclosure

6.4 Final Assembled Prototype

When adding all the previously discussed components together, the result should look something like the model in *figure 38*. This figure shows the assembly file of all the parts. The wooden enclosure, the insert, and three parts. For this model, the parts that were enabled are the 7-segment display element, the compass element and the button element. All models were colored corresponding to their eventual material and/or paint layer.

After manufacturing, the toolkit was assembled. The wooden top was glued

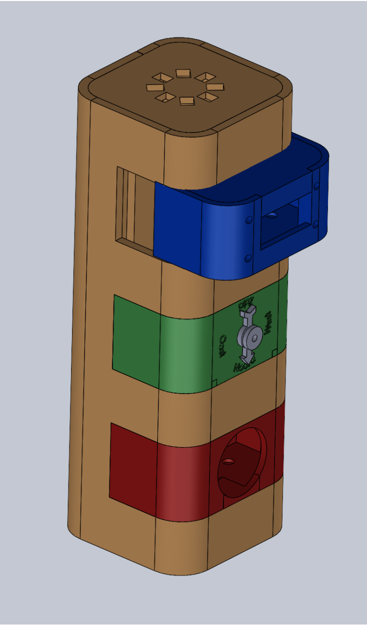
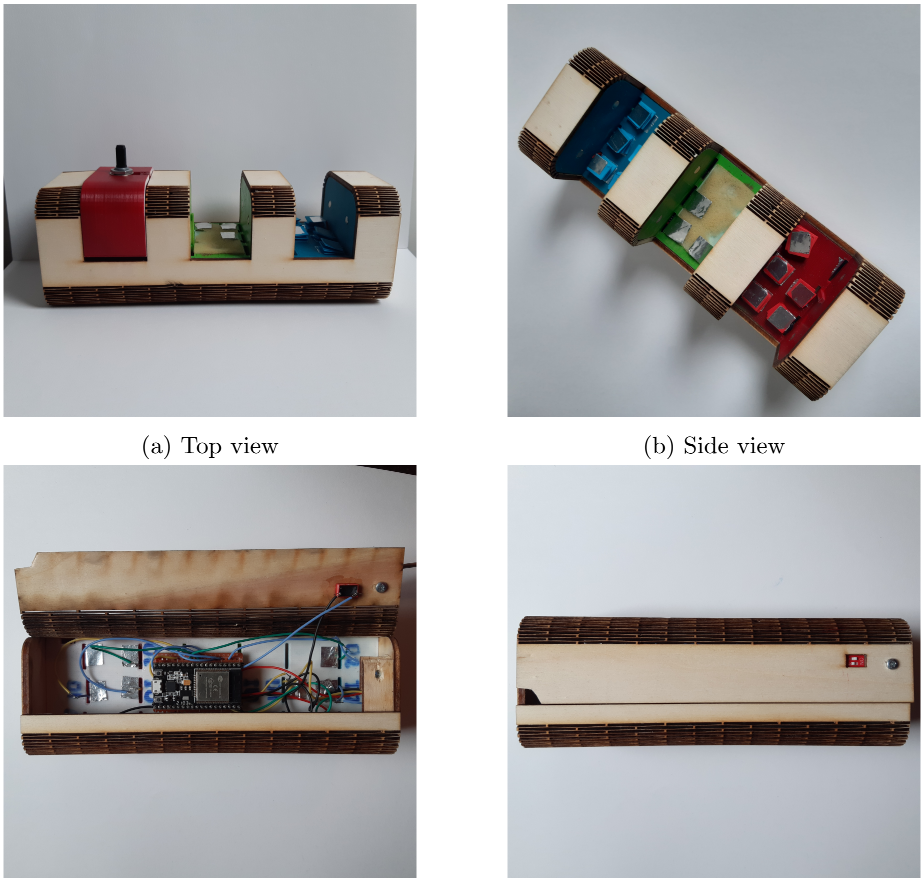


Figure 38: Final assembled 3D model

to the insert with the LED-ring sandwiched in between. Then the wooden surrounding was glued to the insert, being careful to align the outer wall cutouts with the walls of the insert, since any misalignment could block the elements from sliding in properly. Once the glue dried, the bent corners proved quite rigid where they were really flexible before. Then the bottom was glued to the outer walls and the insert. Through all this the large overhang of the back wall was left hanging loose (*figure 39d*), so that there would be a latch left to be able to reach the electronics through. This latch was tied down using a M3 bolt and nut (*figure 39c*). A hole was drilled into the insert to be able to secure the ESP32 in the back of the enclosure. The connection points were first spring-loaded via a foam pad, but this proved to be too inconsistent. Not every component would make sufficient contact using this method. The actuator and feedback slots were thus altered to paper springs (*figure 39b*) with a contact point attached on top. This proved reliable enough for the user test. The dip-switch broke during install, which meant that only one of the two channels were still functional. This channel was used as a puzzle completion dummy switch. So each switch trigger would be recognized as a single puzzle being completed, and change the next LED in the LED-ring from red to green. Since the other switch was not functional any more, the battery was not added to the prototype. There would be no quick way of disconnecting the battery if needed, so the safer option was to run it fully through a USB cable. A slot was cut out for this cable to feed through in the back of the enclosure (*figure 39d*). Each of the slots were colored in the same colors as the corresponding parts, blue for feedback, green for passive and red for actuators.



(a) Top view

(b) Side view

(c) open back view

(d) back view

Figure 39: Final prototype

A final prototype assembly is displayed in *figure 40*. For this assembly the 7-segment display (feedback), the cipher (passive) and the button (actuator) were used. The parts were able to slide in quite easily, so the wooden enclosure was aligned properly to the insert. Half a millimeter needed to be shaved of the wood around the passive slot, since the elements would get stuck when trying to remove them from the slot. Shaving off half a millimeter proved to be enough to solve this problem. The code running on the ESP was written in Arduino (C++), the code itself can be found in *appendix E*. The intention was to write this code using ESP-IDF, but this was scrapped after the setup of the required environments, and following bug fixing, took too much time. Writing the code in the Arduino environment was thus a deadline motivated decision.

The code checks the three inputs ”ID_A”, ”ID_F” and ”ID_P” upon startup. This is done so that it does not change the active code if by chance a connection slips away during travel. After determining the present parts in the toolkit, the corresponding functionality is activated and the ID of the parts is written to the serial port for the puzzle or interface to receive. All the functionality is initiated from the main class, from here values can be passed to the feedback components to control their behaviour. The inputs received from the actuator parts get written to the serial port to be processed by the interface or puzzle. The feedback functionality is hard-coded, the screen displays a set number, and the buzzer beeps at a set interval, this is done to show the working connection during the demo and user test. There was no time left to implement a feedback control into the interface, this would have been the preferred method, but was not necessary to show the workings of the toolkit.

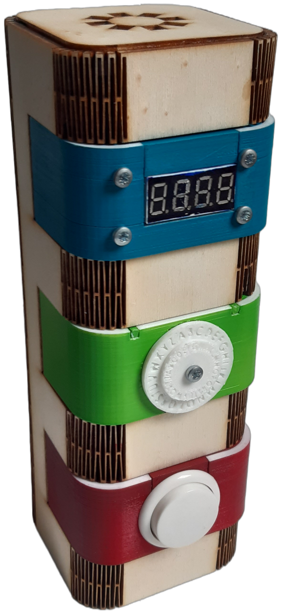


Figure 40: Final assembled prototype

6.5 User Interface

The interface starts off with a screen very similar to the one made for the paper prototype test (*figure 10b*). The whole interface is in dutch, this is because it was intended to test the prototype with local (dutch) children. This sadly fell through due to time constraints. The home page (*figure 41a*) shows the header ”choose your adventure”, with a selection row for story type and difficulty. The story types are placeholders for now, being ”nature”, ”adventure” and

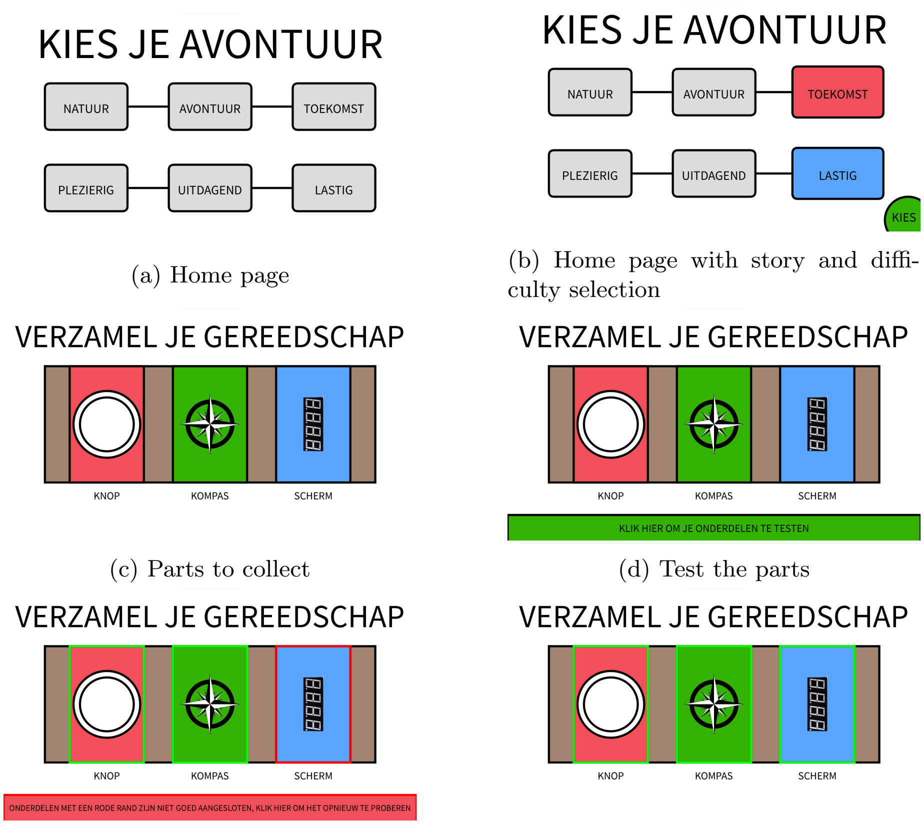
”future”, this are free to be filled in by the client based on the stories they end up developing. The second row is the difficulty selection, this was purposefully not made to be a standard easy-medium-hard scale. This product is developed for children, they might be triggered to think ”I am not doing easy, I'm not dumb” or ”easy is no fun”. This could cause them to choose a difficulty that is not suited for them, resulting in a not so pleasant experience. To avoid ”easy” looking worse than ”hard” and in an effort to make all difficulty levels sound like they would be fun, the naming was changed to be ”pleasant”, ”challenging” and ”difficult”. After selecting the preferred story type and difficulty level, a button pops up displaying ”choose” allowing the user to set their choice (*figure 41b*). Next it displays a screen where it highlights the parts you need to collect for that story and difficulty selection (*figure 41c*) with the header ”collect your tools”. After 10 seconds the screen will change to the one shown in *figure 41d*, adding a test button to the screen. Once this button is clicked, it moves to either *figure 41e* or *figure 41f* based on a check performed that returns if you have the correct part inserted into the toolkit. *figure 41e* shows what happens when the wrong, or no, part is connected to the feedback slot. It displays that part with a red line around it with the message on the bottom of the screen in red ”the components with a red border are not connected correctly, click here to give it another shot”. If all the parts are correctly connected the screen of *figure 41f* is shown. After the toolkit returns a positive check, the users are sent out into the park, to find and complete their puzzles. The full code for the interface can be found in *appendix D.*

7 Evaluation

After having developed the prototype, it was tested though a user test. This user test was executed on fellow students and can be used to evaluate the prototype in its current state, this user test and its results will be explained in the following section. From this test evaluation a list of improvements has been set up under the header ”future developments”. The future developments are divided into two sections. The first section shows upgrades that already have a clear possible solution in place. A new iteration of the current prototype would be developed if this section were to be implemented. The ”to be researched” section shows elements that need more research before an educated design decision can be made and it shows elements in the current design that have not been tested properly. An summary of the evaluation can be found in the evaluated requirements list in *appendix F.*

7.1 User Test

The user test was set up in a similar fashion as the proof of concept test. The goal of the test is to see if the prototype functions as expected. The prototype and the interface will be tested. A consent form will be handed to participants before starting the test. The consent form used is the same as in the proof of concept



ONDERDELEN MET EEN RODE RAND ZIJN NIET GOED AANGESLOTEN, KLIK HIER OM HET OPNIEUW TE PROBEREN

(a) Home page

(b) Home page with story and difficulty selection

(c) Parts to collect

(d) Test the parts

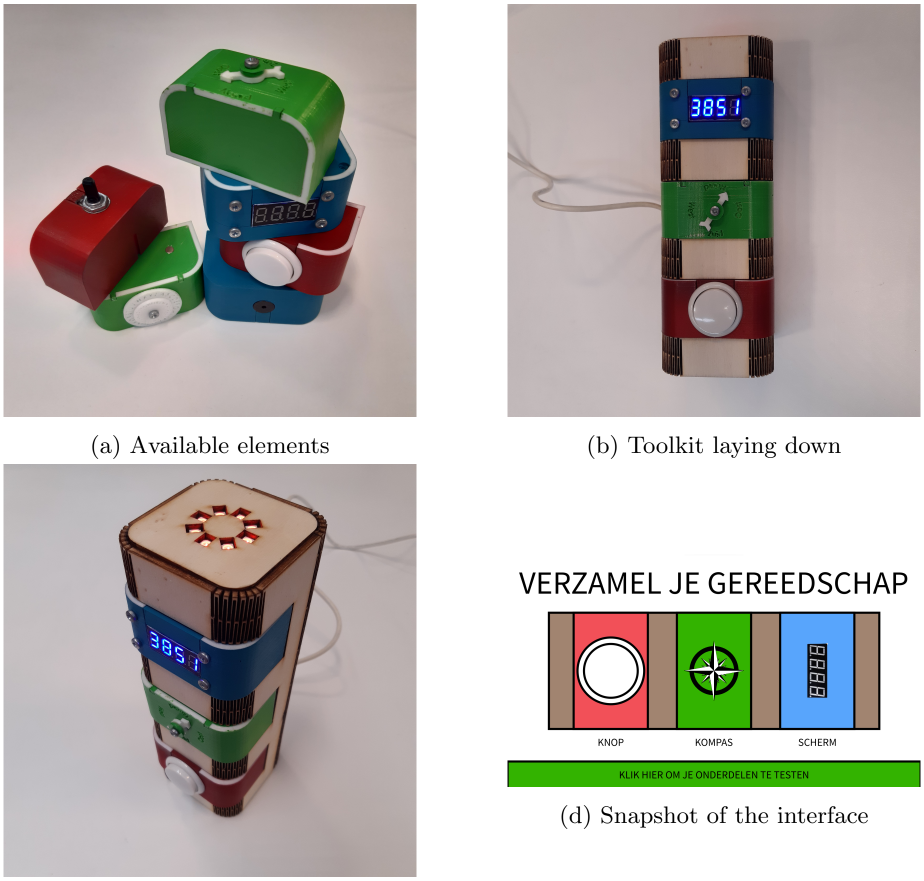
(e) A wrong part selection

(f) Correct part selection

Figure 41: Final interface prototype

test, and can be found in *appendix B*. Participants received all the possible parts scrambled and a toolkit, with the instruction to fill in their preferences in the interface and follow the instructions received from the interface. After having assembled the toolkit with the parts they expect to use the interface will review if they have connected the correct parts. Based on this, participants are either done with the interacting with the prototype, or they will have to revise their part selection and run the check again. After completing this process they are done with interacting with the physical prototype. They will be asked to fill in a short survey after completing the user test. This survey is an updated version of the one used in the proof of concept test and can be found in *appendix C*.

Physical Setup Participants were sat down at a table with the elements in front of them, scrambled, like in *figure 42a*, the toolkit (*figure 42b and 42c*) and a laptop with the interface loaded on it (*figure 42d*). The toolkit was already connected to the laptop, that is why you can see a cable hanging from the toolkit in *figure 42*. Participants would use the laptop to advance through the interface, once they had to check their components they would be assisted in restarting the interface.



(a) Available elements

(b) Toolkit laying down

(c) Toolkit standing upright

(d) Snapshot of the interface

Figure 42: User test setup

Results The test has been executed with exclusively with fellow students. This test was at first intended to be performed on the target group. But the prototype was not in a state that was suitable to be tested with children. The prototype relied on a wired connection and the interface had to be restarted at certain points to trigger the right inputs. This is not a setup suitable to be tested with children and therefore was decided to not do. The results of the survey (*appenix C*) do not show a large deviation from the survey results from the proof of concept test (*appendix A*). The graph in *figure 43* shows a comparison in the average answers given to the survey questions in each of the tests. This graph clearly shows quite comparable average answers. The first three questions were slightly lower in the final user test. The first two are most likely a bit lower due to the expectation that the prototype brings with them. Most participants were quite flustered when the test ended, since they expected a lot more functionality to be implemented already. All other questions returned a slightly higher result in the final user test. Most significant is the deviation in question 6, the average rose over two points for this question. This question was rephrased in between tests because this questions had to be regularly explained in the proof of concept test. The clearer phrasing is probably a factor weighting in the higher average received for this question. Another possible explanation would be the change from paper to physical. Physical components tend to make concepts a lot more tangible, influencing and increasing expectations of what a part might be able to accomplish. The physicality is also likely to be the cause of the increase in average on question 4, since this question essentially considers the same aspects. The parts, and mainly the sliding mechanisms, need some alterations. Most participants needed a few tries to find the right alignment, to be able to slide the part in. The slider only works if you align the part perfectly, they should be more lenient, since you cannot expect children to have perfect motoring skills. In addition, there is also no clear orientation given in the physical design, so participants would often turn their part around a couple of times before finding the right orientation and inserting it. Another comment that was given was that the motivation for assembly was lacking, this was to be expected, since the motivation will be enforced by adding a story around the whole assembly and puzzle completion process. In personal tests it was found that the method used to bend the corners of the wood resulted in a course texture, which would get stuck on the mesh that is often used in the bottle holders of backpacks. Even though the size does allow the prototype to fit inside these holders, getting stuck on the mesh prohibits it from sliding into the pocket properly.

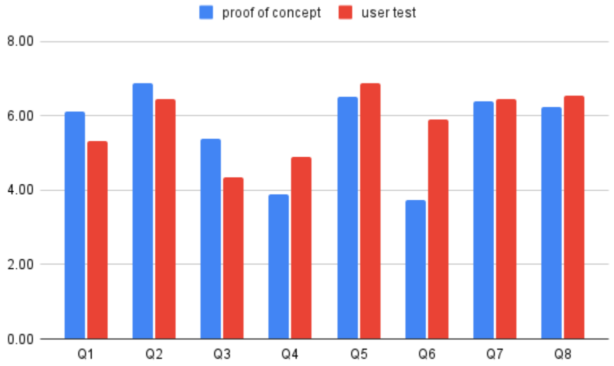


Figure 43: Average survey answers of proof of concept and final user test compared

7.2 Future Developments

To Be Changed There are already some clear and concise fields to improve upon based on the user test. The guiding slots need to be adjusted to have a V shape, instead of the line that it is currently. This V shape would allow part to slide in more easily, since finding a point with the larger opening the V shape would create is a lot easier than with the current implementation. Adding a different angle to each of the V-shapes allows the element to still go in straight, but to not fit, and not reach the connection points, in slots of different colors. There also needs to be some design feature to signify the orientation of the different modules. This can either be done by adding a patter or line to the toolkit and parts, if this patter is continues, the part is oriented correctly. The connection pads are made from paper springs, it is highly recommended to change these to metal springs, just like in standard AA battery boxes. This would allow for a more reliable connection between the element and the toolkit base. The springs do need to be soft enough for all points to make proper contact, if the springs are too stiff, not all contact points will make proper contact. The magnets also need to be improved, a stronger type of magnet is needed for the parts to stay in securely, if the slot, which is currently helping parts stay in through friction, is adapted to a V-slot, the magnet might not be strong enough anymore to hold in the elements. The outside of the toolkit proved to be a bit too rough. This could be solvable by rounding over the corners of the toolkit, but this might have a negative effect on the structural integrity of the bent corners. A more solid solution would be to make the caps (top and bottom) extend over the bent outer wall, and round the edges of these parts (top and bottom caps). This would keep the structural integrity as is, but also allow for a smoother surface to slide the mesh of water bottle pouches against.

To Be Researched The toolkit is meant to have a wireless connection to the puzzles. This communication setup still has to be developed. This can either be done in a similar fashion as the elements are currently connected to the toolkit, but metal pads can be eroded if they are placed permanently outside. A more future proof method would be to set up a wireless charging coil inside the toolkit which powers the puzzle, the puzzle then starts up and enables a Bluetooth connection to the toolkit. There are other solutions possible, but these two seem the most feasible. In the current design, no test were performed with children, so this is a logical next step. This prototype needs to be tested with children to determine more of its limitations. Something else that needs to be researched is the disability compatibility. No research has been done into color blindness before settling on a color coding scheme (blue, green, red), so it is uncertain at this point if this color coding actually accomplishes what is is designed to do. It should ensure that elements are not forced into a slot they are not supposed to be inserted in and mainly to avoid any possibility of user causing shorts. A solution would be to change the color coding to be suitable for color blindness, another option would be to combine this problem with the orientation, and add a secondary distinction based on which the elements can be matched to the slots. An important part of the final product is the encapsulating story. This story should have a positive effect on the experience as a whole, since the story allows the designer to frame the toolkit creation process and highlight the playful learning elements. Proper attention needs to be put into the development of this story and really tying everything together, since this story can greatly improve the flow and experience of the final product.

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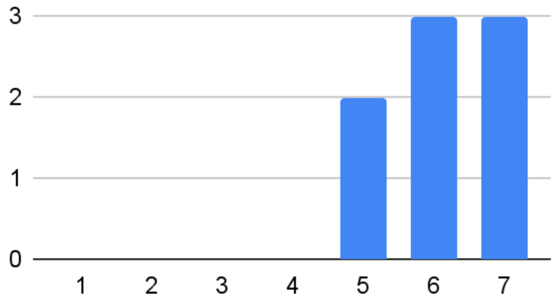
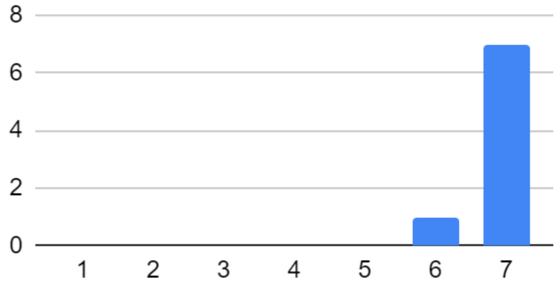
Appendix

A Proof of concept user test survey

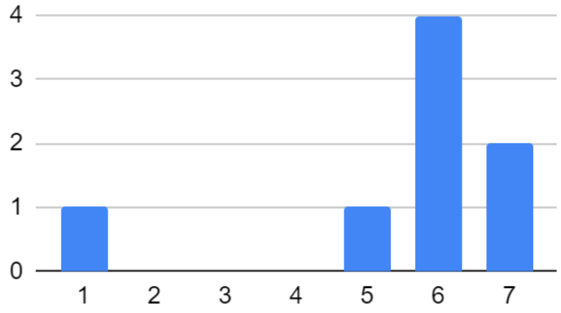
1. Did you understand what was expected from you?



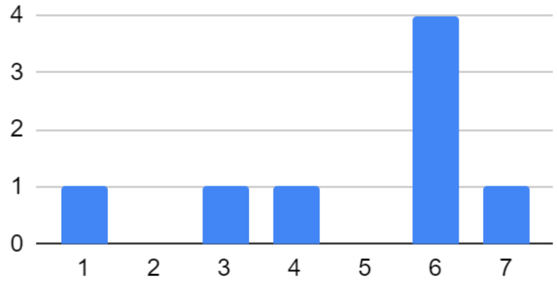
2. Did you understand the interface? (paper with sliders)



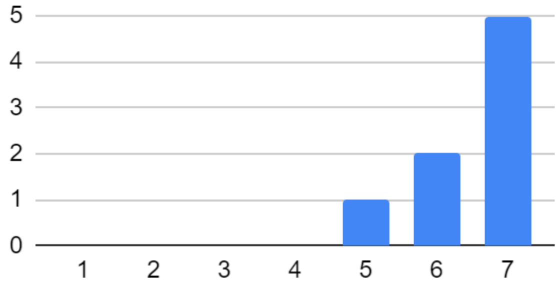
3. Was it clear why you had to pick certain parts?



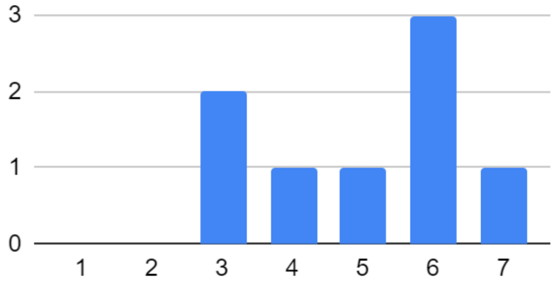
4. Did you have expectations of how each part would behave?



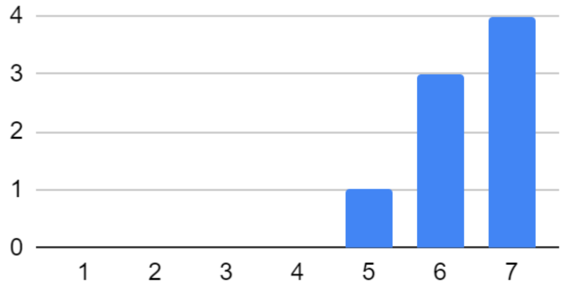
5. Was it clear where you had to put the different parts?



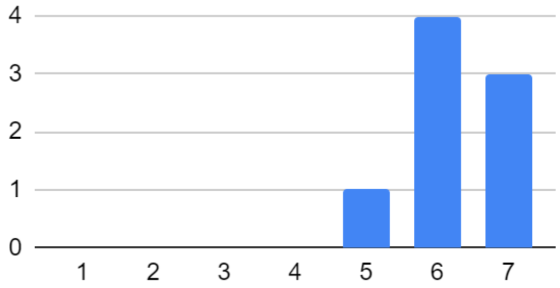
6. Did you expect the parts to have an influence beyond customization?



7. Do you expect a group of children (8 to 12 years old) to be able to complete this process?



8. Would you have enjoyed such an activity (imagine fully developed) when you were younger (target gr…



B Proof of Concept User Test Consent Form

The goal of this user test is to trail the testing method and validate the concept. You will be given a prototype with which you will have to interact. During this interaction notes will be taken concerning your interactions with this prototype, this is to be able to see how the prototype functions, not how you function. Afterwards you will receive a short survey. Any information you supply will not be traceable to you, no personal information will be requested.

As a participant you are expected to interact with the prototype as casually as you can. You will receive a short explanation beforehand introducing the prototype. If you have any questions beforehand, during, or afterwards, please just ask them, this will only help sort out unclearities within the concept.

IMPORTANT:

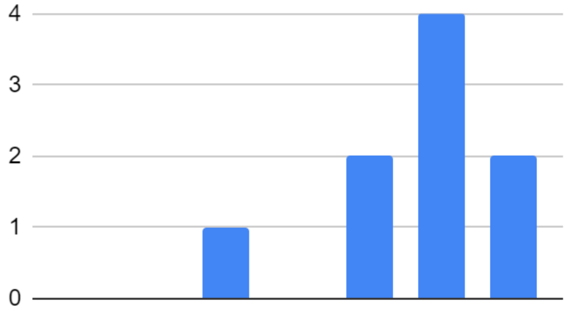
- You are allowed to **quit at any time** during the research! You do not even have to give a reason.
- The prototype is being tested. You are not the subject of this test!
- Have fun :D

By agreeing to participate in this user test you will consent to having the data found though the test, either via your interactions with the prototype or your answers to the survey, be used to further the development of this project.

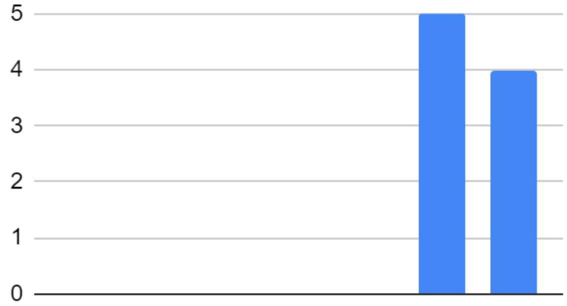
This research was accepted by the ethics committee representing the EEMCS faculty of the University of Twente. For any complaints you can contact: ethicscommittee-cis@utwente.nl

C User Test Survey

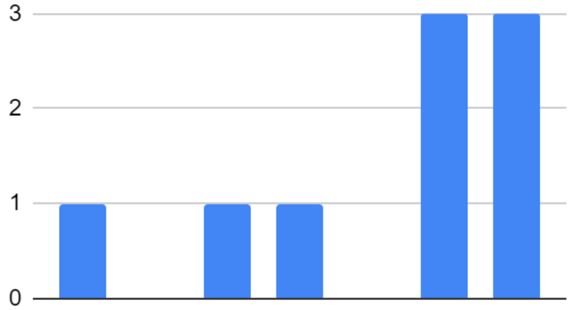
1. Did you understand what was expected from you?



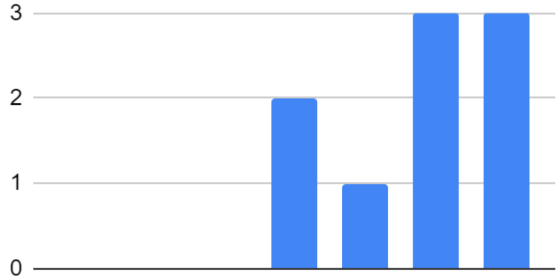
2. Did you understand the interface? (on PC)



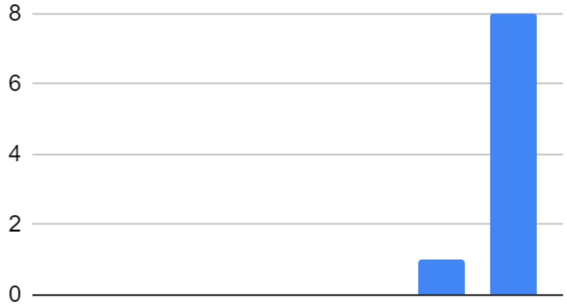
3. Was it clear why you had to pick certain parts?



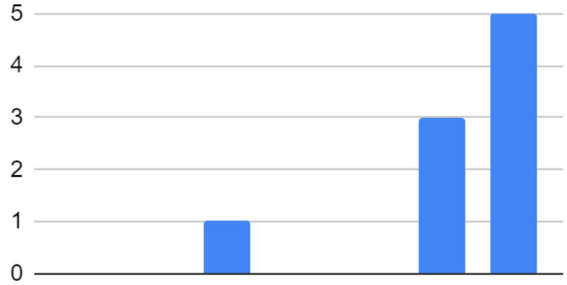
4. Did you have expectations of how each part would behave?



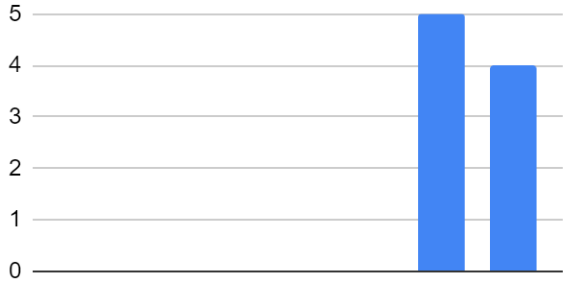
5. Was it clear where you had to put the different parts?



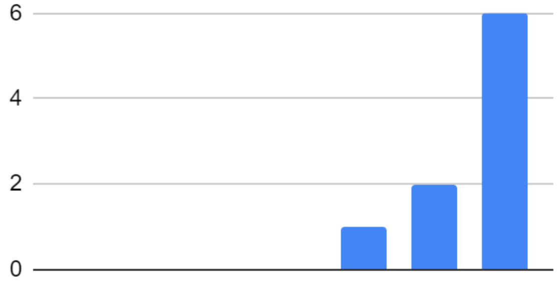
6. Did you expect the parts to have an influence on the behaviors' of the toolkit?



7. Do you expect a group of children (8 to 12 years old) to be able to complete this process?



8. Would you have enjoyed such an activity (imagine fully developed) when you were younger (8 to 12 year…



D User Interface Code

```
//main class
import processing.serial.*;

Serial myPort;
static String incoming;
int sensorVal=0;

selection sel;
partsToTake take;

public int displayState = 0;
public int difficulty, story;
int acts, feeds, pass;
Boolean foundAct, foundFeed, foundPas, butPress, butHold;

void setup() {
  fullScreen();   // set the window size
  sel = new selection(displayWidth, displayHeight);
  take = new partsToTake(displayWidth, displayHeight);
  displayState ++;
  story = 0;
  difficulty = 0;
  foundAct = false;
  foundFeed = false;
  foundPas = false;

  String portName = "COM6";
  myPort = new Serial(this, portName, 9600);
}

void draw() {
  background(255, 255, 255);

  if (displayState == 1) {
    sel.display();
    sel.buttons();
    sel.next();
  }

  if (displayState == 2) {
    take.display();
    take.selectPart();
    take.next();
  }

  if (displayState >= 3) {


    if (myPort.available() > 0) {
      incoming = myPort.readStringUntil('\n');
      incoming = trim(incoming);
      println(incoming);
    }


    if (displayState == 3) {

      if (incoming.equals("act: 1")) {
        acts = 1;
        foundAct = true;
      } else if (incoming.equals("act: 2")) {
        acts = 2;
        foundAct = true;
      }

      if (incoming.equals("feed: 1")) {
        feeds = 1;
        foundFeed = true;
      } else if (incoming.equals("feed: 2")) {
        feeds = 2;
        foundFeed = true;
      }

      if (incoming.equals("pas: 0") || incoming.equals("pas: 1")) {
        pass = 1;
        foundPas = true;
      } else if (incoming.equals("pas: 2")) {
        pass = 2;
        foundPas = true;
      }
      take.display();
      if (foundPas == true && foundFeed == true && foundAct == true
    ) {
        take.checkPart(acts, pass, feeds, myPort);
      }
    }

    if (displayState == 4) {
      if (incoming.equals("Button: PRESS")) {
        butPress = true;
      } else {
        butPress = false;
      }
      if (incoming.equals("Button: HOLD")) {
        butHold = true;
      } else {
        butHold = false;
      }

      take.display();
      take.actuators(butPress, butHold);
    }
  }
}
```

```
//selection screen
class selection {
  int xSize, ySize;
  float iconSizeX, iconSizeY;
  boolean kiesActief;

  selection(int x, int y) {
    xSize = x;
    ySize = y;
    iconSizeX = 0.2*xSize;
    iconSizeY = 0.2*ySize;
    strokeWeight(10);
    rectMode(CENTER);
    textAlign(CENTER, CENTER);
    kiesActief = false;
  }

  void display() {
    fill(220, 220, 220);

    line(0.2*xSize, 0.4*ySize, 0.8*xSize, 0.4*ySize);
    rect(0.2*xSize, 0.4*ySize, iconSizeX, iconSizeY, 25, 25, 25, 25);
    rect(0.5*xSize, 0.4*ySize, iconSizeX, iconSizeY, 25, 25, 25, 25);
    rect(0.8*xSize, 0.4*ySize, iconSizeX, iconSizeY, 25, 25, 25, 25);

    line(0.2*xSize, 0.75*ySize, 0.8*xSize, 0.75*ySize);
    rect(0.2*xSize, 0.75*ySize, iconSizeX, iconSizeY, 25, 25, 25, 25);
    rect(0.5*xSize, 0.75*ySize, iconSizeX, iconSizeY, 25, 25, 25, 25);
    rect(0.8*xSize, 0.75*ySize, iconSizeX, iconSizeY, 25, 25, 25, 25);

    fill(242, 80, 88);
    if (story == 1) {
      rect(0.2*xSize, 0.4*ySize, iconSizeX*1.1, iconSizeY*1.1, 25, 25, 25, 25);
    } else if (story ==2) {
      rect(0.5*xSize, 0.4*ySize, iconSizeX*1.1, iconSizeY*1.1, 25, 25, 25, 25);
    } else if (story ==3) {
      rect(0.8*xSize, 0.4*ySize, iconSizeX*1.1, iconSizeY*1.1, 25, 25, 25, 25);
    }
    fill(88, 165, 252);
    if (difficulty == 1) {
      rect(0.2*xSize, 0.75*ySize, iconSizeX*1.1, iconSizeY*1.1, 25, 25, 25, 25);
    } else if (difficulty == 2) {
      rect(0.5*xSize, 0.75*ySize, iconSizeX*1.1, iconSizeY*1.1, 25, 25, 25, 25);
    } else if (difficulty ==3) {
      rect(0.8*xSize, 0.75*ySize, iconSizeX*1.1, iconSizeY*1.1, 25, 25, 25, 25);
    }

    fill(0, 0, 0);
    textSize(200);
    text("KIES JE AVONTUUR", 0.5*xSize, 0.1*ySize);

    textSize(60);
    text("NATUUR", 0.2*xSize, 0.4*ySize);
    text("AVONTUUR", 0.5*xSize, 0.4*ySize);
    text("TOEKOMST", 0.8*xSize, 0.4*ySize);

    text("PLEZIERIG", 0.2*xSize, 0.75*ySize);
    text("UITDAGEND", 0.5*xSize, 0.75*ySize);
    text("LASTIG", 0.8*xSize, 0.75*ySize);
  }

  void buttons() {
    if (mouseX < 0.3*xSize && 0.1*xSize < mouseX && 0.3*ySize < mouseY && 0.5*ySize > mouseY) {
      story = 1;
    } else if (mouseX < 0.6*xSize && 0.4*xSize < mouseX && 0.3*ySize < mouseY && 0.5*ySize > mouseY) {
      story = 2;
    } else if (mouseX < 0.9*xSize && 0.7*xSize < mouseX && 0.3*ySize < mouseY && 0.5*ySize > mouseY) {
      story = 3;
    }
    if (mouseX < 0.3*xSize && 0.1*xSize < mouseX && 0.65*ySize < mouseY && 0.85*ySize > mouseY) {
      difficulty = 1;
    } else if (mouseX < 0.6*xSize && 0.4*xSize < mouseX && 0.65*ySize < mouseY && 0.85*ySize > mouseY) {
      difficulty = 2;
    } else if (mouseX < 0.9*xSize && 0.7*xSize < mouseX && 0.65*ySize < mouseY && 0.85*ySize > mouseY) {
      difficulty = 3;
    }

    if (kiesActief == true && mouseX > .9 * xSize  && mouseY > .87 * ySize){
      displayState = 2;
    }
  }

  void next(){
    if (story != 0 && difficulty != 0){
      fill(51, 179, 0);
      circle(.97*xSize, .95*ySize, iconSizeY);
      fill(0,0,0);
      text("KIES", .96*xSize, .93*ySize);
      kiesActief = true;
    }
  }
}
```

```
//check the parts and display accordingly
class partsToTake {
  int xSize, ySize;
  int act, feed, pas;
  PImage compass, cipher, display;
  int realAct, realPas, realFeed;
  boolean sameAct, samePas, sameFeed;
  boolean bpress, bhold;

  partsToTake(int x, int y) {
    xSize = x;
    ySize = y;
    strokeWeight(10);
    rectMode(CENTER);
    act = 0;
    feed = 0;
    pas = 0;
    compass = loadImage("compass.png");
    cipher = loadImage("cipher.png");
    display = loadImage("7segment.png");
  }

  void display() {
    stroke(0);
    fill(161, 132, 112);
    rect(.5*xSize, .5*ySize, .8*xSize, .5*ySize);
    fill(242, 80, 88);
    rect(.25*xSize, .5*ySize, .18*xSize, .5*ySize);
    fill(51, 179, 0);
    rect(.5*xSize, .5*ySize, .18*xSize, .5*ySize);
    fill(88, 165, 252);
    rect(.75*xSize, .5*ySize, .18*xSize, .5*ySize);

    fill(0, 0, 0);
    textSize(150);
    text("VERZAMEL JE GEREEDSCHAP", 0.5*xSize, 0.1*ySize);

    imageMode(CENTER);
    textSize(50);
    if (pas == 2) { //compas
      image(compass, .5*xSize, .5*ySize, 280, 280);
      text("KOMPAS", .5*xSize, .8*ySize);
    } else if (pas == 1) { //cipher
      fill(255);
      circle(.5*xSize, .5*ySize, 310);
      image(cipher, .5*xSize, .5*ySize, 300, 300);
      fill(0);
      text("CIPHER", .5*xSize, .8*ySize);
    }

    if (feed == 1) {
      //7segment
      pushMatrix();
      translate(.75*xSize, .5*ySize);
      rotate(.5*PI);
      image(display, 0, 0);
      popMatrix();
      text("SCHERM", .75*xSize, .8*ySize);
    } else if (feed == 2) {
      //buzzer
      fill(0, 0, 0);
      circle(.75*xSize, .5*ySize, 100);
      fill(70, 70, 70);
      circle(.75*xSize, .5*ySize, 30);
      text("BUZZER", .75*xSize, .8*ySize);
    }

    if (act == 2) { //encoder
      text("DRAAIKNOP", .25*xSize, .8*ySize);
      pushMatrix();
      translate(.25*xSize, .5*ySize);
      rotate(.25*PI);
      rect(0, 0, 220, 220);
      popMatrix();
    } else if (act == 1) {       //button
      text("KNOP", .25*xSize, .8*ySize);
      fill(255);
      circle(.25*xSize, .5*ySize, 310);
      circle(.25*xSize, .5*ySize, 250);
    }
  }

  void selectPart() {
    if (story == 1) { //natuur
      if (difficulty == 1) { //makkelijk
        pas = 1;
        act = 2;
        feed = 1;
      } else if (difficulty ==2) { //medium
        pas = 1;
        act = 2;
        feed = 2;
      } else if (difficulty == 3) { //moeilijk
        pas = 1;
        act = 1;
        feed = 2;
      }
    } else if (story == 2) { //avontuur
      if (difficulty == 1) {
        pas = 2;
        act = 2;
        feed = 1;
      } else if (difficulty ==2) {
        pas = 2;
        act = 1;
        feed = 2;
      } else if (difficulty == 3) {
        pas = 2;
        act = 1;
        feed = 1;
      }
    } else if (story == 3) { //toekomst
      if (difficulty == 1) {
        pas = 1;
        act = 2;
        feed = 2;
      } else if (difficulty ==2) {
        pas = 2;
        act = 2;
        feed = 1;
      } else if (difficulty == 3) {
        pas = 2;
        act = 1;
        feed = 1;
      }
    }
  }

  int screentimer;

  void next() {
    screentimer ++;
    if (screentimer > 80) {
      fill(51, 179, 0);
      rect(.5*xSize, .95*ySize, xSize, 0.12*ySize);
      fill(0, 0, 0);
      text("KLIK HIER OM JE ONDERDELEN TE TESTEN", .5*xSize, .94*
    ySize);
      if (mouseY > 0.9*ySize) {
        displayState = 3;
        screentimer = 0;
      }
    }
  }

  Serial ComPort;
  void checkPart(int a, int p, int f, Serial myPort) {
    screentimer ++;
    realAct = a;
    realPas = p;
    realFeed =f;
    ComPort = myPort;

    if (realAct == act) {
      println("same actuator");
      sameAct = true;
    } else if (realAct != act) {
      println("wrong actuator");
      sameAct = false;
    }

    if (realPas == pas) {
      println("same passive");
      samePas = true;
    } else if (realPas != pas) {
      println("wrong passive");
      samePas = false;
    }

    if (realFeed == feed) {
      println("same feedback");
      sameFeed = true;
    } else if (realFeed != feed) {
      println("wrong feedback");
      sameFeed = false;
    }

    noFill();
    if (sameAct == false) {
      stroke(255, 0, 0);
    } else {
      stroke(0, 255, 0);
    }
    rect(.25*xSize, .5*ySize, .18*xSize, .5*ySize);

    if (samePas == false) {
      stroke(255, 0, 0);
    } else {
      stroke(0, 255, 0);
    }
    rect(.5*xSize, .5*ySize, .18*xSize, .5*ySize);

    if (sameFeed == false) {
      stroke(255, 0, 0);
    } else {
      stroke(0, 255, 0);
    }
    rect(.75*xSize, .5*ySize, .18*xSize, .5*ySize);

    if (sameAct == false || samePas == false || sameFeed == false) {
      fill(242, 80, 88);
      rect(.5*xSize, .95*ySize, xSize, 0.12*ySize);
      fill(0, 0, 0);
      textSize(40);
      text("ONDERDELEN MET EEN RODE RAND ZIJN NIET GOED AANGESLOTEN, KLIK HIER OM HET OPNIEUW TE PROBEREN", .5*xSize, .94*ySize);
      if (screentimer > 40 && mouseY > 0.9*ySize) {
        displayState = 2;
        screentimer = 0;
        ComPort.write("found type");
      }
    }

    if (sameAct == true && samePas == true && sameFeed == true && screentimer > 40) {
      displayState = 3;
    }
  }

  void actuators(boolean press, boolean hold) {
    bpress = press;
    bhold = hold;
    if (bpress == true) {
      text("KLIK", .25*xSize, .5*ySize);
    }
  }
}
```

E Arduino Code

```
//main
#include <TM1637Display.h>
#include <FastLED.h>

#define ID_A 34
#define ID_P 35
```

```
#define ID_F 36

int Actuator_Type = 0;
int Feedback_Type = 0;
int Passive_Type = 0;
int Share_Type = 0;
String type_check;

//initiation actuator functions
void CheckAct();
void Button();
void Encoder();

//initiation feedback functions
void CheckFeed();
void Display();
void Buzzer();

//initiation passive functions
void CheckPas();

//leds
void SetupLed();
void DisplayLed();

void setup() {
  Serial.begin(9600);
  pinMode(ID_A, INPUT_PULLUP);
  pinMode(ID_F, INPUT_PULLUP);
  CheckAct(ID_A);
  CheckFeed(ID_F);
  CheckPas(ID_P);
  SetupLed();
}

void loop() {
  //feedback
  if (Feedback_Type == 1) {
    Display(3851);                  //what is displayed on the 7-segment display
  } else if (Feedback_Type == 2) {
    Buzzer(1000);                   //the note that is played
  }

  //actuator
  if (Actuator_Type == 1) {
    Button();
  } else if (Actuator_Type == 2) {
    Encoder();
  }

  DisplayLed();

  if (Serial.available()) {
    type_check = Serial.read();
  }

  if (type_check.equals("found type")) {
    Share_Type = 1;
  }

  if (Share_Type == 0) {
    Serial.print("act: ");
    Serial.println(Actuator_Type);
    Serial.print("feed: ");
    Serial.println(Feedback_Type);
    Serial.print("pas: ");
    Serial.println(Passive_Type);
    //     Share_Type ++;
  }
}
```

```
//actuators
#define ROT1 27 //first encoder pin
#define ROT2 26 //second encoder pin
#define BUT 27 //button input

//encoder variable initiation
int aState;
int aLastState;
int counter = 0;

//button varialbe initiation
int bState;
int bLastState;
int holdTimer;

void CheckAct(int ID) {
  if (analogRead(ID) > 3500) { //Button
    Actuator_Type = 1;
    pinMode(BUT, INPUT_PULLUP);
    bLastState = digitalRead(BUT);
  }
  if (analogRead(ID) < 500) { //Encoder
    Actuator_Type = 2;
    pinMode(ROT1, INPUT_PULLUP);
    pinMode(ROT2, INPUT_PULLUP);
    aLastState = digitalRead(ROT1);
    Serial.println("act: encoder");
  }
}

void Button() {
  bState = digitalRead(BUT);

  if (bState == LOW) {
    if (bState != bLastState) {
      Serial.println("Button: PRESS");
    }
    if (bState == bLastState) {
      Serial.println("Button: HOLD");
    }
  }
  bLastState = bState;
}
```

```

void Encoder() {
  aState = digitalRead(ROT1);
  if (aState != aLastState && aLastState != 1) {
    if (digitalRead(ROT2) != aState) {
      counter ++;
    } else {
      counter --;
    }
    Serial.print("Position: ");
    Serial.println(counter);
  }
  aLastState = aState;
}
```

```
//feedback
#define CLK 14 //clock pin
#define DIO 13 //data pin
#define BUZZ 13 //buzzer pin

TM1637Display display(CLK, DIO);

void CheckFeed(int ID) {
  //display
  if (analogRead(ID) > 3500) {
    Feedback_Type = 1;
    display.setBrightness(7);
    Display(0000);
    Serial.println("feed: display");
  }
  else if (analogRead(ID) < 1000) {
    Feedback_Type = 2;
    pinMode(BUZZ, OUTPUT);
    Serial.println("feed: buzzer");
  }
}

void Display(word n) {
  display.showNumberDec(n, true);
}

void Buzzer(int note){
  tone(BUZZ, note);
  delay(100);
  noTone(BUZZ);
  delay(10000);
}
```

```
//ledring
#define D0 22
#define D1 23
#define button 25

#define NUM_LEDS 8
CRGB leds[NUM_LEDS];
#define Dim 10

```

```
int State;
int LastState;
int ledCounter;

void SetupLed() {
  FastLED.addLeds<WS2812, D1, GRB>(leds, NUM_LEDS);
  FastLED.setBrightness(255);
  pinMode(button, INPUT_PULLUP);
  LastState = digitalRead(button);
  ledCounter = 0;
}

void DisplayLed() {
  State = digitalRead(button);
  if (State != LastState) {
    if (ledCounter < 8) {
      ledCounter ++;
    } else {
      ledCounter = 9;
    }
  }
  for (int i = 0; i <= ledCounter; i++) {
    leds[i] = CRGB(0, 255, 0);
  }
  for (int i = ledCounter; i <= 8; i++) {
    leds[i] = CRGB(255, 0, 0);
  }

  if (ledCounter == 9){
    //nothing yet
  }

  FastLED.setBrightness(Dim);
  FastLED.show();
  LastState = State;
}
```

```
//passive
void CheckPas(int ID) {
  if (analogRead(ID) > 3500) {
    Passive_Type = 2;
    Serial.println("pas: compas");
  }
  else   if (analogRead(ID) < 1000) {
    Passive_Type = 1;
    Serial.println("pas: cipher");
  }
}
```

F Requirements Table With Evaluation

		Method of Validation	Checklist
1. Technical Requirements			
1.1	The toolkit shall be based on the esp32 platform	Visual test	Confirmed. The ESP is housed in the prototype and can be seen in *figure 39a*
1.2	The toolkit shall be able to communicate with the puzzles	Technical test	Not completed, is left up for further development
1.3	The toolkit shall be easily transportable	User test	The size is comparable to a water bottle, and fits within water bottle pouches and is thus transportable
1.4	The toolkit shall consist of multiple parts	Visual test	The toolkit consists of multiple parts
2. Appearance Requirements			
2.1	The toolkit shall be appropriately sized for children	User test	This was not tested yet
2.2	The toolkit shall have visual progression trackers	User test	The prototype has visual progression tracking (led ring) but this has not been tested in implementation yet
2.3	The toolkit shall have clear attachment point for toolkit-puzzle communication	User test	Not completed, is left up for further development
2.4	The toolkit shall have clear indications of where parts need to be connected	User test	Completed, needs some improvement
2.5	The toolkit shall fit the current design language in use by the client	Visual test	Completed
3. Functional Requirements			
3.1	The toolkit shall be based on the esp32 platform	Visual test	Semi-confirmed, the code is written in Arduino but runs on an ESP
3.2	The toolkit shall be build-able by children ages 8 to 12	User test	This was not tested yet, but older test participants expect it to be doable for the target group
3.3	The toolkit shall be usable for multiple sessions	User test	This was not tested yet
3.4	The toolkit shall trigger different solutions based on part selection	Technical test	The part selection is registered in the toolkit, but no functional implementation has been developed yet
4. Safety Requirements			
4.1	The toolkit shall not use a potentially dangerous power supply	Technical Test	No definitve battery has been selected yet.
4.2	It shall not be possible to assemble the toolkit in a incorrect manner	User test	Tests proved successful
4.3	The toolkit shall have no mechanical potential of harming user during assembly	Technical Test	So far, no issues were found. The prototype has not been tested to failure yet, so it is not conclusive.

Table 4: Evaluated toolkit requirements