The Air we Breathe

‘Increasing environmental knowledge in adolescents through physicalized air quality data’

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Abstract

With the decline of global wellbeing that has taken place of the last decades changes to policies and actions have only recently begun to step up. With this increase in responsibility for the world around us efforts are being made to counteract the damages done and possibly reverse some of these. With the direction that the world is travelling in the importance of awareness under the individuals has become larger than ever. Taking that as the main inspiration, and combining this with one the sustainable development goals setup by the United Nations a data physicalization has been created to test whether the introduction of DIY methods on user input can change the user experience of young adolescents, when dealing with the topic of air quality around the globe. Following a design process that was constructed for Creative Technology this physicalization has come to realization in four distinct phases. The phases consisted of starting with ideation, followed by specification, realization and evaluation. The data physicalization that was eventually created and tested consisted of the comparison between a traditional input method and two variations on a DIY input method that utilized more freedom for the user and non-visual feedback. In order to find out if the user experience was indeed influenced by these methods: efficiency and effectiveness, engagement and enjoyment were analyzed. The DIY methods showed to create a better user experience within its user in comparison to those that utilized the traditional input method.

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Furthermore I would like to thank all of the users that participated in the user and pilot testing for the evaluation of my prototype physicalization. Your partaking has aided in the confirmation of my previous expectations as well as exceeding them in certain cases.

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Introduction

1.1 Motivation

The true single thing that all of us have in common is the way our body works, what it needs to survive and how the quality of these needs impacts our ability to live. Whether it's about the food that we eat, the activities we fill our lives with or the air we breathe [4]. The latter being the specific topic to be focused on here. Air quality has been a major link in the survival chain which was seen steadily decreasing in quality up until recent years [5]. Now that the current generation of engineers and scientists are working on the air quality of the future it is important to remember that it is not only the current generation that has to be made aware, but perhaps even more importantly, the future generations need to be able to continue on the foundations being set today. For that reason this graduation project will be targeted to young adolescent students, as they are the ones to build upon these foundations being laid out today. Engaging students in projects that can raise awareness for the current state of the air they breathe is a key aspect in making sure that more mindful decisions are made and aspirations are sparked. In order to attempt this reaction within young adolescents, knowledge must be obtained on how students might be able to effectively interact with air quality data.

In order to create the first step of this process a data physicalization will be made and evaluated to look into the user's experience. Where this project will differ from normally produced data physicalizations is in that fact that a DIY element will be introduced to the user. Playing into the fact that the users are of a younger age this DIY element may bridge a gap that allows for an element of exploration to be combined with learning, as a non-typical input interaction gives the user freedom over the control of the physicalization itself.

1.2 Objective

In order for us to say if a user's experience was influenced by different methods for a data physicalization we have to look at the efficiency, the effectiveness, engagement and enjoyment. Efficiency can be defined as the time that it takes for a user to process information conveyed by the physicalization, where effectiveness stands as the accuracy with which this information was conveyed. Furthermore engagement will be seen as a measure of the user's mental and physical activity during their interaction with the physicalization and the user's enjoyment plays a key part to any physicalization as you cannot say that is useful if the user does not like using it.

The objective of this graduation project is to see whether a DIY approach to a data physicalization aimed towards young adolescents is a good way to create a positive user experience.

1.3 Research Question

With the goal of this graduation project being to investigate the difference in the user experience with different input approaches the main research question for this thesis is formulated as follows:

> *Does the implementation of a DIY element in the physicalization of Air Quality Data influence the user's experience?*

In order to accurately and confidently address the main research question several sub-questions have been formulated:

- How do the efficiency and effectiveness of the different DIY approaches to the data physicalizations compare to a traditional input method?
- How well engaged were the users of the data physicalizations that utilized a DIY approach in comparison to one that used a traditional input method?
- Are the different input methods used in the data physicalization considered enjoyable by the users?

1.4 Outline

Subsequent to this outline the structure of the paper will be as follows. Chapter 2 will be on the background research. It will contain a section on the current state of the art regarding awareness of air quality in the public and learning methods for young adolescents. Furthermore this chapter will contain a section of what data physicalizations are and include some examples that functioned as inspiration for the one created for this GP. In order to frame the concept of what a data physicalization is and illustrate its uses. Chapter 3 will describe the methodology used for the creation of GP. Chapter 4 will take a look into the first ideation phase of the GP. Here the implementation of a Sustainable Development Goal will be discussed, as well as the use and presentation of data within the creation of the physicalization and the first ideas on what the prototype would be like. In chapter 5 the selected and core concepts of the design/ideation phase are carried over into the specification phase. Here all of the requirements for the functionality and usability of the physicalization will be set and a concrete design for the look and interactions will be created. Furthermore this chapter will lay the foundation for the system

specifications and illustrate how a user would use the prototype by means of a user scenario. Transitioning from the Specification phase in to chapter 6: the realization phase, this chapter will report on how the physicalization was actually build. Describing the electronic components used and the code behind it, as well as how the physical form of the prototype was created. Chapter 7 will be all about the evaluation of the prototype build in chapter 6. Here the user study and its results are looked into in order for us to answer the research question in chapter 8: the conclusion. Lastly chapter 9 will give insight on some of the challenges that were faced during the creation of the GP, as well as give recommendations for changes and future work on the topic.

Background research

2.1 Awareness and learning

In order to create a data physicalization on the topic of air quality data. It is important to first get a basic understanding of the current awareness around this topic as well as an effective way in which the target audience may learn. This in order to analyze the issue at hand and get an understanding of how the problem may be effectively challenged.

2.1.1 Air Quality awareness

In modern day education, adolescents already have a substantial foundation when it comes to their awareness of the environment. It is the factual knowledge itself that they are lacking in. Where, in the context of this GP, the term ‘awareness; is used to indicate a general sense of the topic, knowing it is there, being able to describe it in a broad sense but no depth when it comes to topic wide facts. Knowledge on the other hand will be handled in order to represent a factual based understanding of the topic at hand. Apart from being taught about ecosystems and elements, there is no real subject or topic which addresses sustainability in a way that environmental awareness does. As an example that shows there is a lack of this, a study that looked into the environmental awareness of adults in America [6]. In this study adults living in a multitude of locations spread across The United States are asked about their use of air quality communication networks such as the RAAN and ROAR, as well as general access to AQI forecasts and their database. Ramírez, Ramondt, van Bogart and Perez-Zuniga (2019) state that “Results indicate that communication of air quality is disconnected from the public”. This disconnection, just like a lot of other factors that play a role in adulthood, can find their roots in a person's upbringing, if not education. For this reason it is important to attempt to build an early understanding of the environmental air quality.

In order to properly address the adolescent it is important to understand to what degree they already have awareness over the air quality, so that this foundational awareness can be further built on and expanded to knowledge that will stay with them and possibly even impact their future decision making. Ahmad,Noor and Ismail (2015) tell us that a large portion of middle school students already appear to have a relatively well-based awareness of the environment in general. Niankara and Zoungranab (2018) further add to this by stating that this awareness does however not directly correlate to knowledge of the topic. Furthermore, Ahmad,Noor and Ismail (2015) found that: “While students’ attitude towards the environment in general is good, it is also important to note that lower percentages were recorded on two items: (a) interest to learn more about sustainable environment (78.6%) and (b) interest to join sustainable environment

activities (68.9%)". This gap in knowledge, combined with an already present willingness to learn implies that there is room for opportunities when it comes to the effectiveness of this GP.

This interest to learn more about sustainable environment, combined with the fact that there is a substantial gap between the two factors indicated that there is still a relatively large margin of already interested students, whose awareness may be well enough to be interested in the topic but who's knowledge of the specifics may not yet be at a point where their attention is captured. Niankara and Zoungranab (2018) describe that depending on students' interest in the biosphere, their awareness differs based on their interests, where students with a higher interest show a better awareness. This awareness and in turn the students' multipotentiality to become more knowledgeable on environmental air quality goes hand in hand with elevating the individual's interest in the topic.

2.1.2 Young adolescent learning

In order to properly most effectively play into the learning behavior of adolescents a more tangible or practical approach can be utilized. Where a mental connection is made between an event and the knowledge that came with it in order to better pick up and hold on to information. Recent knowledge on the environment among adolescents has been shown to not be as good as their awareness, which is what this project is aimed to tackle and therefore is no surprise. In order to tackle the boundary step of transitioning from awareness to knowledge, a method must be applied that captures the user's attention, as well as spark their interest. Khoiri, Sunarno, Sajidan and Sukarmin (2021) conclude that "The absence of the implementation of contextual learning can limit meaningful experiences for students." This is in turn supported by Koirala (2019), who presents the fact that through a practical approach scientific concepts and learning material can be better passed down onto, and can be better taken in by students, compared to traditional teaching manners. This plays well into the direction of data physicalization, and thus builds on the foundation of this GP utilizing an alternative learning method.

These findings are backed by evidence showing that prior experiences aid in the episodic memory, executive function, and decision-making. Murtya, Calabroa and Lunaab (2016) describe that this process allows adolescents to be more flexible with their previous experiences. Being more flexible with previous experiences will allow the adolescents to translate concepts and facts learned through a more practical approach into knowledge that can

be used in their future in order to make decisions. In the case of air quality data, this can be turned into more of an experience, in order to play into these claims. The effectiveness of previous experiences is moreover also linked to attention [12] and emotional processing [13], both factors that can aid in building knowledge of a topic.

A potential approach to this can be through the use of a DIY kit, here the user would have another experience added onto the end result (in this case the obtaining of knowledge on air quality through data physicalization) in order to further stimulate the use of the episodic memory.
According to a DIY based study conducted by Sancho-Gil, Hernández-Hernández and Fendler (2015) “Parents also had a wider view of students’ lives, incorporating activities both in and outside school, and easily drew connections between the two, stressing how the development of digital competence went beyond school walls.” Showing that outside parties are able to recognize a change in capacity on the users end, thus proving its effectiveness. The DIY project [9] mentioned regarded digital competence rather than environmental knowledge, but although the purpose was different to that of this GP, the method can still be applied and yield similar results.

2.1.3 Conclusion

In order to properly address the task at hand, this being to find how air quality knowledge under adolescents can be increased. There must first be a solid foundation of understanding as to how aware adolescents are on the topic of environmental awareness and how they can most effectively learn or transfer this awareness over to actual knowledge. Where it can be said that the current awareness of adolescents is good, their knowledge is lacking behind. This gap can be traced back to a range of factors, one of which being their interest in the topic on itself. As shown by the literature, adolescents who already have an interest are more easily capable of converting their awareness into factual knowledge. In order to advance with this research efforts could be made to determine what factors make it so that some individuals can more easily transfer awareness to knowledge outside of their previous personal interests. This would be of great use as the goal is to increase knowledge in general and not just in those who would already be willing to know more. The research that was found on this topic can be recognized as reliable and accurate as they have been from recent years, as well as having a high concentration of peer reviewed articles.

When it comes to how adolescents can best learn it is made clear that this is through alternative methods that create an experience for the user, rather than a more traditional manner. Being engaged in an experience creates the opportunity for the user to utilize this previous experience in future decision making and thus makes the user be more actively involved/engaged within the matter. This increased engagement makes for a more effective practice, resulting in more effective transitions from awareness to knowledge. The research that was found on this topic once again had a good concentration of peer reviewed articles and were all from recent years. Making it accurate enough to be utilized for a project of this nature.

In order to further advance with this GP it can be looked into how effective practical learning is and what feedback forms would be most effective. Although the literature supports the use of the alternative/practical approach. Feedback forms should still be examined in order to provide the project with an effective form that works well for the user. This is important for proper advancement of the GP as not a lot is known for the intended target group. Aside from the medium being effective according to previous, theoretical research. Thus looking into whether or not the results match the literature is a road that should be explored further.

2.2 Data Physicalizations

In order to understand the means by which this GP aims to answer its main research question an understanding of the audience is one thing. The method by which the audience is intended to be taught and with which they will interact is another. But what exactly the medium of data physicalizations that is being talked about is and some examples of them to better understand will be laid out in this section.

2.2.1 What are data physicalizations

The term data physicalization is identified by Jansen and colleagues (2015) as “a research area that uses physical data representations to help people explore and communicate data”. What this essentially entails is that data physicalization is a form of communication, separate from the ones that we use in our everyday lives, in order to effectively relay information based in data. Data physicalization can be seen as a branch-off to data visualization. One main form of data visualization is the use of charts. The all too familiar pie-chart and bar chart are some of the most well-known examples of this. But even videos explaining data with the aid of graphical assistance fall under the category of data visualization. All with the goal of making something that will mostly consist of terms that don’t make a lot sense to people easier to understand by translating them to a domain we can more easily process and understand.

Data physicalization builds on the basis of data visualization but, as is suggested by the term itself, translates data into the physical domain. This added dimension brings many advantages to data physicalization in comparison to the more tradition visualization and tackles the main issue of visualizations. This being that visualization are limited in their audience. As well as struggling with the representation of more abstract data, that cannot easily be translated into a chart or which may be hard to understand in video. The advantages of data physicalizations include: tangibility as described by both Schneider, Jermann, Zufferey and Dillenbourg (2011) as well as Dragicevic, Jansen and Vande Moere (2021), added depth perception, being able to play into people’s other senses such as touch, smell, sound and sometimes possibly even taste. Data physicalization helps to engage the user with the data though interaction, rather than just seeing visuals which, according to Stusak, Schwarz and Butz (2015) has been shown to decrease information decay within the users. It is this possibility for interaction and ability to be adapted for any audience that make physicalizations something more than visualizations.

2.2.2 Use cases of data physicalizations

Data physicalizations can find their application purposes in a large variety of fields. The main use cases are for demonstrational or educational purpose and the other large branch in which data physicalizations find themselves is in art. In the case of this graduation project we wanted to incorporate some of the art elements of physicalization in the sense that the prototype was to have a visual appeal where its main purpose would remain to be educational. One article that describes these educational purposes in more detail is that of Dragicevic, Jansen and Vande Moere (2021). This article branches of into the traditional educational applications, as well as analytics that help analysis or communication boundries that may be overcome with the aid of physicalizations.

One example of how physicalizations are used is a presentation by Hans Rosling. In this presentation [21] Rosling demonstrated how population growth can be interactively represented in the physical domain with the use of storage containers. The reason why this example is mentioned first is because it is an easy to understand and very beginner friendly introduction to the world of data physicalization.

Another example is the Augmented Reality Sandtable or ARES [22] which was developed for military planning. ARES combines the use and interactivity of sandtables, which have been around for thousands of years with height projection mapping. Here the physical domain on easily manipulated medium of sand is used, which of itself is not regarded a data physicalization. When this terrain, created with the sand, is then however taken and made into physical form of a height map. Which up to this point consisted of a flat image. It can now be regarded as a clear form of a data physicalization and has proven to aid the users to better understand the lay of the land.

Lastly it is important to note that no matter what type of data is being looked at, the physicalization will only be beneficial once a meaningful interaction is created. This entails that the data should not solely be presented to the user, but some form of connection has to be created between the action the user did to engage with the data and the information that is directed back to them, in order to take advantage of the added dimension.

2.2.3 Conclusion

Data physicalizations are well on their way to start playing an impactful role within our everyday life. The applications are almost limitless and the opportunities they offer to convey data that is sometimes proficiency dependent to the everyday person is wonderful. When creating a data physicalization however it is important to keep in mind the following key aspects. To start off with it is important to understand the use case that you are making the physicalization for. Because of the broad arrangement of possibilities that physicalizations offer and the doors they open it is of essence to select the exact method you want to go with. Having the ability to reach to all of the different elements they offer is great but trying to overwhelm your user is not what you want to be doing. Rather focusing on your core use case will help you decide which approach will fit best. Secondly it is of great importance to create an interaction with the chosen data that creates a meaningful interaction so that the physicalization will actually help the user understand. Picking the right use case with an interaction that is of no significance to either the user of the data used will result in an experience that will not feel natural or will simply not work.

Methods and Techniques

In line with the trend followed in the Bachelor that have lead up to this graduation project thesis the approach chosen was The Creative Technology Design Process (LINK HERE).

3.1 The Creative Technology Design Process

The Design Method used in the Creative Technology Design Process is a method that has been designed in order for students to position themselves in contrast to adjacent disciplines, which in the case of Creative Technology are Industrial Design Engineering, as well as ICT. The Creative Technology Design Process aids the designer of a research in making logical steps that progressively lead to a well based and structured paper that is easy to follow and most importantly makes it efficient for the researcher to construct their processes. As can be seen in figure 3.1 the design process follows I made up of four phases and the following structure.

The first phase of the process after the research question has been formulated is the conceptualization or ideation phase. Here the researcher is tasked with creating the starting foundation for the entire project, which in this case was the Air Quality Data Physicalization. During the Ideation phase the first looks, functions and interactions must be thought of. In the case of this project and many alike that follow this design process these first ideas come from brainstorming and inspiration gathered from background research to create a set of ideas as a core concept is to always try and discover multiple routes in order to come up with the best concepts. The Ideation phase can be found in chapter 4 of this thesis.

The next phase of the design process is called the specification phase. As the name of this phase suggests it further build on the foundational concept made in the ideation phase and specifications on the design are made. These specifications include the final choice of a concept look function. As well as constructing a list of components that may be used in order to construct the physicalization for the next phase. The specification phase can be found in chapter 5 of this thesis.

The third phase of the design process is called the realization. Here the look, function and components are all brought together and realized in order to actually construct the prototype physicalization and make it function. This section will describe the components that were actually used as well as the construction materials and code behind the prototype. The realization phase can be found in chapter 6 of this thesis.

The last phase of the Creative Technology Design Process is the evaluation. Here a rundown of the elements that were taken into the user testing will be presented. Furthermore the results of the user study will be looked into and analyzed together with the building of an answer to the hypothesis for the user testing, using these user test results.

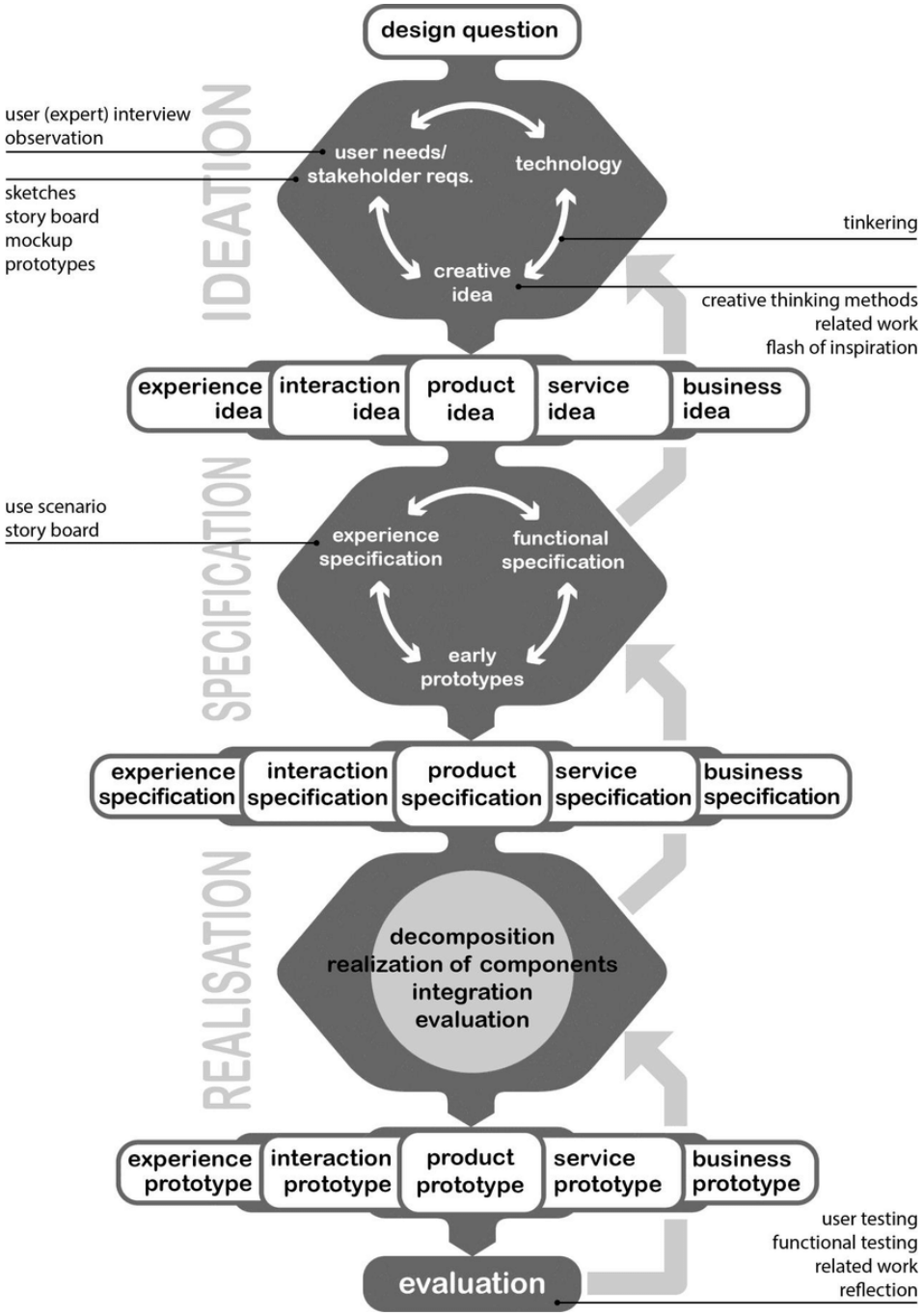

Figure 3.1: The Creative Technology Design Process

Design

This chapter will focus on the ideation phase of the Creative Technology Design Process. Here, multiple designs will be discussed, as well as ideas for the type of interaction that will be looked for.

4.1 Brainstorming

The backbone of the thesis was to create a data physicalization that would convey information about global air quality. The project consisted of multiple stages. First it was the implementation of a sustainable development goal, as well as the inclusion of related data on the topic. Next it was the creation of a data physicalization that would be able to convey the chosen data and lastly there would have to be a user test evaluation.

4.1.1 Integration of SDG

Starting off with the project the only objective was to create a data physicalization about air quality. Wanting to create something more than this the choice was made to include the integration of a UN [1] sustainable development goal into the project. The sustainable development goals can be seen below in figure 4.1. After deliberation on whether the climate action or life on land goal could already be seen being a part of the project, the choice was made to integrate sustainable development goal 4: Quality Education.

Figure 4.1: UN [1] Sustainable development goals

Within the sustainable development goal of Quality Education the United Nations has declared 10 targets for the year 2030:

4.1) By 2030, ensure that all girls and boys complete free, equitable and quality primary and secondary education leading to relevant and effective learning outcomes

4.2) By 2030, ensure that all girls and boys have access to quality early childhood development, care and pre-primary education so that they are ready for primary education

4.3) By 2030, ensure equal access for all women and men to affordable and quality technical, vocational and tertiary education, including university

4.4) By 2030, substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship

4.5) By 2030, eliminate gender disparities in education and ensure equal access to all levels of education and vocational training for the vulnerable, including persons with disabilities, indigenous peoples and children in vulnerable situations

4.6) By 2030, ensure that all youth and a substantial proportion of adults, both men and women, achieve literacy and numeracy

4.7) By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development

4.a) Build and upgrade education facilities that are child, disability and gender sensitive and provide safe, non-violent, inclusive and effective learning environments for all

4.b) By 2020, substantially expand globally the number of scholarships available to developing countries, in particular least developed countries, small island developing States and African countries, for enrolment in higher education, including vocational training and information and communications technology, technical, engineering and scientific programmes, in developed countries and other developing countries

4.c) By 2030, substantially increase the supply of qualified teachers, including through international cooperation for teacher training in developing countries, especially least developed countries and small island developing States

With the sustainable development goal selected and target 4.7 as inspiration the objective was slightly altered to now look into how different types of data physicalization interactions could impact young adolescent's user experience with the physicalization.

4.1.2 Data

Next up on the list of items to decide on during the ideation phase was the types of data that were going to be implemented and a part of the data physicalization. For this project a choice had to be made on the type of air quality data that was going to be the main driving force behind the data physicalization, as well as the countries that were going to be used for the user to interact with.

Air Quality Indication Values

The air around us is made up of a lot of different aspects. For this reason it was it first thought to be relatively hard. Considering air quality people may choose to look at the humidity of the air, the temperature, the oxygen levels or even the pressure levels. For this project the choice was made to look at two of the factors that are responsible for air being called polluted. These factors are the fine and respirable particle matter or PM2.5 and PM10 (from now on AQ or air quality). Furthermore the specific data that will be used is that of the AQ during the day of the respected country chosen. This in order to reflect on the time of day that most activity is present and therefore gives a better insight into the effect of humans on the air quality. As for the database that is used there were two options. There was the WAQI [2] database and the IQAir [3] database. In the end the choice was made to go with the data presented in the IQAir database as this one seemed to give more accurate readings, as well as allow for a better analysis per country.

Countries

In order to get an adequate test size the choice was made for 10 countries to be a part of the data physicalization. In order to select which countries were going to be a part of the physicalization two trains of thought had to be kept in mind. The final selection of countries must have a good spread of the entire spectrum, from good to bad AQ and they must have geographical significance (e.g. cover the entire globe or at least all continents). Using these

trains of thought the AQ of all countries that were represented in the IQAir database were observed for 10 days. The average values per country over these 10 days were then compiled into an ordered list. After this 10 countries were selected from the list, equally spread out over the spectrum of AQ, as well as being spread out across the globe.

This list, from best AQ to worst, ended up becoming:

- New Caledonia (Oceania)
- Sweden (Europe)
- Canada (North America)
- The Netherlands (Europe)
- Albania (Europe)
- Peru (South America)
- South Africa (Africa)
- South Korea (Asia)
- Qatar (Middle East/ Asia)
- Bangladesh (Asia)

4.2 First rough ideas

4.2.1 Design 1

The first design that was iterated over the ideation phase was that of a somewhat regular globe, but the base of which would function as the data physicalization where the user could use cutouts of countries. These cutouts would contain an RFID chip that would tell the system which country the user wants to explore. The system would then fill up a basin with the amount of water from its internal tank that corresponded to the AQ that could be found in this country. This design would approach visual feedback in a way that is not normally done. The sketch made for the first design can be seen in figure 4.2.

For this system the prototype would require the implementation of an RFID scanner and a water pump which would be controlled by a microcontroller like those from Arduino.

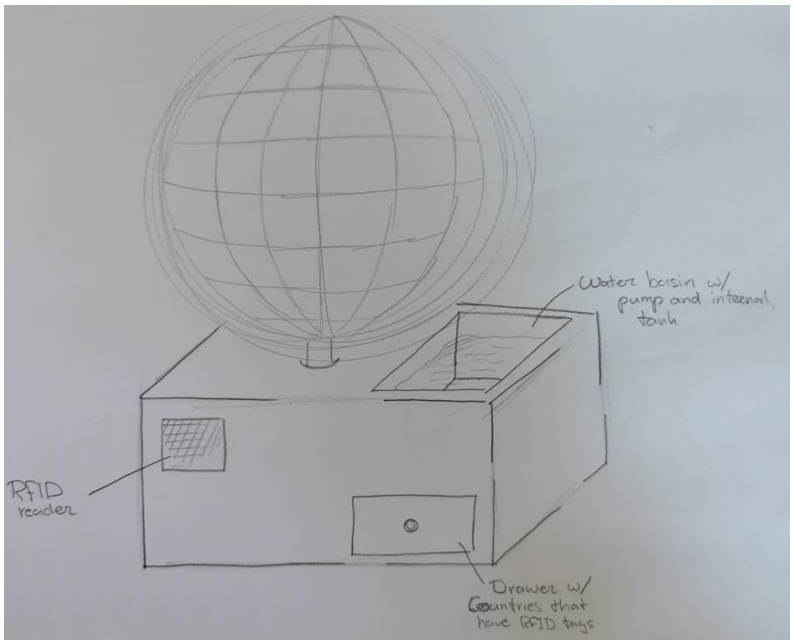

Figure 4.2: Sketch of first design

4.2.2 Design 2

The second design that was iterated over the ideation phase was that of another globe which would allow the user to place a different weight for each of the countries on an RFID scanner. When the weight is placed on the RFID scanner the system would know which country the user is wanting to explore and a small speaker unit in the corresponding country on the globe would start buzzing. The reason why an RFID scanner would be used instead of a scale is in order to allow for imperfections in the placement of the weight and for the device to look uniform. This design would combine both visual and audible feedback to the user in the form of the size and weight of the ‘country blocks’ and the buzzing made by the speakers in the globe. The sketch that was made for the second design can be seen in figure 4.3.

For this system the prototype would require the implementation of an RFID scanner and some buzzers which would be controlled by a microcontroller like those from Arduino.

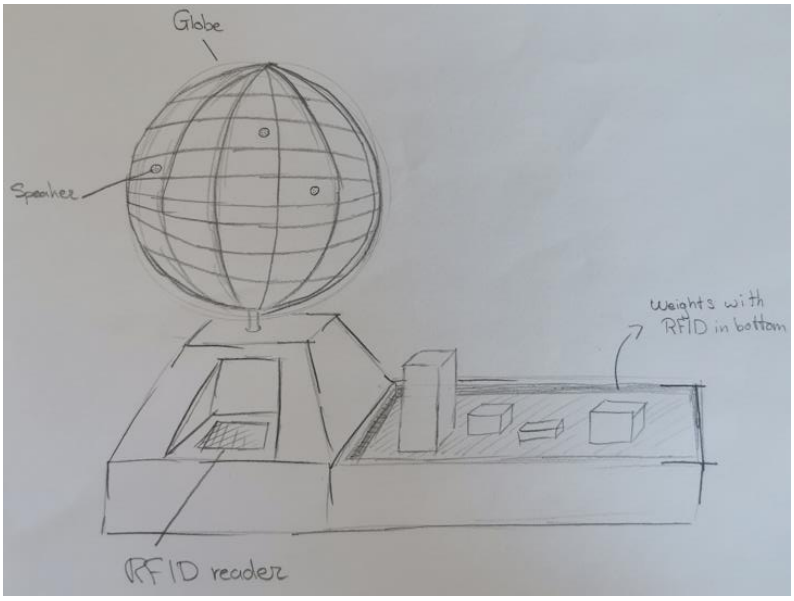

Figure 4.3: Sketch of second design

4.2.3 Design 3

For the final idea created in the ideation phase a different approach was taken. Instead of wanting to go digital with the use of RFID readers and microcontrollers this system would be entirely mechanical. The system would consist of a flat map of the earth where certain countries would be cut loose from the top plate. These countries would be attached to springs underneath that would lock when pressed down with enough force. The way in which the user would differentiate the AQ of the participating countries is by the variation in force required to push the countries down into their locked state. This design would combine the use of visual feedback in the form of countries being pressed down into the plate by varying amounts with the kinesthetic experience of having to apply the force yourself. This device would also need an unlock mechanism that could be pressed to release all the springs and reset the board. The sketch that was made for the third design can be seen in figure 4.4.

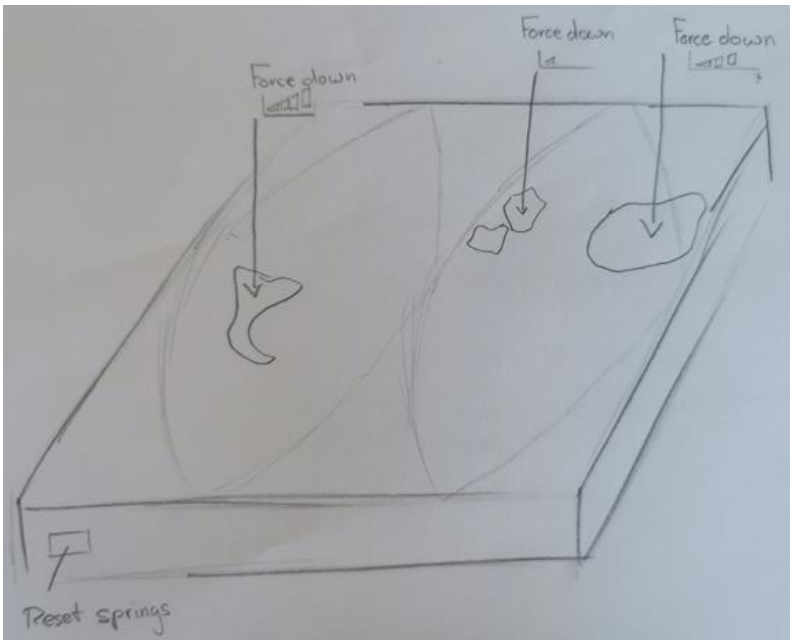

Figure 4.4: Sketch of third design

4.2.4 Final design direction

The final design direction for the data physicalization was inspired by the three initial ideas but deviate from them. The physicalization will be centered around a globe, in which a form of visual feedback will be implemented. Apart from this globe the system would include some form of kinesthetic experience or input method for the user so that the system would include both visual non-visual feedback. Lastly the design would focus on finding a good user experience.

4.3 Conclusion

Over the course of this chapter the ideation process behind the start of the data physicalization was presented. First the implementation of a sustainable development goal was accomplished by going for sustainable development goal 4: Quality Education. Furthermore, focusing the objective of the physicalization to creating a good user experience meant had now become the objective thanks to the inspiration of target 4.7.

After this the data that was to be used in the physicalization was selected. The choice was made to define AQ in the scope of this project as the concentration of fine and respirable particle matter. The specific data that was going to be used was the data from the IQAir database. Which was going to be observed over a 10 day period. From the data collected over this 10 day period a list was then created, ranking the participating countries from best to worst

air quality. In combination with the geographical spread of the countries the list was reduced to 10 countries. These 10 countries were going to be adopted into the data physicalization.

Lastly in this chapter three designs that were created during the ideation phase were discussed. These designs were all weighed up to one another and in combination with the project objective the final design direction was fabricated. This final design would include both visual and non-visual feedback for the user, include a globe and be focused on finding a good user experience.

Specification

Taking the ideas and concepts created in the ideation phase of the Creative Technology Design Process this chapter will discuss the specifications of the prototype that is going to be created during the realization phase. These specifications will consists of solidifying the concept, the design, the interactions and the requirements for the prototype.

5.1 Requirements

In order to start working on the conceptualization of the prototype a list of requirements must be created. These requirements will fall under two categories: functionality requirements, and usability and user experience requirements.

5.1.1 Functionality requirements

Functionality requirements are a set of targets that the prototype must have in order to operate properly. The list of functionality requirements for the data physicalization of this project consist of:

- The physicalization must be able to convey data in the physical domain.
- The physicalization must have a reset function.
- The physicalization must be able to switch between different input modes.
- The physicalization must contain a representation of the globe.

5.1.2 Usability and user experience requirements

Usability and user experience requirements are a set of requirements for the interactions that the user may have with the device, as well as user experience elements that may be measured with use of the data physicalization. In the case of this data physicalization the user experience requirements are chosen to provide a comparative measure between the DIY methods, as well as to the traditional input method.

- The physicalization must allow for the user to only use one input method at a time.
- The physicalization must allow for the users own input and should not have a predetermined display.
- The physicalization must be safe for users to interact with.
- The physicalization must provide a platform for efficiency and effectiveness.
- The physicalization must provide a platform for engagement.
- The physicalization must provide a platform for enjoyment.

5.2 Design specifications

Now that the requirements for the data physicalizations have all been set in stone the design of the device can be created. When it comes to the design two groups are created. The looks and the interactions.

5.2.1 Looks

For the final design iteration a sketch has been created on the eventual looks. This sketch can be seen in figure 5.1. For the final design a three part installation will be made. The central part of the design will be the base where the majority of the electronics can be housed. On top of this central unit there will be a globe, on which the participating countries will receive the implantation of an LED. This globe will act as the centerpiece of the design and function as the main medium for visual feedback. On the left side of the central unit there will be a smaller separate unit that may house the sliding potentiometer. To the right of the central unit there will be a tub which the user can fill with medium of choice. This tub will be housed within an external shell so that it may be removed for ease of resetting the medium, as well as ease of access to the inner workings of the module.

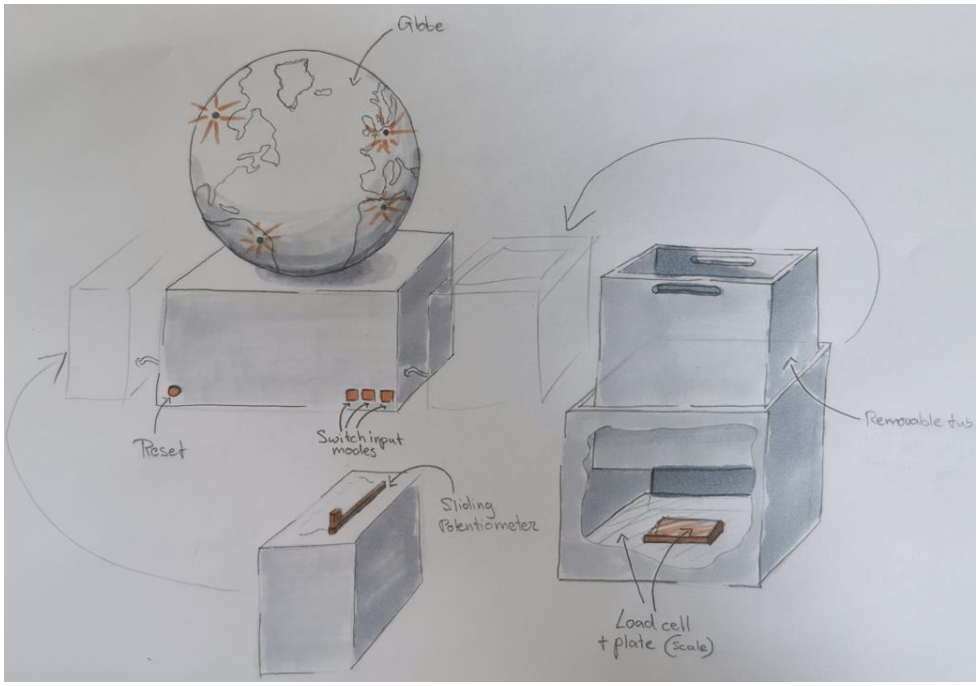

Figure 5.1: Final design

5.2.2 Interaction methods

Now that the looks of the device have been determined the interaction methods can be specified further. The three interaction methods that will be used with this data physicalization will be the slider -, filling -, and emptying method. From these methods the slider functions as the more traditional input method and the other two classify as the DIY input approaches.

Slider method

The first method that the data physicalization will contain is the use of a slider in order to set the desired air quality value. The slider will be attached to the roof of its unit, where the user may move the slider up and down. Moving the slider up will result in a better air quality value being selected whereas moving the slider down will result in a worse air quality being selected. The way the slider would function is by mapping the resistance values to correspond to the countries.

Filling method

The filling method will the first of the DIY approaches. The user will be tasked with filling a removable tub that sits within its own unit. The medium that the tub will be filled with are marbles. This was chosen as they have a decent weight to volume ratio and their spherical shape would allow for an effective use of the volume provided within the tub. Underneath this there will be a load cell. The load cell will translate the weight that is being put on it by the marbles in the tub into a digital reading. This reading is then mapped in a similar way to that of the slider. In the case of the filling method, the more weight that is added the better the air quality value will be.

Emptying method

The emptying method is in essence the same as the filling method. This is the second DIY approach and will consist of all the same elements as the filling method. Where the emptying method will differentiate itself from the filling method is in the fact that here, the more weight that is added onto the system, the worse the air quality value will be. This would be achieved by utilizing the mapping applied in the filling method, and reversing it.

5.3 System specifications

In order for the data physicalization to be created the slider and DIY input methods have to be created. These approaches would require a sliding potentiometer and a load cell. The system in its entirety will require more components than just that however. First of all a

microcontroller will be needed in order to make the physicalization work. For this project this will be the Arduino Uno [24]. The list of all the primary components that will be needed are:

- Arduino Uno
- Sliding potentiometer
- Load cell
- Shift registers
- LEDs
- Push buttons

These components will now be discussed in a bit more detail to explain what they are and what they do.

5.3.1 Arduino Uno

The Arduino Uno, which can be seen in figure 5.2, is the core component of this entire physicalization. The Arduino is an Italian made microcontroller that has been designed to function well for rapid prototyping of devices and DIY engineering. The reason why the Arduino has become so successful and beloved in the engineering community is due to the ease of use and the engineering behind it. The build in functionalities allow the Arduino to interact with a plethora of components right out of the box. This list includes motor, sensors, LEDs as well as analogue inputs. Furthermore the Arduino comes with its own coding tool. The Arduino IDE [25] is an open source software program where code for the Arduino to run off can be written. Once the code has been written, this can then be uploaded to the Arduino microcontroller's internal memory for it to run off. Thus not requiring the device to be permanently attached to the computer.

In case of this project, the choice was made to not use an external power source and in turn keep the Arduino plugged into the laptop, for ease of access to the code, as well as the device always remaining stationary and thus not needing to be moved a lot.

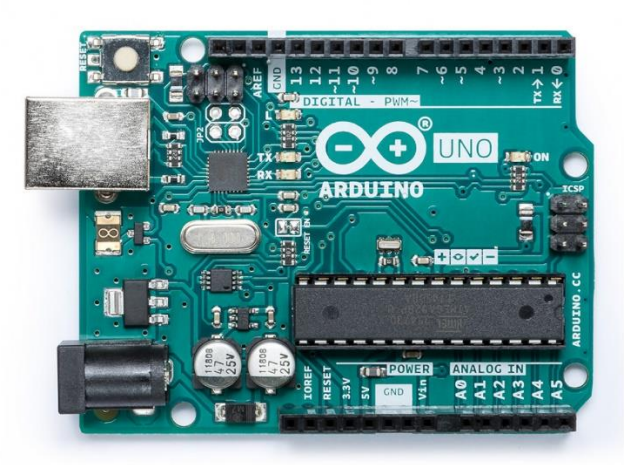

Figure 5.2: Arduino Uno top view

5.3.2 Sliding potentiometer

Sliding potentiometers function in essentially the same way that a regular potentiometer would. That is, that is has a variable resistor which will limit the flow of current through the device. Thanks to this mechanism the outgoing flow can be measured and used as a variable input source to any project. The physical different between a regular potentiometer and a sliding one is in the name. Where the regular potentiometer has the appearance of a knob and can be turned like the dials of a clock, a sliding potentiometer is a slider, it can travel along 1 axis. The choice to go with the sliding potentiometer was made because it would result in a somewhat more intuitive feel as well as ease of use for young adolescents.

5.3.3 Load cell

In order for the system to register the weight that is put in the tub of the DIY unit a system was required for the force of the weight to be measured. Although the initial plan was to go with a force sensor, this was later swapped out for a load cell. The reason behind this choice was the fact that the force sensors required a very even weight distribution, as well as having the surfaces on which it is attached, and where the weight is coming from to be exactly parallel. The fact that the force sensor seemed to be a lot more fragile also played a role. As said the choice was thus made to go with a load cell. The type of load cell that was used is something called a strain gauge load cell. What this type of load cell essentially does is it measures electrical resistance changes in response to, and proportional of, strain applied to the device. In the case of the ‘scale’ that is created for this project, it measures the force applied to it.

5.3.4 Shift registers

A shift register [26] a device that will in sense increase the number of outputs that one may be able to use. In the case of this project shift registers were needed for the control of the LEDs as there were not enough output pins on the Arduino Uno itself. The way in which a shift register handles the increasing of outputs if by storing and transferring binary data. The shift register is able to transfer a single line of binary input, consisting of 8 bits, to 8 different output pins. Each of the bits in the binary line are allocated to one output pin. These pins all work on a flip-flip mechanism where the shift register will allocate an output based on whether the bit that corresponds to the output pin is written as a 1 or a 0. Here the 1's indicate that the output pin should be active or on and 0 means the pin should be inactive or off.

5.3.5 LEDs

LEDs will be used within this project as the form of visual feedback. When the signal to the LED is active it will produce a light bright enough to be easily noticed by the user. With an inactive signal the LED will remain off.

5.3.6 Push buttons

There are four functionalities that have to be able to be selected when using the data physicalization. The system has to be able to reset the LEDs and tare the scale when in between users as well as switch between all three input modes. These actions will be handled with the use of push buttons. When a button is pressed this will send a signal to separate pins on the Arduino, where the Arduino will see from which pin the signal originates, in order to automatically perform the given action.

5.4 Conclusion

Over the course of this chapter the overall system requirements were made clear. The functionality requirements describe that the system should be able to convey data in the physical domain, have a reset function, switch between different input modes and contain a representation of the globe. Furthermore the list of usability and user experience requirements state that the system should allow for the user to only use one input method at a time, for the users own input and should not have a predetermined display, be safe to interact with as well as provide a comparative platform for: efficiency and effectiveness, engagement and enjoyment. From here on out the final design sketch was created and the interactions, as well as components were gone over. The user can be assigned to use either the slider method, which

would function as the traditional form of input or one of the two approaches to the DIY input of using marbles to indicate the air quality value.

Realization

With all of the specifications for the data physicalization set in stone the project can now be materialized and created before the user testing and evaluation phase. During the realization phase described in this chapter various components will be laid out in reference to the system as a whole, the housing for the prototype will be discussed and the code explained.

Electronic components

With all the components that have gone into the prototype a distinction has been made between the electronic and housing elements. The electronic components listed in this chapter are those that would require some extra explanation as to how they are implemented. As these consist of modules and are therefore standalone parts, rather than listing all elements.

Sliding potentiometer

The potentiometer used in the construction of the prototype is a 10 kΩ sliding potentiometer with an analogue output. This potentiometer possesses a total of 6 pins, of which 3 were used for the installation. These three pins are the VCC input pin, which is connected to the 5v output of the Arduino Uno, the second pin is the GND pin, which is connected to the ground of the Arduino Uno, and the third pin is the OTA output pin, which is connected to the analogue input 1 pin of the Arduino Uno.

Load Cell

The load cell used in the construction of the prototype is a 1KG strain gauge load cell. This entails that the specific load cell used in this project is rated for taking up to 1KG of force safely and reliably. Going over the limit of 1KG will not break the device as it is plenty strong but it may damage it to the point where the readings will become unreliable or unstable. This load cell can however not simple be connected directly to the Arduino Uno. The load cell is first wired up to a HX711 load cell amplifier. This step is necessary as the strain gauge within the load cell only gives of tiny measurements. These are then amplified and translated into values that correspond to whatever unit of measurement is required. In this case grams. The outputs of the HX711 load cell are connected to the Arduino Uno. The GND pin is connected to the ground of the Arduino Uno. The DT pin is connected to the Arduino Uno’s output pin 2. The SCK pin is connected to the Arduino’s output pin 3. The last pin of the HX711 is the VCC input pin which is connected to the 5v output of the Arduino Uno.

Shift register

As stated before the shift registers used in the prototype allow for the addition of outputs without the need of a larger microcontroller. Because of this shift registers have quite a few pins that need to be connected. The shift registers used in this project are the SN74HC595N 8-bit shift register. As there shift registers have no notations of pins figure 6.1 has been provided to give a clearer overview of the pin connections described here. To start off with, the shift register has a total of 8 outputs are discussed previously. These output pins are pins: 1,2,3,4,5,6,7 and 10. These pins are each connected to their own 330 Ω resistors, which then lead into an LED. The resistor is a required addition here as, with the use of the shift register the Arduino Uno's internal pullup resistors cannot be used to be directly connected the LEDs. The output of the LED is then connected directly to the ground of the Arduino Uno.

Continuing with the connections of the shift register, pins 9 and 15 are the voltage input pins and are thus connected to the 5v output on the Arduino Uno. Pins 8 and 12 on the shift register are connected to the ground of the Arduino Uno. This leaves the 4 more pins to be connected. As this project uses two shift registers in series, pin 13 (the latch pin) from the first shift register is connected to both pin 6 on the Arduino Uno and pin 13 on the second shift register. This same method applies to pin 14 (the clock pin) where pin 14 on the first shift register is connected to both pin 14 on the second shift register and pin 7 on the Arduino Uno. Lastly pin 5 on the Arduino Uno is connected to pin 11 (the data pin) on the first shift register. As we use two shift registers the data needs to be passed onto the second shift register as well, but in contract to how this is tackled with the latch and the clock pin, this is done by connecting pin 16 (the data output pin) from the first shift register to pin 11 on the second shift register. This will leave pin 16 on the second shift register without a connection.

Figure 6.1: Shift register pin layout

Circuitry

The electronics circuit that was created for the realization and of which the main components were explained in the section above, can be found in Appendix A.

Housing

The housing of the data physicalization consisted of laser cut pieces of mdf plywood. This plywood has a thickness of 4mm and was therefore ideal for the construction of the housing for the slider, DIY methods, central housing and the globe as it delivered a good balance of weight to strength.

Slider Housing

The housing of the slider module consists of an mdf plywood box of 20x10x12,5 cm and can be seen in figure 6.2. The housing has an opening in the top where the sliding potentiometer penetrates through in order for the user to easy access the slider itself and move change its position.

Figure 6.2: Slider module

DIY methods Tub Housing

The housing for the DIY module consists of two parts as can be seen in figure 6.3. The module consists of the outer shell which hold the electronics and the load cell on its bottom plate and the inner tub which can be removed for easy access to these electronics as well as functioning as a quick method of dumping the contents out.The dimensions of the outer shell are 15x15x12,5 cm whereas the tub needs to fit inside and therefore is 14,1x14,1x12,5 cm. The outer shell also has holes drilled into each of the 4 sides, near the bottom plate. This is in order

to increase and allow airflow out the bottom in order to not create a near-vacuum underneath the tub when it is placed in the shell. If these holes were not present the tub would be sucked onto the load cell and a constant false measurement of applied force would be taken. It also further improves the ability for the tub to be taken out of the outer shell easily. The tub itself also has slots cut out of the top for the user to more easily get a hold of the tub to lift it up.

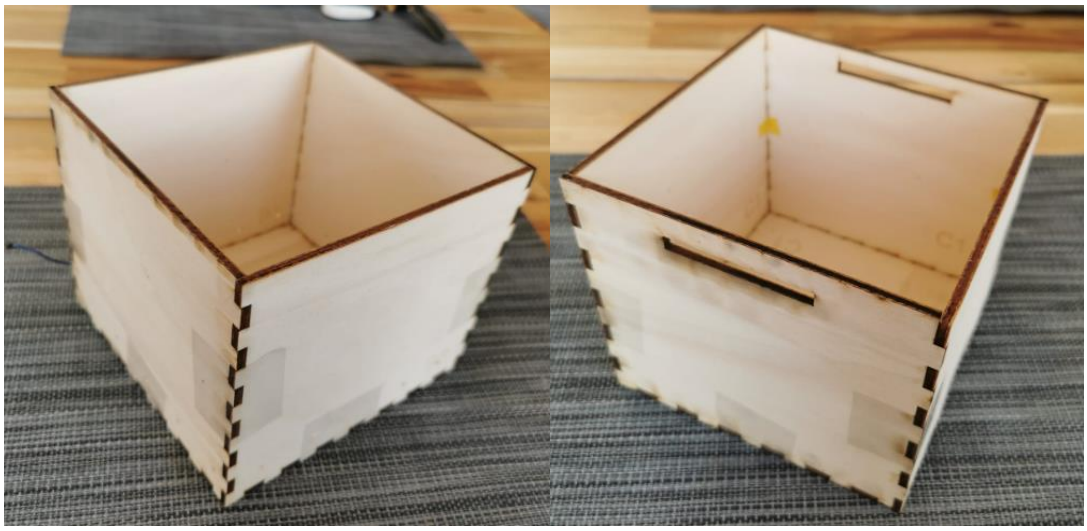

Figure 6.3: DIY / Tub module

Central housing

The central housing hold the majority of the electronics inside as well as the Arduino Uno and therefore had to be quite large to accommodate all of this, plus allow room for the wiring to the LED to have some freedom. The central unit can be seen as the bottom construction in figure 6.4 and consists of a 20x20x12,5 cm box with a hole cut in the top for the wiring of the LED's to go through to the globe which rests on top.

Figure 6.4: Central module

Globe

The globe was the most difficult part of this project's construction. At first the plan was to 3d print a plastic globe but in line with the sustainable development goals of the UN this choice was cancelled. Instead the globe were to also be made out of the mdf plywood that the rest of the modules consisted of. After doing research on the possible shapes the choice was made to go with a truncated dodecahedron as it was close enough to a sphere to convey the image of a globe, while consisting of a reasonable number of parts. The final shape consists of a combination of hexagons and pentagons with a side length of 4,6 cm each as the first version has a side length of 4 cm but deemed too small for the LEDs to fit well inside of the country borders. The final construction of the globe was left in 2 pieces, the top half and the bottom half, which can be separated from one another for easy access to the wires connected to the LEDs. The final challenge for the globe was the creation of a 'UV map' of the earth that allowed for it to be projected onto this shape. This was eventually tackled as can be seen in figure 6.5, where the globe is shown.

Figure 6.5: Globe element

Code

The code that was created for this project had to contain a few elements:

- It had to contain a method for a reset option of the LEDs
- It had to allow for the switching between modes using the push buttons
- It had to have a method for the slider input to be read and mapped
- It had to have a method for the load cell input to be read and mapped for both DIY approaches
- It had to be able to send instructions to all 10 LEDs using the shift registers

All of this was accomplished and can be found in Appendix B where the entire code made in the Arduino IDE can be seen.

Evaluation

7.1 User Study

The goal of the user study is to figure out if the implementation of a DIY element to the input for a data physicalization about air quality will affect the user's experience by means of comparing a more traditional input method with 2 approaches to DIY.

7.1.1 Variables

The independent variables of this study are: The different input methods utilized by the physicalization consisting of: moving the slider for different air quality values, filling up the tub for good air quality values and emptying the tub for good air quality values). The dependent variables of this study are the Efficiency (time taken to answer the tasks) of the input methods, the Effectiveness (accuracy of the answers given) of the input methods, the engagement (both physical and intellectual activity) with each of the input methods as well enjoyment of each of the input methods.

7.1.2 Hypothesis

Based on the general assumption that the children will be better engaged with a more fun based effort as well as feeling more playful, in addition to a better visual and physical representation the tub-method would outperform the slider base test in user experience. Within the 2 specs of the tub-method the assumptions made that the children will subconsciously associate a higher value with a higher volume or "more means better". Because of which the filling up for a better AQI score will most likely outperform the emptying for a better AQI score.

7.1.3 Study Design

The study will follow the 'between subjects design'. Three groups will be interacting with the same study flow, with the exception of the method they will use for the interaction. The selection of student to method will be random in both positions (e.g. student 1 method 1, student 7 method 3, student 14 method 2, etc.) and person but equal in sample size.

7.1.4 *Participants*

36 Participants were involved with the conducting of the user study. The only specific requirement is for the students was for them to fall within the age range of 11-13. Previous experience or active engagement with the subject may be taken into account in the analysis if shown to be significant but will not impact one's ability to participate in the study. Recruitment was done through teacher contact. Via whom the consent forms and information brochures were transferred to the parents.

7.1.5 Procedure

In order to effectively introduce the subject, as well as background information on who is behind the study and why the study is being performed, a general introduction will be given in front of the class. This should also start to break down a barrier between the students and the researcher as they are introduced before the study starts and will therefore hopefully act more natural during the study itself. The study will take place in a 1 on 1 scenario and last around 15 minutes each. During each study there will be the moderator and observer present with the student. Firstly the student will be asked about their current knowledge or engagement with the topic. Following this the moderator will give a small introduction to the use of the device, as well as lay out the flow of the experiment. Thirdly the student is asked to interact with the device. Fourthly the student will be asked some questions about the interaction they just had and given the opportunity to ask questions themselves. Lastly the student will return to the classroom where they, at the end of the full experiment (all participants are done) will receive a final note that they will be asked to fill out (moderator not present), asking their opinion on the device.

7.1.6 Tasks

The general flow for the task performance was similar in all three methods and was as follows:

1: The user is to use the slider or either container method (depending on their assigned method) to examine the use of the device and ‘play’/ get a feel for it’.
Here Examine implies to use the input method, see what happens, walk around it (find the outputs)

2: The user is to use the slider or either container method (depending on their assigned method) to light up specific AQI value corresponding countries.

The specific tasks to be performed were the same for each method in order to get an effective comparison and consisted of:

1: Could you please find the country with the worst air quality?
2: Could you please find the country with the best air quality?
3: What is the difference in air quality between country X and Y?
4: Which of the countries have an air quality that is comparable to that of country X?
5: Could you please rank countries X, Y and Z in the order of best to worst air quality?
6: Could you please rank countries X, Y and Z in the order of worst to best air quality?
7: Could you please tell me which countries lie between country X and Y when it comes to their air quality?

In order to reduce the amount of answer exchanges outside of the experiment as well as reduce the learning effect while interacting with the device (data physicalization) a set of order and country variations were created between the users. These variations can be found in Appendix E, where the entire user testing document used during the experiment can be found.

7.1.7 Data Collection

As a primary form of data collection all of the answers to the questions and tasks during the task were written down by the observers, as well as the answers to the after experiment notes being collected at the end of the day. In the case of the note that was handed out at the end of the day, there the use of the different task variations was used in order to make sure the answers from the experiment were grouped together with the answers to the note, from the same student without collecting any Personally Identifiable Information. This was done by letting the students write their name on the note they would receive at the end of the day during the experiment. All of the notes were then given to the teacher who is familiar with the names of the students in order to hand them out. Once the students had filled in the information the teacher would collect the notes and remove the names off the top of the note by trimming them off.

Other than the answers received directly form the users, the observers are tasked with note taking on the behavior and facial expressions of the users in order to get insight into the natural/autonomous responses to the user's interactions with the data physicalization.

7.2 Results

The list of independent and dependent variables described above will be used in order to create a structured analysis of the results. For each of the independent variables their effect on

the independent variables will be looked into. This will yield the following structure: First the efficiency while using the slider will be looked into, followed by the efficiency of the tub having to be filled for good AQ, followed by the efficiency of the tub having to be filled for bad AQ. This method of comparing the dependent variable in each of the independent variables will then be applied to the effectiveness, the engagement and the enjoyment. A full list of all of the answers to the interview questions, experiment tasks and after experiment questions can be found in Appendix G.

During the testing phase of the slider method there were multiple students that requested to stop with the tasks and continue to the questions. This resulted in an uneven sample size per question for the results of the slider method. In the case of this analysis the choice was made to go with pairwise deletion, also known as available-case analysis. Because of this the analysis will be performed on the available sample sizes. This mean that the data of the slider test will be on a sample size of 10 or 11 instead of 12. For a list of the tasks that were not performed, please refer to Appendix G where all of the answers from the experiment can be found.

7.2.1 Efficiency

The efficiency of the different input approaches used by the data physicalization are determined by the time it took the participants to answer the tasks prescribed to them during the tasks phase of the experiment.

Slider

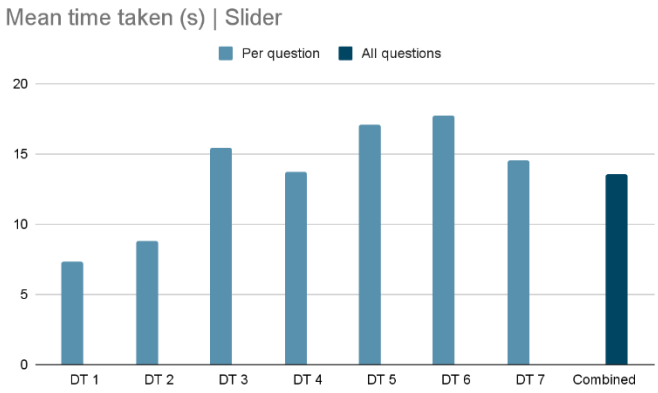

Figure 7.1: Average time to answer tasks for the slider input method

In figure 7.1 the average time for the users who used the slider method to answer the tasks can be seen. The average time it took the students to answer DT1 was 7.36 seconds, DT2 took an average of 8.81 seconds, DT3 took an average of 15.45 seconds, DT4 took an average of 13.73 seconds, DT5 took an average of 17.1 seconds, DT6 took an average of 17.72 seconds and DT7 took an average of 14.54 seconds. The average time it took the users of the slider per task was 13.53 seconds. As was expected the questions where comparisons between countries were asked or where the user was tasked to look at the values of multiple countries and order them took longer than DT1 and DT2 where the user was simply tasked with finding the countries with the min. and max. values.

Filling

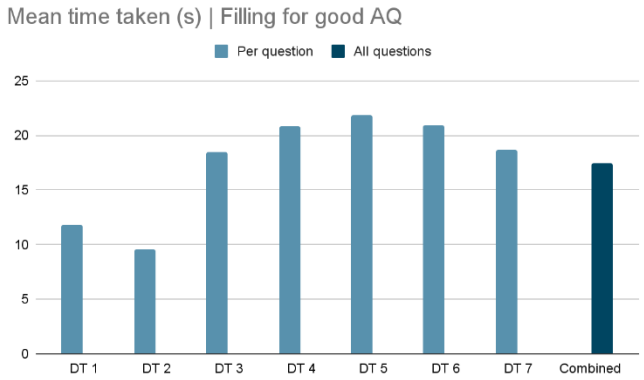

Figure 7.2: Average time to answer tasks for the filling input method

In figure 7.2 the average time for the users who used the filling method to answer the tasks can be seen. The average time it took the students to answer DT1 was 11.83 seconds, DT2 took an average of 9.58 seconds, DT3 took an average of 18.5 seconds, DT4 took an average of 20.83 seconds, DT5 took an average of 21.83 seconds, DT6 took an average of 20.92 seconds and DT7 took an average of 18.66 seconds. The average time it took the users of the slider per task was 17.45 seconds. As was also illustrated in the slider methods efficiency the questions where comparisons between countries were asked or where the user was tasked to look at the values of multiple countries and order them took longer than DT1 and DT2 where the user was simply tasked with finding the countries with the min. and max. values. One interesting element that changed between the slider and the filling method is the fact that relation of the time taken between both task 1 & 2, as well as 3 & 4 has reversed.

Emptying

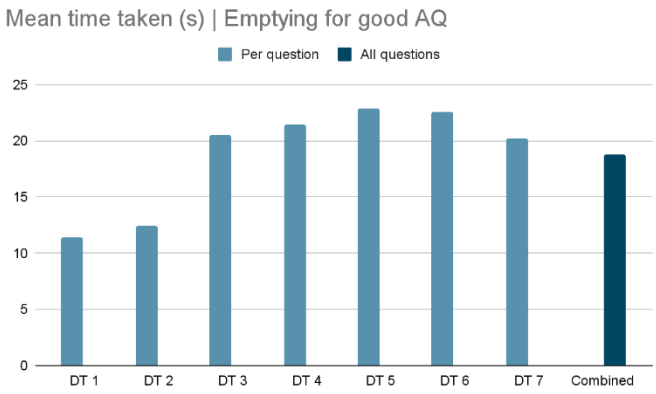

Figure 7.3: Average time to answer tasks for the emptying input method

In figure 7.3 the average time for the users who used the emptying method to answer the tasks can be seen. The average time it took the students to answer DT1 was 11.42 seconds, DT2 took an average of 12.42 seconds, DT3 took an average of 20.5 seconds, DT4 took an average of 21.42 seconds, DT5 took an average of 22.83 seconds, DT6 took an average of 22.58 seconds and DT7 took an average of 20.17 seconds. The average time it took the users of the slider per task was 18.76 seconds. As was also illustrated in the slider methods efficiency the questions where comparisons between countries were asked or where the user was tasked to look at the values of multiple countries and order them took longer than DT1 and DT2 where the user was simply tasked with finding the countries with the min. and max. values. Here, the same relation between task 3 & 4 can be observed as in the filling method. But the relation between task 1 & 2 seems to take a preference to that seen in the slider.

Comparison

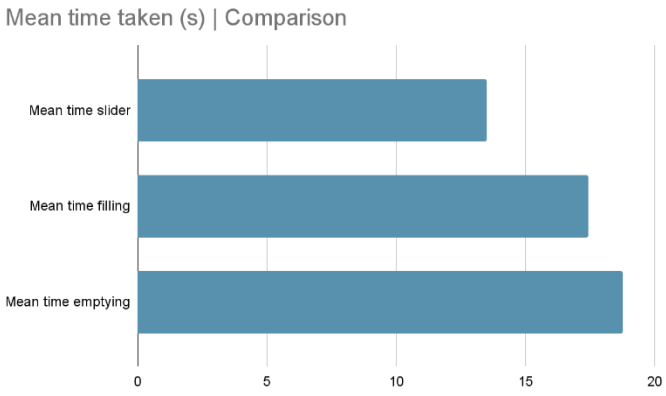

Figure 7.4: Comparison of average time to answer tasks across all 3 methods

Now looking at the differences in average time taken to answer the tasks across the three methods used. It can be seen that the slider takes the least overall time with an average of 13.53 seconds as stated previously. The average time for the tasks of the filling method comes in at 17.45 seconds. This is an increase to the slider time of 129%. The emptying method then comes in at an even higher average than the filling method of 18.76 seconds. Which translates to an increase to the slider time of 139%.

7.2.2 Effectiveness

The effectiveness of the different input approaches used by the data physicalization are determined by the accuracy of the answer to the tasks prescribed to them during the tasks phase of the experiment.

Slider

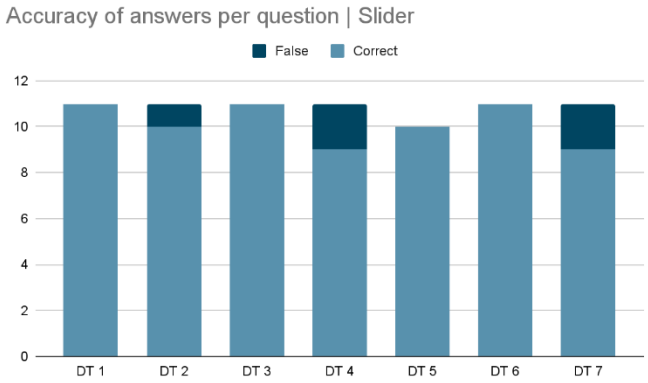

Figure 7.5: Accuracy in terms of correctness for tasks of slider method

As shown in figure 7.5 the users that participated in the slider test had a total of 4 tasks where no mistakes were made, 1 task where a single mistake was made and 2 tasks where 2 mistakes were made. This translates to the accuracy of DT1 being 100%, the accuracy of DT2 being 90.91%, the accuracy of DT3 being 100%, the accuracy of DT4 being 81.82%, the accuracy of DT5 being 100%, the accuracy of DT6 being 100% and the accuracy of DT7 being 81.82%.

Filling

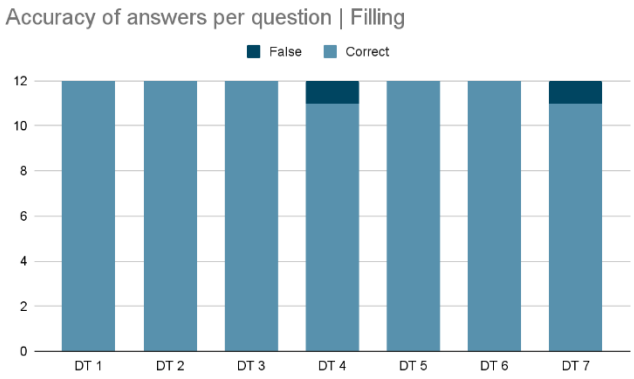

Figure 7.6: Accuracy in terms of correctness for tasks of filling method

As shown in figure 7.6 the users that participated in the filling test had a total of 2 tasks where a single mistake was made. This translates to the accuracy of DT1 being 100%, the accuracy of DT2 being 100%, the accuracy of DT3 being 100%, the accuracy of DT4 being 90.91%, the accuracy of DT5 being 100%, the accuracy of DT6 being 100% and the accuracy of DT7 being 90.91%. In comparison to the slider method, no mistakes were made in DT2.

Emptying

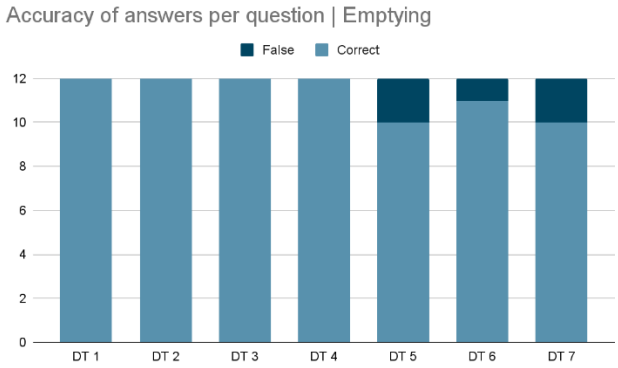

Figure 7.7: Accuracy in terms of correctness for tasks of emptying method

As shown in figure 7.7 the users that participated in the filling test had a total of 1 task where a single mistake was made and 2 tasks where 2 mistakes were made. This translates to the accuracy of DT1 being 100%, the accuracy of DT2 being 100%, the accuracy of DT3 being 100%, the accuracy of DT4 being 100%, the accuracy of DT5 being 80.82%, the accuracy of DT6 being 90.91% and the accuracy of DT7 being 80.82%. In comparison to the slider and

filling method, no mistakes were made in DT2 or DT4, but mistakes were now made in DT5 and DT6 which are raking tasks.

Comparison

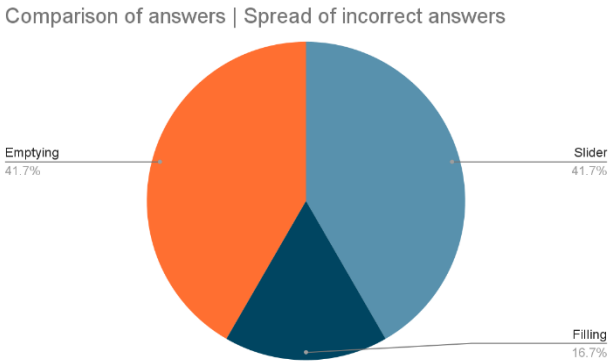

Figure 7.8: Comparison by means of incorrect answer spread for all 3 methods

Looking at the spread of mistakes made over all three methods, as seen in Figure 7.8. Both the Slider and the Emptying method resulted in had the same amount of mistakes. This spread illustrated that 41.7% of the mistakes across the entire experiment were made using the slider method. 41.7% of the mistakes made were in the Emptying method and only 16.7% of the mistakes made were with the use of the Filling method. Thus demonstrating that with the use of the filling method the students were able to more accurately answer the tasks.

7.2.3 Engagement

The engagement of the user is based on the physical and intellectual activity of the user during and after the use of the physicalization. For the physical activity observations were made on the body language of the user. For the intellectual activity more aspects were considered. Here the user's response to AT3 was used, the amount of questions asked regarding the physicalization or topic and the memorability of the interactions and data presented during the testing phase.

Physical activity

For the slider method only 3 of the users displayed an active stance throughout the entire testing. The other users all started on the same level of active body language but this reduced as the tasks progressed. For the filling methods all of the participants displayed an

active body language and seemed to be interested in working to get to answer the tasks as best as they could. Furthermore the precision with which they altered the amount of marbles present within the tub increased as they used the device more. Lastly the users of the emptying method acted in a similar manner to that of the filling method the participants as they all displayed an active body language throughout the experiment. Something that did not happen in the same way that was perceived within the filling method was the increase of precision with which the marbles were altered.

Intellectual activity

One of the questions asked right after the experiment (AT3) was what the user believed the purpose of the use of a system like this would be. Although the answers to these questions are not of a direct relation to the intellectual activity it may give insight into how serious the user might take this topic after being exposed to the data presented in the physicalization. The categories that the answers given fell into were: no effort made (N.E.), holiday destinations (H.D.), global wellbeing (G.W.), stimulation of air preservation (S.o.A.P.) and geographical spread of air quality (G.S.). These categories can then be clustered into two groups where the no effort and holiday destination responses fall under the lower seriousness or lower intellectual activity range, whereas the others show more thought went into their answer and thus showed more intellectual activity.

Slider

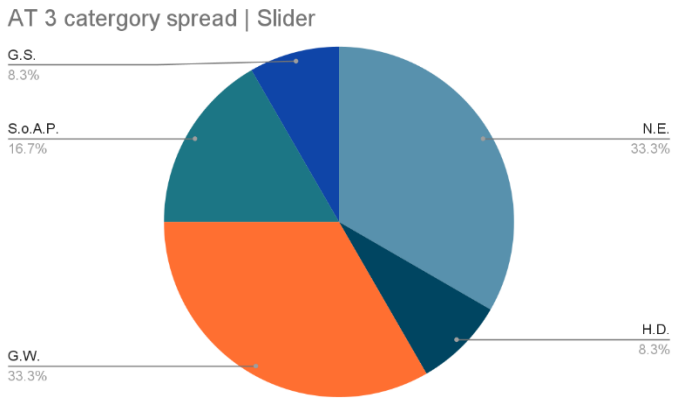

Figure 7.9: Distribution of AT3 response themes for the slider method

As can be seen in figure 7.9 the majority of the users of the slider method responded to AT3 with the topic of Global Wellbeing at 33.3%. The second largest category that these users

responded with was the no effort category. These responses consisted of the user not knowing what to say or stating that there were no benefits from their point of view. Following this the third largest response topic was that of stimulation of air preservation at 16.7% of the responses. Tied in last place with 8.3% of the responses respectively were the topic of global spread of air quality and those that responded with a holiday destination related answer.

Filling

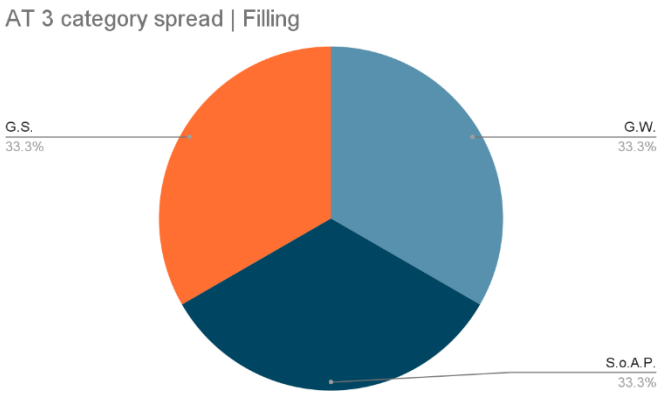

Figure 7.10: Distribution of AT3 response themes for the filling method

As illustrated in figure 7.10 the users of the filling method came back to answer AT3 with an even spread of topics. Here the topics of global spread of air quality, global wellbeing and the stimulation of air preservation all got an equal 33.3% response rate. Furthermore, in comparison to the slider method, the topics that were stated as taking less mental engagement were not mentioned at all.

Emptying

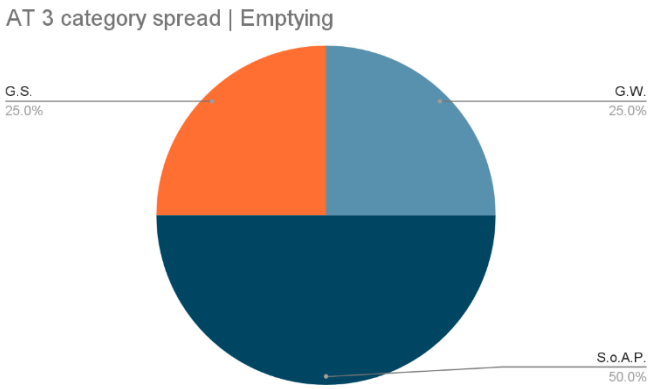

Figure 7.11: Distribution of AT3 response themes for the emptying method

As illustrated in figure 7.11 the users of the emptying method came back to answer AT3 with the same three topics as the filling method but a different spread. These topics were those of global spread of air quality at 25%, global wellbeing at 25% and the largest shareholder being the stimulation of air preservation at 50% of the responses being centered on this topic. Furthermore, as was the case with the filling method the topics that were stated as taking less mental engagement were not mentioned at all.

Another way in which intellectual activity or mental engagement can be observed is by the interactions that come from the user and are targeted to the researcher in order to learn more about the topic. In the case of this research the users were actually asked if they had any questions after they had finished using the experiment. Here the users of the slider method returned 1 question, the users of the filling method returned 6 questions and the users of the emptying method returned 4 questions.

A core aspect of intellectual activity is the fact that when somebody is more engaged with something, then they tend to remember these things better. This was put to the test by use of the first questions on the note handed to the users after the experiment was completed. The responses to the first two questions on this note can be found back in Appendix G. Here it can be seen by the responses to PR1 that the users of the slider method appeared to remember the feedback from the LED's as well as the looks of the globe more than the other two input methods. For both the filling as well as emptying method the users seemed to better recall the manner in which they had to utilize the marbles to select the appropriate countries. The responses to PR2 trail back to a more quantitative memorability. Here it showed that the users

that were given the slider method were generally able to recall less information about the countries that they had interacted with than the other two DIY methods utilizing marbles.

7.2.4 Enjoyment

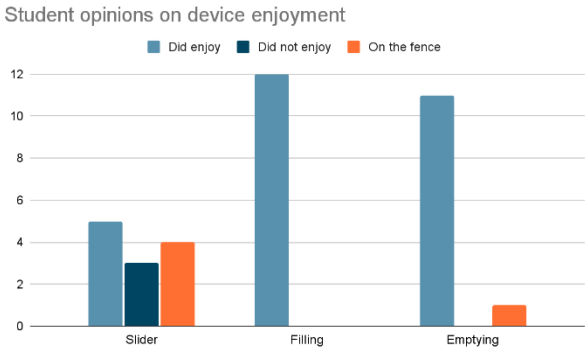

Figure 7.12: Student conveyed enjoyment for all 3 methods

During the after testing interview the users were asked to reflect on their use with the device and state what they thought about it. All of these responses can be found back in Appendix G but translated to results shown in figure 7.12. Here it can be seen that the users stated to enjoy the filling method the most with a 100% positive feedback rate. Closely behind the filling method comes the emptying method, where 90.91% of the users reported to enjoy using the device. Where 1 person was still not sure whether they enjoyed using the physicalization or not. Where the opinions on whether or not the device was enjoyable really start to differentiate between users is with the slider method. The slider method yielded a total of 5 people saying they enjoyed it, 3 people saying they did not enjoy it and 4 people saying that they are not sure whether they enjoyed it or not. This means that only 45.45% of the users from the slider method stated that they believed the physicalization was enjoyable.

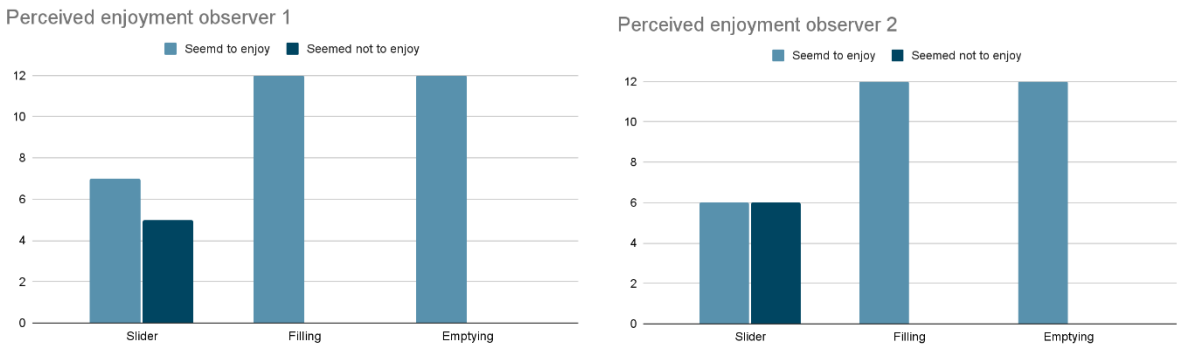

Figure 7.13: Perceived user enjoyment from observer 1 & 2 for all 3 methods

In order back up the potentially biased opinions given to the question mentioned in the section above. Where the users were asked to give their opinion on whether they believed the physicalization was enjoyable. Two observers were present to look at the audible and facial expressions that could be linked to the user's enjoyment. The facial expressions that were taken into consideration for this analysis were expressions such as smiles and frowns. Whereas the audible expressions were more in the direction of sighs, laughs. From this, the charts seen in figure 7.13 were constructed. There charts seem to match the opinions given by the students quite well. With a slight lean towards having less of an enjoyable experience for those that used the slider and were still on the fence. Whereas the one person from the emptying method displaying behavior that seemed to indicate he was at least enjoying the physicalization more than he was disliking using it.

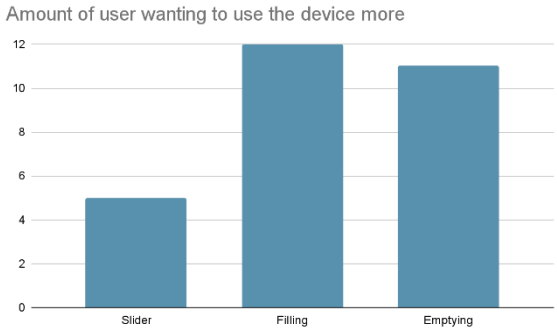

Figure 7.14: Amount of user wanting to use device after experiment for all 3 methods

Lastly the users were asked whether or not they would be willing to use the device more often after the experiment if they were to have access to it. Here, as can be seen in figure 7.14 the users of the slider method only had 45.45% of the users respond that they would be wanting to use the device more often. In comparison to this both of the DIY approaches yielded a far greater interest in using the device more after testing. With 100% of the users of the filling method wanting to and 90.91% of the users from the emptying method being interest in using the device more.

7.3 Conclusion

In the evaluation the items of efficiency, effectiveness, engagement and enjoyment are discussed. During this conclusion the outcome of these comparisons between methods will be determined.

7.3.1 Efficiency and effectiveness

The efficiency is determined by the time it took the user to respond to a task with their answer, whereas the effectiveness is determined by the accuracy of the answers given. The efficiency and effectiveness of all three input methods were determined and now compared to one another. From this comparison it can be seen that the slider is the most efficient method for getting answers, followed by the filling method, which took 129% longer and the emptying method that took 139% longer.

When this efficiency data is combined with the effectiveness of the different approaches it can be seen that although the slider method is the fastest it does yield the most mistakes, in combination with the emptying method, which was the slowest. The filling method falls in between the slider and emptying method when it comes to speed but has a significant advantage over these methods when it comes to the accuracy of the answers given with only 2 mistakes instead of the 5 mistakes made in both other methods. Given the time differences it can be concluded that the DIY methods both have an impact on the efficiency but only the filling method seems to have an impact on the effectiveness with is consisting of only 16.7% of the mistakes made.

7.3.2 Engagement

Looking at the numeral different approaches made in order to measure the engagement of the user the following results came to light. With respect to the physical engagement both DIY approaches seemed to have an impact on the maintaining of an active stance throughout the conducting of the tasks presented. The users of the slider method seemed to have a decay in this active stance whereas the users of the filling and emptying remained active.

The intellectual engagement had a lot more aspects to be taken into consideration. Here the users of the slider method were the only approach to include the two response topics that were considered to be low effort. Whereas the DIY approaches both consisted of the top three mental effort topics. Furthermore the DIY approaches yielded more topical questions than the slider method, suggesting that they were more mentally engaged with the topic. Here the filling method received 6 questions and the emptying four, whereas the slider method only received 1 question. Lastly the DIY approaches both resulted in better memorized data and more of the users of the DIY methods seemed to recall the actual input method they were using rather than the look of the device.

7.3.3 Enjoyment

When it comes to the user enjoyment the filling method seemingly appears to yield the best results. In the users own feedback, as well as in both the observations made and the willingness to use the device more outside of the experiment the filling method was the most attractive to the users, scoring a 100% in all of these analysis. Following in the footsteps of the filling methods comes the other DIY method, the emptying. The emptying was not perceived as enjoyable as the filling method in both the students own feedback, as well as the user's willingness to use the physicalization again. In both cases there was one student from the emptying method who felt the physicalization was not as enjoyable. The slider shows a significant lack of enjoyment when compared to both the DIY methods. The slider group had 27.27% state that they did not enjoy using the device, as well as 33.3% of the users stating they did not know how they felt. From the observations it also shows that the slider method did not seem to be received as well by the users as the DIY approaches and lastly only 45.45% of the users from the slider method said that they would be willing to use the device again.

Conclusion

The backbone of this bachelor thesis was to create a data physicalization of air quality that would yield a positive user experience. In line with this the objective was to see whether a DIY approach to a data physicalization aimed towards young adolescents is a good way to create a positive user experience. This meant that the physicalization itself had to be efficient, effective, stimulate engagement and be enjoyable to use. This chapter will aim to answer the main research question:

> *Does the implementation of a DIY element in the physicalization of Air Quality Data influence the user's experience?*

In order to answer this main research question multiple sub questions were constructed. The first sub-question was:

> *How do the efficiency and effectiveness of the different DIY approaches to the data physicalizations compare to a traditional input method?*

This sub-question was answered in chapter 7. When comparing the efficiency of all three input methods the slider was the faster by 3.92 seconds when compared to the filling method and 5.23 seconds when compared to the emptying method. The speed of the method seemed to however be negatively related to the effectiveness of the method. Where the slider method yielded a total of 5 mistakes due to impreciseness. The emptying method also seemed to yield a total of 5 mistakes, but in comparison to the slider method these mistakes were not made due to the user wanting to be fast, but rather due to confusion about the input method itself.
The filling method proved to be the best approach for a balance between efficiency and effectiveness. With it being the middle place holder when it comes to the speed, being 1.31 seconds faster than its comparable emptying method and only having resulted in 2 incorrect answers.

The second sub-question to answer was:

> *How well engaged were the users of the data physicalizations that utilized a DIY approach in comparison to one that used a traditional input method?*

This sub-question was answered in chapter 7. Looking at the data presented in chapter 7 the DIY methods seemed to be the best approach when it came to keeping the users physically engaged, as their stance throughout the user testing remained active, whereas that of the slider method deteriorated as the user testing progressed. The data also showed that the DIY methods had the advantage over the slider when it came to the intellectual engagement with more students linking the physicalization to genuine learning objectives when talking about air quality. Furthermore the users of the DIY methods showed more interest throughout the experiment as they asked a total of 9 more topic or physicalization related questions than then users of the slider method did. Lastly the user of the DIY methods displayed a better memorization of the input method, rather than the device looks as well as a better memorization of the data on the countries and their air quality.

The last sub-question to answer was:

> *Are the different input methods used in the data physicalization considered enjoyable by the users?*

This sub-question was answered in chapter 7. For this sub-question the answer can be clearly and directly traced back the answers the students gave to when they were asked what they thought about their use with the device and the when asked if they would like to use the device more often. The students of both DIY approaches responded fond of the physicalization, with 100% of the filling method liking the device as well as wanting to use it more often. The emptying method was close behind with almost all students like and wanting to use the physicalization more. The slider proved to not be enjoyable to the users, with only 45.45% of the participants claiming to like the device and wanting to use it more. With these answers being supported by the observations made.

Based on the answers to the sub-questions it can be said that the implementation of DIY elements did influence the user's experience. The DIY methods stimulated a better user experience than the more traditional slider method as the users appeared to be more engaged and the overall enjoyment was far better. From the two DIY methods the filling of the tub proved to be better a better approach as the time to answer was shorter than that of the emptying method, as well as the accuracy of the answers being better.

Discussion

9.1 Challenges

Some of the challenges brought to light with the creation of the physicalization were the fragility of the globe as well as the connection between the different input methods. Both of these challenges came due to the construction of the physical elements. The globe was constructed in such a way that it would form a truncated icosahedron, a shape that would be close enough to a sphere to appear round, yet still flat enough to be laser cut. This however gave rise to the issue of stability. With all faces being tangent on an edge to one another there were no solid contact points for a good glue up. A fix for this would have been to angle all of the sides after laser cutting, in order for them all to have a face for glue up. This would have yielded a stronger bond and a less fragility.

As for the connections between the different input methods. This was an effect of the fragility of the electrical wires. These wires are good for internal circuits but do not hold up outside of the device. In order to fix this a separate connector could be constructed out of a more sturdy material through which the wires would be drawn. This would yield a stronger construction and much less chance for failure.

Lastly the size of the globe itself deemed to be an issue. The globe used in the final prototype has already been enlarged by 18% in comparison to the first rendition. This made it so that some of the smaller countries that were on the list could have an LED installed in them without overlapping too much with their neighboring countries and causing confusion. Ideally the globe would be large enough for an LED to fit into even the smallest country without overlapping their borders for the best readability. This issue then becomes a matter of balance between readability and bulkiness.

9.2 Recommendations

Over the course of this bachelor thesis a prototype data physicalization was created in order to find out whether the implementation of a DIY input approach would be influential on the user experience. Working from the results of the user test it has been concluded that this implementation did indeed have an influence on the user experience and seemingly a positive one and therefore the comments made by the users from the DIY methods can turn out to be useful in the progression of this project beyond this bachelor thesis.

Most of the students that had feedback on the DIY approaches had some things to say about the actual use of the marbles themselves. Some of the students suggested that the marbles themselves were somewhat cumbersome to use as they deemed to be quite an unforgiving medium. With marbles getting away from the user as well as the user not being able to quickly make accurate adjustments. Changing to a medium to what allow for the precision offered by the marbles to be matched, while being more forgiving when it comes to the handling would be optimal.

Apart from the medium some of the students commented on the looks being cool or nice. With these kinds of feedback being the best types the actual looks of the physicalization may be explored and different visuals may be used to better convey the sense of a globe. Where some students commented on the fact that is may need more color or contrast in order to more easily identify the countries/regions that issue may be tackled at the same time.

Lastly one of the comments the students made were that their time with the interaction took too little time or was too short. In order to look at the use of a data physicalization in the realm of education in the long term, a higher effort can be made by actually having the young adolescent users interact with the device naturally or in lessons in order to look at the long term effect and see if the novelty of the new and exciting device stays or fades.

9.3 Future work

Due to the positive feedback this project receive when it came to the DIY methods, these could be further expanded on by exploring different variations on DIY approaches. The approaches used in this project were purely based on visual and kinesthetic feedback. However there are many more types of mediums to be explored such as tactile sensation, sound, volume and potentially even heat. Moreover the physicalizations that were used in this project all consisted of the combination between some non-visual input and visual output. Altering the combination of different visual outputs may be a direction that could lead to even more promising results. This projected compared the user experience in terms of efficiency, effectiveness, engagement and enjoyment between DIY approaches and a more typical approach to an interactive data physicalization. Where this research could become more substantial is if these DIY data physicalization were to be compared to more traditional learning methods such as can be seen in everyday school lessons. The sample size of countries used can also be increased. This prototype proved the functionality of 10 countries. From the list

created an expansion can be added on in order to make the device somewhat more diversified and challenging.

Apart from the possible directions that this data physicalization can be taken in more research can also be done on the implementation of DIY within child teaching physicalizations. Seeing as data physicalizations are becoming more and more popular the direction that this project was targeted in is sure to be explored by more people that more a greater understanding of the topic due to prior experience.

Lastly the greatest improvement over the current method used in the user testing would be the inclusion of a video recording, from which the behavior and expressions from the user can be analyzed after the experiment has been conducted. This was not possible during the testing of this prototype due to some regulations of the location where the user testing was conducted but would allow for the researcher to be more tentative and focused on assisting the user during the experiment. Possibly making it even more of a natural interaction for the user.

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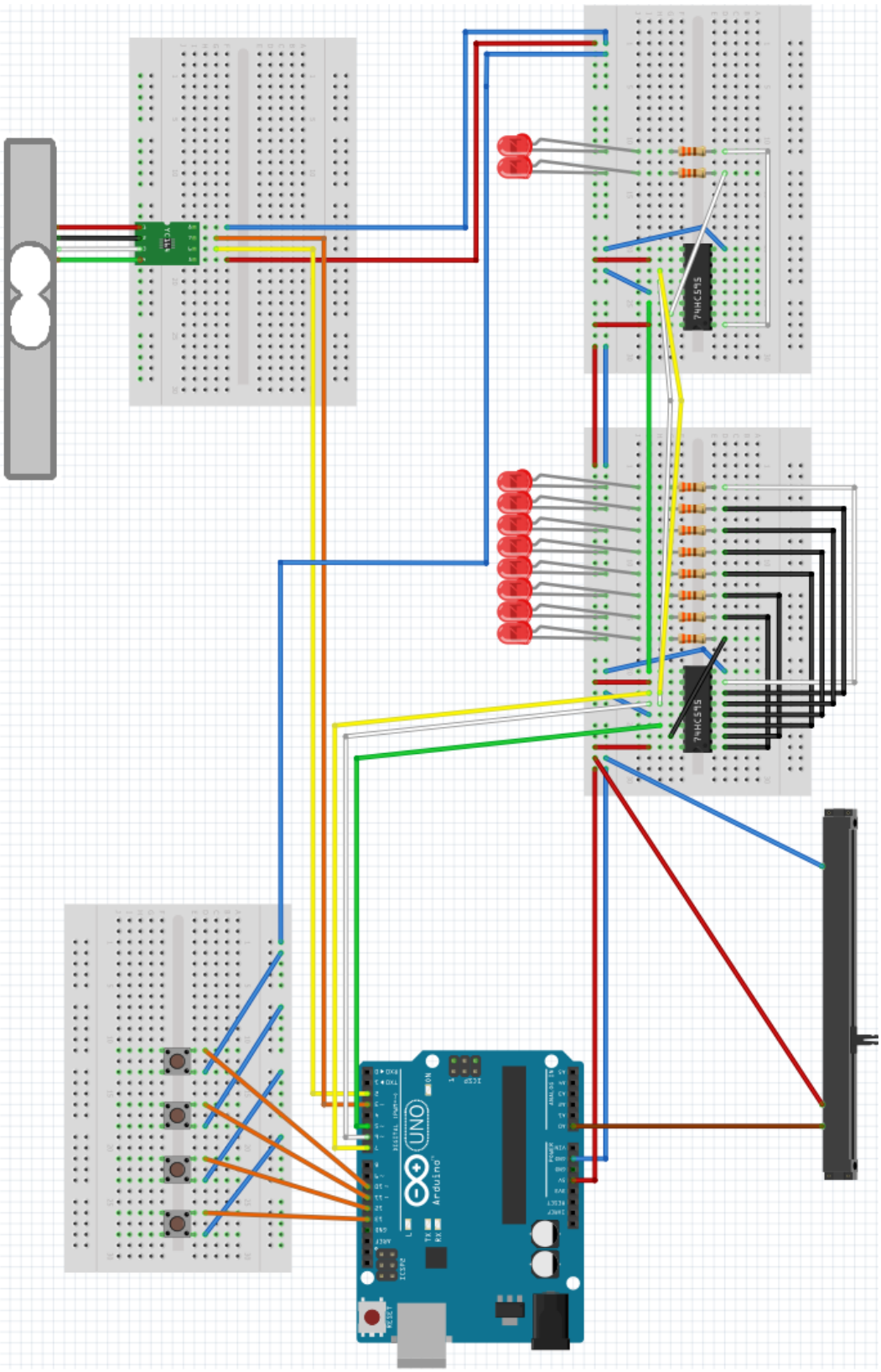
Appendix A: Prototype electronics schematic



Appendix B: Prototype code

```
/*  The Air we Breath Graduation Project Code for Arduino Uno

    This program allows for the user to switch between different
    input modes where use if made of either a slider or load
    cell scale. With these inputs a variety of LEDs will be lit
    up depending on the value of the input.

    Made by: Sander de Kreij - s2154188
 */

//Pin connected to DS of 74HC595
int dataPin = 5;
//Pin connected to ST_CP of 74HC595
int latchPin = 6;
//Pin connected to SH_CP of 74HC595
int clockPin = 7;

const byte buttonPin1 = 10;
const byte buttonPin2 = 11;
const byte buttonPin3 = 12;
const byte buttonPin4 = 13;

bool firstShiftBool = false;
bool secondShiftBool = false;
bool slidingPotBool = false;

float weightValue = 0;
bool weightIncBool = false;
bool weightDecBool = false;
```

```
#include "HX711.h"
HX711 scale;

int calFactor = 1080;
int scaleClock = 2;
int scaleData = 3;

int PerGrams = 50;
int M = PerGrams;

void setup() {
  //set pins to output because they are addressed in the main loop
  pinMode(latchPin, OUTPUT);
  pinMode(buttonPin1, INPUT_PULLUP);
  pinMode(buttonPin2, INPUT_PULLUP);
  pinMode(buttonPin3, INPUT_PULLUP);
  pinMode(buttonPin4, INPUT_PULLUP);
  Serial.begin(9600);

  scale.begin(scaleData, scaleClock);
  scale.set_scale(calFactor); //This value is obtained by using the SparkFun_HX711_Calibration
  sketch
  scale.tare(); //Assuming there is no weight on the scale at start up, reset the scale to 0
}

void loop() {
  Serial.println(weightValue);
  if (digitalRead(buttonPin1) == LOW) {
    slidingPotBool = true;
    weightIncBool = false;
    weightDecBool = false;
    Serial.println("Mode = Slider");
  } else if (digitalRead(buttonPin2) == LOW) {
    slidingPotBool = false;
```

```
    weightIncBool = true;
    weightDecBool = false;
    Serial.println("Mode = Weight means Good");
  } else if (digitalRead(buttonPin3) == LOW) {
    slidingPotBool = false;
    weightIncBool = false;
    weightDecBool = true;
    Serial.println("Mode = Weight means Bad");
  } else if (digitalRead(buttonPin4) == LOW) {
    Serial.println("Resetting");
    scale.tare();
    resetLeds();
    slidingPotBool = false;
    weightIncBool = false;
    weightDecBool = false;
    Serial.println("Reset done");
  } else {}

  if (slidingPotBool == true) {
    slidingPot();
  } else {}

  weightValue = scale.get_units();

  if (weightIncBool == true) {
    weightInc();
  } else if (weightDecBool == true) {
    weightDec();
  } else {}
}


// the heart of the program
void shiftOut(int myDataPin, int myClockPin, byte myDataOut) {
```

```
// This shifts 8 bits out MSB first,
//on the rising edge of the clock,
//clock idles low
//internal function setup
int i = 0;
int pinState;
pinMode(myClockPin, OUTPUT);
pinMode(myDataPin, OUTPUT);
//clear everything out just in case to
//prepare shift register for bit shifting
digitalWrite(myDataPin, 0);
digitalWrite(myClockPin, 0);
//for each bit in the byte myDataOut&#xFFFD;
//NOTICE THAT WE ARE COUNTING DOWN in our for loop
//This means that %00000001 or "1" will go through such
//that it will be pin Q0 that lights.
for (i = 7; i >= 0; i--)  {
  digitalWrite(myClockPin, 0);
  //if the value passed to myDataOut and a bitmask result
  // true then... so if we are at i=6 and our value is
  // %11010100 it would the code compares it to %01000000
  // and proceeds to set pinState to 1.
  if ( myDataOut & (1 << i) ) {
    pinState = 1;
  }
  else {
    pinState = 0;
  }
  //Sets the pin to HIGH or LOW depending on pinState
  digitalWrite(myDataPin, pinState);
  //register shifts bits on upstroke of clock pin
  digitalWrite(myClockPin, 1);
  //zero the data pin after shift to prevent bleed through
  digitalWrite(myDataPin, 0);
```

```
  }
  //stop shifting
  digitalWrite(myClockPin, 0);
}

void Leds(byte a, byte b) {
  digitalWrite(latchPin, 0);
  //move out the message for specific LEDs to turn on
  shiftOut(dataPin, clockPin, a);
  shiftOut(dataPin, clockPin, b);
  //return the latch pin high to signal chip
  //so that it stops listening
  digitalWrite(latchPin, 1);
}

void resetLeds() {
  digitalWrite(latchPin, 0);
  //move out the message for all led's to turn off
  shiftOut(dataPin, clockPin, 0);
  shiftOut(dataPin, clockPin, 0);
  //return the latch pin high to signal chip
  //so that it stops listening
  digitalWrite(latchPin, 1);
}

void slidingPot() {
  //  Serial.println("Slider Reached");
  int sliderValue = analogRead(A0);
  if (sliderValue <= 19) {
    Leds(0, 1);
  } else if (sliderValue > 19 && sliderValue <= 54) {
    Leds(0, 2);
  } else if (sliderValue > 54 && sliderValue <= 200) {
    Leds(0, 4);
```

```
  } else if (sliderValue > 200 && sliderValue <= 360) {
    Leds(0, 8);
  } else if (sliderValue > 350 && sliderValue <= 532) {
    Leds(0, 16);
  } else if (sliderValue > 532 && sliderValue <= 685) {
    Leds(0, 32);
  } else if (sliderValue > 685 && sliderValue <= 850) {
    Leds(0, 64);
  } else if (sliderValue > 850 && sliderValue <= 974) {
    Leds(0, 128);
  } else if (sliderValue > 974 && sliderValue <= 1009) {
    Leds(1, 0);
  } else if (sliderValue > 1009) {
    Leds(2, 0);
  }
}

void weightInc() {
  //  Serial.println("Inc Reached");
  if (weightValue <= 1 * M) {
    Leds(0, 1);
  } else if (weightValue > 1 * M && weightValue <= 2 * M) {
    Leds(0, 2);
  } else if (weightValue > 2 * M && weightValue <= 3 * M) {
    Leds(0, 4);
  } else if (weightValue > 3 * M && weightValue <= 4 * M) {
    Leds(0, 8);
  } else if (weightValue > 4 * M && weightValue <= 5 * M) {
    Leds(0, 16);
  } else if (weightValue > 5 * M && weightValue <= 6 * M) {
    Leds(0, 32);
  } else if (weightValue > 6 * M && weightValue <= 7 * M) {
    Leds(0, 64);
  } else if (weightValue > 7 * M && weightValue <= 8 * M) {
```

```
    Leds(0, 128);
  } else if (weightValue > 8 * M && weightValue <= 9 * M) {
    Leds(1, 0);
  } else if (weightValue > 9 * M) {
    Leds(2, 0);
  }
}

void weightDec() {
  //  Serial.println("Dec Reached");
  if (weightValue <= 1 * M) {
    Leds(2, 0);
  } else if (weightValue > 1 * M && weightValue <= 2 * M) {
    Leds(1, 0);
  } else if (weightValue > 2 * M && weightValue <= 3 * M) {
    Leds(0, 128);
  } else if (weightValue > 3 * M && weightValue <= 4 * M) {
    Leds(0, 64);
  } else if (weightValue > 4 * M && weightValue <= 5 * M) {
    Leds(0, 32);
  } else if (weightValue > 5 * M && weightValue <= 6 * M) {
    Leds(0, 16);
  } else if (weightValue > 6 * M && weightValue <= 7 * M) {
    Leds(0, 8);
  } else if (weightValue > 7 * M && weightValue <= 8 * M) {
    Leds(0, 4);
  } else if (weightValue > 8 * M && weightValue <= 9 * M) {
    Leds(0, 2);
  } else if (weightValue > 9 * M) {
    Leds(0, 1);
  }
}
```

Appendix C: Information Brochure

Informatie voor ouders/verzorgers van deelnemers aan het onderzoek naar een effectieve leermethode voor lucht kwaliteit.

Doel van het onderzoek

In opdracht van Dr. Champika Manel Epa Ranasinghe wordt er vanuit de Universiteit Twente onderzoek gedaan naar een effectieve methode om kinderen meer betrokken te maken op wereldwijde luchtkwaliteit. Dit onderzoek is een afstudeerproject waarvoor een prototype 'data fysicalisatie' is gemaakt. Dit prototype is ontworpen om een meer traditionele vorm van visueel leren te vervangen met een meer interactieve vorm om er voor te zorgen dat de informatie beter te onthouden is. Zodat de leerlingen effectiever kunnen leren over dit onderwerp. Het doel van dit onderzoek is dus ook om de verschillende methodes van data interactie rondom wereldwijde luchtkwaliteit met elkaar te vergelijken om zo te kunnen zien welke methode het meest effectief is.

Hoe werkt het onderzoek

In het algemeen zal dit onderzoek één op één plaats vinden. Hier is voor gekozen om zo effectief mogelijk de verschillende methodes met elkaar te vergelijken zonder interactie van andere leerlingen en/of afleidingen die de resultaten kunnen beinvloeden. In totaal zal het onderzoek maximaal 15 minuten kunnen duren.

Presentatie

Voordat de leerlingen het prototype zullen testen zal er een kleine presentatie worden gegeven van ongeveer 2 a 3 minuten. In deze presentatie zal aan de leerling het een en andere worden uitgelegd over wat de Universiteit Twente is, wie de onderzoeker is, waarom dit onderzoek word gedaan en hoe het prototype werkt.

Observatie

Na de presentatie zal de leerling gevraagd worden om het prototype uit te proberen. Hierbij zal de leerling gedurende ongeveer 5 minuten of minder met behulp van verschillende taken, een interactieve wereldbol aansturen. Op deze wereldbol staan een aantal landen weergegeven waarvan de luchtkwaliteit kan worden vergeleken. Door de wereldbol aan te sturen zullen verschillende landen geactiveerd worden. Het doel is om zo een link te leggen tussen de luchtkwaliteit die de leerling heeft 'geselecteerd' en de landen die hier mee overeenkomen. Om zo een algemeen overzicht te bieden. De observaties zelf zijn gericht op het gedrag van de leerling bij het uitvoeren van de gegeven taken (hoe energiek, hoe snel, hoe veel vragen worden er gesteld aan de onderzoeker en welke antwoorden worden er gegeven).

Informatie voor ouders en niet voor leerlingen:
Tijdens de interactie met het prototype zullen de leerlingen worden opgedeeld in 3 groepen, deze 3 groepen zullen ieder met een andere versie van het prototype werken. Om de resultaten zo echt mogelijk te laten zijn is de volgende informatie alleen bestemd aan de ouders en zullen de leerlingen hier niet specifiek over worden ingelicht. Alle 3 de groepen zullen de zelfde taken krijgen. Deze taken kunnen bestaan uit het vinden van een land bij een gegeven luchtkwaliteit

(of andersom), het verschil in waarde tussen 2 landen vinden en zelf ontdekkingen maken over waar het verschil in luchtkwaliteit door kan komen. Het verschil tussen de 3 groepen zit hem in de methode waarmee ze om zullen gaan met het prototype. Groep 1 zal een simpele schuif gebruiken om zo de ingevoerde luchkwaliteit te veranderen, groep 2 zal een bak op vullen met ballen, waarbij een vollere bak overeenkomt met een goede luchtkwaliteit en groep 3 zal een bak op vullen met ballen, waarbij een vollere bak overeenkomt met een slechte luchtkwaliteit.

Interview

Na het prototype zelf te hebben gebruikt zal er nog een klein interview plaatsvinden van een paar minuten (3-5 minuten op basis van de antwoorden/vragen van de leerling) om de ervaring te bespreken, en er achter te komen hoe effectief de gebruikte methode is geweest voor het onthouden van de gepresenteerde data. Daarnaast word er gekeken wat voor soort connecties de leerling heeft kunnen leggen tussen de verschillen in luchtkwaliteit en de bijbehorende landen. Uiteraard zijn er bij dit interview ook genoeg kansen voor de leerling om zelf vragen te stellen of wellicht al suggesties te geven aan de onderzoeker.

Vrijwilligheid deelname

Bij het besluit om uw kind geen deel te laten nemen aan het onderzoek hoeft u niets te doen. Het bijgeleverde toestemmingsformulier hoeft dan niet ingevuld te worden. Verder hoeft er ook niet gemeld te worden waarom uw kind niet mee mag doen. Als u besluit dat uw kind wel mee mag doen heeft uw kind altijd nog de optie om later zelf te beslissen niet meer mee te willen doen. Dit mag hij/zij op elk moment aangeven waarna het onderzoek direct stop zal worden gezet zonder daarvoor een reden te hebben gekregen.

Voor- en nadelen van deelname aan dit onderzoek

De uitkomst van dit onderzoek kan bijdragen aan een toekomst waar het mileu en het welzijn van de omgeving een groter aandachtspunt wordt. Hierdoor kunnen toekomstige generaties wellicht opgroeien met een beter inzicht en gevoel voor de consequenties van hun acties op de natuur, met in dit geval luchtkwaliteit als focuspunt. Voor uw kind zijn er geen nadelen bij deelname aan dit onderzoek. De enige moeite die word gevraagd is een paar minuten uit een schooldag, waarna de rest van de dag gewoon zoals normaal zal verlopen.

Verzameling en gebruik van informatie

Bij deelname aan dit onderzoek is er specifiek voor gekozen om geen persoonlijke gegevens te verzamelen op een video opname na als hier toestemming voor wordt gegeven (deze video beelden zullen direct na analyse worden verwijderd). Er zal dus nergens gevraagd worden om gegevens die na afloop van het onderzoek terug kunnen leiden naar u of uw kind. De informatie die tijdens dit onderzoek wel zal worden opgeslagen zijn de antwoorden en reacties/acties van uw kind. Deze zullen enkel worden opgeslagen in de zin dat ze terug te vinden zijn in het onderzoeksartikel. Zonder dat deze op enige manier terug kunnen leiden naar uw kind. Deze informatie zal op schriftelijke wijze worden genoteerd waarmee naar afloop van het onderzoek conclusies op het gebruik en effect van het prototype kunnen worden gemaakt. Bij ondertekening van het toestemmingsformulier gaat u er mee akkoord dat deze gegevens dus mogen worden verzamelt en worden geanalyseerd. Toestemming tot video opname staat apart vermeld in dit toestemmingsformulier en kan dus worden geweigerd terwijl algemene toestemming tot deelname wel wordt gegeven. In het algemeen geldt er voor dit onderzoek dat

de verzamelde informatie niet zal worden opgeslagen buiten het onderzoeksartikel om en zou dus mogelijk wel als referentie kunnen dienen in toekomstige artikelen. Daarnaast zullen alle video beelden direct na analyse worden verwijderd. Mochten er vragen zijn over de specifieke vorm van notities of hoe de data wordt gebruikt kunt u altijd contact opnemen met de onderzoeker.

Goedkeuring onderzoek

In aanvang van dit onderzoek is er goedkeuring verleend vanuit de Ethishe Commissie can de faculteit EEMCS aan de Universiteit Twente. Dit houdt in dat het onderzoek voldoet aan internationaal vastgestelde richtlijnen en regels waar steng aan word gehouden.

Verdere informatie

Bij verdere vragen of mocht u meer willen weten of het onderwerp of onderzoek kunt u altijd contact opnemen met Dhr. Sander de Kreij, de student in kwestie achter dit onderzoek (contactgegevens onderstaand aanwezig) of Dr. Champika M. Epa Ranasinghe, de beleider van het onderzoek. Als u vragen heft over uw rechten als deelnemer van het onderzoek, of wenst meer informatie te krijgen, vragen te stellen of andere zorgen desbetreffende dit onderzoek te bespreken met iemand anders dan de onderzoeker(student) zelf, neem dan alstublieft contact op met de Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

Dhr. Sander de Kreij
s.dekreij@student.utwente.nl

Dr. Champika M. Epa Ranasinghe
c.m.eparanasinghe@utwente.nl

Appendix D: Consent Form

Toestemmings formulier voor The Air we Breathe

Aan de ouders/verzorgers van

Vink alstublieft de toepasselijke vakjes aan	**Ja**	**Nee**
Deelname aan de studie		
Ik heb de studie informatie van [DD/MM/JJJJ] gelezen en begrepen, of deze is mij voorgelzen. Ik heb vragen kunnen stellen over de studie en deze vragen zijn met mijn tevredenheid beantwoord.	□	□
Ik bevestig hierbij dat mijn kind vrijwillig mag deelnemen aan de studie en begrijp dat hij/zij mag weigeren antwoord te geven op vragen en op elk moment kan kiezen niet langer deel te nemen aan het onderzoek, zonder enige reden te hoeven geven.	□	□
Ik begrijp dat bij deelname van dit onderzoek antwoorden op een vragenlijst die door uw kind zelf worden ingevoerd worden verzameld, er notities worden gemaakt van observaties gedurende het onderzoek en gesprekstof van het interview schriftelijk worden genoteerd door de observant. Na analyze van deze resultaten zal al het materieel worden worden vernietigd.	□	□
Gebruik van informatie in de studie		
Ik begrijp dat de de informative die mijn kind levert enkel schriftelijk zal worden gebruikt in een onderzoeksartikel in de vorm van een afstuduurproject aan de Universiteit Twente.	□	□
[OPTIONEEL] Ik geef toestemming voor het opnemen en analyseren van een video zoals uitgelegd in de informatie brochure. Na analyse wordt deze video verwijderd en wordt verkregen data geanonimiseerd.	□	□
[OPTIONEEL] Ik geef toestemming om antwoorden en vragen van mijn kind anoniem the quoten binnen het onderzoeksartikel.	□	□
Toekomstig gebruik en hergebruik van informative door anderen		
[OPTIONEEL] Ik geef toestemming voor het anoniem bewaren van de door mijn kind gegeven antwoorden op de vragenlijst, in de bijlage van het onderzoeksartikel. Welke	□	□

op zal worden geslagen binnen het archief van afstudeerprojecten aan de Universiteit Twente.

[OPTIONEEL] Ik geef toestemming voor het anoniem bewaren van de tijdens het onderzoek genoteerde observaties, in de bijlage van het onderzoeksartikel. Welke op zal worden geslagen binnen het archief van afstudeerprojecten aan de Universiteit Twente.	□	□
[OPTIONEEL] Ik geef toestemming voor het anoniem bewaren van de notities over het interview met mijn kind, in de bijlage van het onderzoeksartikel. Welke op zal worden geslagen binnen het archief van afstudeerprojecten aan de Universiteit Twente.	□	□

Ondertekening

Naam van de deelnemer en ouder/verzorger van.	Handtekening	Datum

Ik heb de informatie uit de brochure juist gelezen en overgebracht aan de mogelijke deelnemer en naar mijn beste vermogen gezorgd dat de deelnemer begrijpt waar vrijwillig toestemming voor wordt gegeven.

Sander de Kreij		
Naam onderzoeker	Handtekening	Datum

Contactgegevens onderzoeker voor verdere informatie:

Sander de Kreij

S.dekreij@student.utwente.nl

Appendix E: User study Form

Date Performed	6/4/2022 … 7/4/2022
Researcher	Sander de Kreij
Project	The Air we Breathe

User Testing

Goals

The goal of this user testing is to put our prototype to the test. We want to answer the questions stated below in order to find out in what way we can get children within the age range and scope of this experiment to be best engaged with Air Quality data. From this user testing we will gather information and insight in the effects of different engagement approaches in order to validate our ideas.

Questions

During the testing all individual users per method will receive a separate variation on the order and specific countries of a question. This will result in the variations being able to be used once per method. This has been chosen in order to allow for a random method and variation allocation while avoiding the students' ability to accidently spill the information on the answers to tasks they have been asked to perform. As a secondary benefit of this it allows for the users to be analyzed separately from one another based on the method they have used and the variation they were assigned, rather than their name or any other PII.

Pre-Testing Questions

The Pre-Testing questions do not necessarily function towards getting an answer to the research question but they are more so designed to ensure that all students will be able to start the experiment with the same level of local interest and to ease their way into starting the interaction. (As well as some positive stimulation).

PT1	Do you think you understand how to operate the device after my explanation?
PT2	Have you yourself ever done anything with air quality already? And if so, what do you know about it?
PT3	Where on earth do you expect the air quality to be the worst?
PT4	I think you are going to do great, how about yourself?

Before the Questions are asked the students are told that they will have 1-2 minutes to get familiar with the system and explore the countries a little bit.

During-Testing Questions/Tasks Variation 1

DT1	Could you please find the country with the worst air quality?
DT2	Could you please find the country with the best air quality?
DT3	What is the difference in air quality between country X and Y?
DT4	Which of the countries have an air quality that is comparable to that of country X?
DT5	Could you please rank countries X, Y and Z in the order of best to worst air quality?
DT6	Could you please rank countries X, Y and Z in the order of worst to best air quality?
DT7	Could you please tell me which countries lie between country X and Y when it comes to their air quality?

During-Testing Questions/Tasks Variation 2

DT5	Could you please rank countries X, Y and Z in the order of best to worst air quality?
DT3	What is the difference in air quality between country X and Y?
DT2	Could you please find the country with the best air quality?
DT1	Could you please find the country with the worst air quality?
DT4	Which of the countries have an air quality that is comparable to that of country X?
DT7	Could you please tell me which countries lie between country X and Y when it comes to their air quality?
DT6	Could you please rank countries X, Y and Z in the order of worst to best air quality?

During-Testing Questions/Tasks Variation 3

DT3	What is the difference in air quality between country X and Y?

DT1	Could you please find the country with the worst air quality?
DT7	Could you please tell me which countries lie between country X and Y when it comes to their air quality?
DT2	Could you please find the country with the best air quality?
DT5	Could you please rank countries X, Y and Z in the order of best to worst air quality?
DT4	Which of the countries have an air quality that is comparable to that of country X?
DT6	Could you please rank countries X, Y and Z in the order of worst to best air quality?

During-Testing Questions/Tasks Variation 4

DT7	Could you please tell me which countries lie between country X and Y when it comes to their air quality?
DT2	Could you please find the country with the best air quality?
DT4	Which of the countries have an air quality that is comparable to that of country X?
DT6	Could you please rank countries X, Y and Z in the order of worst to best air quality?
DT1	Could you please find the country with the worst air quality?
DT5	Could you please rank countries X, Y and Z in the order of best to worst air quality?
DT3	What is the difference in air quality between country X and Y?

During-Testing Questions/Tasks Variation 5

DT4	Which of the countries have an air quality that is comparable to that of country X?
DT7	Could you please tell me which countries lie between country X and Y when it comes to their air quality?
DT5	Could you please rank countries X, Y and Z in the order of best to worst air quality?
DT2	Could you please find the country with the best air quality?
DT1	Could you please find the country with the worst air quality?
DT6	Could you please rank countries X, Y and Z in the order of worst to best air quality?
DT3	What is the difference in air quality between country X and Y?

During-Testing Questions/Tasks Variation 6

DT6	Could you please rank countries X, Y and Z in the order of worst to best air quality?
DT3	What is the difference in air quality between country X and Y?
DT4	Which of the countries have an air quality that is comparable to that of country X?
DT1	Could you please find the country with the worst air quality?
DT7	Could you please tell me which countries lie between country X and Y when it comes to their air quality?
DT2	Could you please find the country with the best air quality?
DT5	Could you please rank countries X, Y and Z in the order of best to worst air quality?

During-Testing Questions/Tasks Variation 7

DT1	Could you please find the country with the worst air quality?
DT3	What is the difference in air quality between country X and Y?
DT2	Could you please find the country with the best air quality?
DT6	Could you please rank countries X, Y and Z in the order of worst to best air quality?
DT4	Which of the countries have an air quality that is comparable to that of country X?
DT5	Could you please rank countries X, Y and Z in the order of best to worst air quality?
DT7	Could you please tell me which countries lie between country X and Y when it comes to their air quality?

During –Testing Questions/Tasks Variation 8

DT7	Could you please tell me which countries lie between country X and Y when it comes to their air quality?
DT4	Which of the countries have an air quality that is comparable to that of country X?
DT2	Could you please find the country with the best air quality?
DT6	Could you please rank countries X, Y and Z in the order of worst to best air quality?
DT3	What is the difference in air quality between country X and Y?
DT5	Could you please rank countries X, Y and Z in the order of best to worst air quality?
DT1	Could you please find the country with the worst air quality?

During-Testing Questions/ Tasks Variation 9

DT3	What is the difference in air quality between country X and Y?
DT4	Which of the countries have an air quality that is comparable to that of country X?
DT7	Could you please tell me which countries lie between country X and Y when it comes to their air quality?
DT6	Could you please rank countries X, Y and Z in the order of worst to best air quality?
DT1	Could you please find the country with the worst air quality?
DT5	Could you please rank countries X, Y and Z in the order of best to worst air quality?
DT2	Could you please find the country with the best air quality?

During-Testing Questions/ Tasks Variation 10

DT6	Could you please rank countries X, Y and Z in the order of worst to best air quality?
DT3	What is the difference in air quality between country X and Y?
DT4	Which of the countries have an air quality that is comparable to that of country X?
DT1	Could you please find the country with the worst air quality?
DT5	Could you please rank countries X, Y and Z in the order of best to worst air quality?
DT7	Could you please tell me which countries lie between country X and Y when it comes to their air quality?
DT2	Could you please find the country with the best air quality?

During-Testing Questions/ Tasks Variation 11

DT5	Could you please rank countries X, Y and Z in the order of best to worst air quality?
DT2	Could you please find the country with the best air quality?
DT6	Could you please rank countries X, Y and Z in the order of worst to best air quality?
DT1	Could you please find the country with the worst air quality?
DT3	What is the difference in air quality between country X and Y?
DT4	Which of the countries have an air quality that is comparable to that of country X?
DT7	Could you please tell me which countries lie between country X and Y when it comes to their air quality?

During-Testing Questions/ Tasks Variation 12

DT2	Could you please find the country with the best air quality?
DT7	Could you please tell me which countries lie between country X and Y when it comes to their air quality?
DT1	Could you please find the country with the worst air quality?
DT5	Could you please rank countries X, Y and Z in the order of best to worst air quality?
DT6	Could you please rank countries X, Y and Z in the order of worst to best air quality?
DT3	What is the difference in air quality between country X and Y?
DT4	Which of the countries have an air quality that is comparable to that of country X?

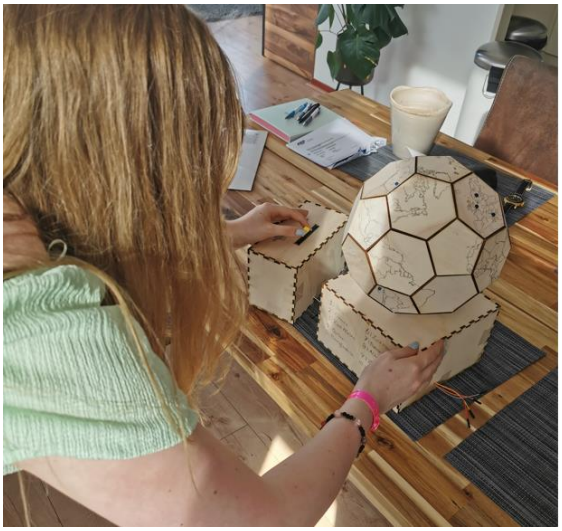
After-Testing Questions

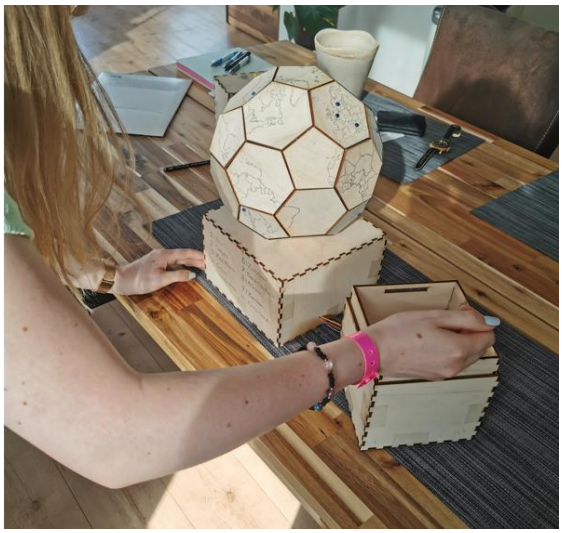
AT1	What did you think about the device?
AT2	Did you think the device was easy to control?
AT3	What do you think the advantage of learning about air quality in different countries is? Like you have just been doing yourself?
AT4	Would you like to use this device more often if you were learning about this topic?
AT5	Do you have any questions for me about what you have just done and or dealt with?

Post-Research Questions

PR1	What can you remember best about when you were using the device?
PR2	What can you remember about the air quality of the countries that you were dealing with when you used the device earlier today?
PR3	If anything, what would you change about the device?
PR4	Any final remarks?

Appendix F: Pictures for Pilot Study





Appendix G: User test Responses

Method 1: Slider:

PT1	PT2
Yes.	No, not really.
Yes, it will be fine.	Yes, we have an air purifier at home so we can see when the air is dirty. When there are too many bad particles.
Yes.	No.
Yes.	No.
I think so.	No.
Yes.	Not as far as I am aware.
Yes.	No.
Yes.	No, not really.
Yes.	No.
Yes.	No.
Yes.	No.
I hope so.	No.

PT3	PT4
In counties that have a lot of traffic.	Yes.
China. They have a lot of factories that make stuff that is used all over the world.	Yes.
Inland.	Yes.
I don’t know, maybe America?	I think so.
Germany?	Yes.
Africa, I know the Sahara is there so it will probably be very hot and bad.	Yes.
Inland.	Yes.
Asia.	Yes.
I think America. There are just so many people there.	Yes.

Australia, we went on holiday there a few years ago and you had to protect yourself against the sun very well because there was something about the air not protecting you as well as here in The Netherlands.	Definitely!
The Middle East. There is almost only sand there.	I think I will.
New York. A lot of people live there, and there are a lot of cars and loads of skyscrapers.	Yes.

DT1	**Time(sec)**	**DT2**		**DT3**	
Bangladesh	10	New Caledonia	10	Sweden > Peru.	17
Bangladesh	9	New Caledonia	12	South Africa < Albania.	16
Bangladesh	6	New Caledonia	10	Albania > South Korea.	13
Bangladesh	7	New Caledonia	6	Qatar < South Africa.	17
Bangladesh	5	New Caledonia	9	Sweden > Canada.	13
Bangladesh	6	New Caledonia	10	Sweden >The Netherlands.	16
Bangladesh	9	New Caledonia	9	Canada > Qatar.	19
–	–	Sweden	7	–	–
Bangladesh	5	New Caledonia	9	Canada > Peru.	13
Bangladesh	8	–	–	South Africa >South Korea.	18
Bangladesh	10	New Caledonia	9	Albania > Peru.	15
Bangladesh	6	New Caledonia	6	The Netherlands > Peru	13

DT4		**DT5**	
New Caledonia and Canada. (Sweden)	13	The Netherlands - South Korea - Qatar	19
The Netherlands and Peru. (Albania)	15	Sweden - Canada - Peru	14
–	–	–	–
Peru and South Korea. (South Africa)	14	New Caledonia - Albania - Qatar	20
Bangladesh and South Africa. (Qatar)	15	The Netherlands - South Africa - South Korea	15
Qatar. (Bangladesh)	13	Albania - Peru - Bangladesh	16

Albania and Canada. (The Netherlands)	14	Canada - South Africa - Qatar	20
Qatar and South Africa. (South Korea)	14	–	–
Sweden and The Netherlands. (Canada)	15	New Caledonia - Sweden - Albania	16
Sweden. (New Caledonia)	13	Albania - Peru - Qatar	17
Sweden and Albania. (Canada)	12	South Africa - South Korea - Bangladesh	18
Peru and South Korea. (South Africa)	13	Canada - Albania - South Africa	16

DT6		**DT7**	
Qatar - Peru - Albania	19	South Africa, South Korea, Qatar (Peru and Bangladesh)	15
Albania - Sweden - New Caledonia	16	The Netherlands, Albania, South Africa (Canada and South Korea)	13
–	–	Peru, South Africa, South Korea, Qatar (Albania and Bangladesh)	15
South Africa - Albania - Canada	21	Sweden ,Canada, The Netherlands, Albania (New Caledonia and Peru)	12
Qatar - South Africa - Canada	18	Peru, South Africa, South Korea (Albania and Qatar)	13
Qatar - South Korea - The Netherlands	15	Canada, The Netherlands, Albania (Sweden and Peru)	15
South Korea - South Africa - Peru	22	The Netherlands, Albania, Peru, South Africa (Canada and South Korea)	17
Bangladesh - South Korea - The Netherlands	14	The Netherlands, Albania. (Canada and South Africa)	16
Qatar - Albania - New Caledonia	18	Canada, The Netherlands, Albania, Peru (Sweden and South Africa)	16
Bangladesh - South Korea - South Africa	16	–	–
South Korea - South Africa - The Netherlands	21	Sweden, Canada, The Netherlands (New Caledonia and Albania)	15

Bangladesh - Peru - Albania	17	Albania, Peru, South Africa (The Netherlands and South Korea)	13

AT1	**AT2**
Alright, nothing special.	Pretty much yes. It all went quite easily.
Fun that the lights turned on to indicate the countries, but the slider was very simple.	Yes, it was very simple.
It looked pretty fun.	Yes.
I did not like using it.	Yes, too easy.
Weird.	Yes.
Alright.	At first no. It wasn't really clear what I had to do until I asked for help. After that it was pretty easy to use.
Fun.	Yes.
Alright.	Yes, but the slider was too simplistic.
Not fun.	Yes.
Easy and a little bit boring.	Yes.
Cool to see that it was made of wood instead of plastic like most of the other stuff I normally use in class.	Yes.
Alright I guess.	Yes.

AT3	**AT4**
Then you know where not to go on holiday.	No.
That way you can know where on earth people need to take better care of the air.	If it were less simple, then yes. I would rather give this to my little brother.
To know where the air is good and bad.	Yes.
I don't know, I can't really change the air.	No.
No idea.	No.
So that we can better take care of the air.	Yes.

So that you can see how the world is doing.	No.
How much nature there is in countries?	Maybe if we happened to have it at home.
I don't know.	No.
Not that much, I can't really change it.	No.
Which countries are and aren't doing well for nature.	Yes.
How clean some countries are.	Yes.

AT5
No.
Can we better the air in countries with bad air or are they a lost cause? Because if the air at home is dirty we have to open a window but you can't do that with countries.
No.
No.
No.
No.
No.
No.
No.
No.
No.
No.
No.

PR1	**PR2**
The explanation was good, so it was pretty easy to use.	The air in The Netherlands was less good than I expected.
It looked nice because it was made from wood.	Asia had worse air than Europe, but New Caledonia had the best air.
The shape of the world was a football so that was pretty cool.	All of the countries lit up one after another.

I did not enjoy using it. There was no challenge.	Not that much.
The globe looked fun.	*(Remained empty)*
It was very easy to control.	South Africa did not have good air.
Not that much.	I believe The Netherlands and Sweden had pretty good air quality.
It wasn't really my piece of cake. The slider was too simplistic.	Nothing really.
It looked fun.	Bangladesh was the worst, Canada was the best.
It was pretty fun to use.	*(Remained empty)*
The fact that different countries started lighting up when you changed the slider position.	The island close to Australia had the best air.
It looked fun.	South Korea had pretty bad air and The Netherlands was clean.

PR3	**PR4**
–	–
Make it a little more interesting, the slider was too simple.	–
–	–
Making it a bit more challenging. This was too easy.	–
–	–
–	–
More color in the device.	–
Less childish.	–
–	–
Making the globe larger.	–
–	–
Maybe making is more challenging. It was fun now but I don't think it would remain so over a longer time period.	–

Method 2: Filling up the tub for **good** AQ:

PT1	**PT2**
Yes.	No.
Yes.	No.
Yes.	No.
Yes.	No.
Yes.	No.
Yes.	No, but I know that things like coal factories are bad for the air quality.
Yes.	No.
Yes.	No.
Yes.	No.
Ik denk van wel.	I did look up what air is once and I saw it mention something there but I didn't get into it that much or continue.
Yes.	No.
Yes.	No.

PT3	**PT4**
Asia.	Yes.
Australia.	Yes.
North Africa, that is where the Sahara is so it will most likely be very warm, and there is a lot of sand in the air.	Yes.
India. I heard that a lot of people live there so the air must be bad.	Sure.
At the coast.	Definitely.
China	Yes.
Inland. At sea the air is nice but inland there are a lot of factories.	Yes.
Russia. They produce a lot of gas for the rest of the world so I don't think the air can't be good.	Yes.
America.	Yes.

Korea.	Yes.
North America.	Yes.
Australia.	Yes.

DT1	**Time(sec)**	**DT2**		**DT3**	
Bangladesh	13	New Caledonia	11	Sweden > Peru.	18
Bangladesh	12	New Caledonia	8	South Africa < Albania.	19
Bangladesh	10	New Caledonia	7	Albania >South Korea.	18
Bangladesh	9	New Caledonia	9	Qatar <South Africa.	19
Bangladesh	11	New Caledonia	9	Sweden > Canada.	17
Bangladesh	12	New Caledonia	13	Sweden >The Netherlands.	21
Bangladesh	12	New Caledonia	7	Canada > Qatar.	19
Bangladesh	10	New Caledonia	9	Qatar < South Korea.	22
Bangladesh	12	New Caledonia	12	Canada > Peru.	18
Bangladesh	13	New Caledonia	10	South Africa >South Korea.	20
Bangladesh	12	New Caledonia	9	Albania > Peru.	16
Bangladesh	13	New Caledonia	11	The Netherlands > Peru.	15

DT4		**DT5**	
New Caledonia and Canada. (Sweden)	21	The Netherlands - South Korea - Qatar	21
The Netherlands and Peru. (Albania)	20	Sweden - Canada - Peru	19
Albania and South Africa. (Peru)	23	The Netherlands - South Korea - Bangladesh	22
Peru and South Korea. (South Africa)	19	New Caledonia - Albania - Qatar	21
Bangladesh and South Africa. (Qatar)	22	The Netherlands - South Africa - South Korea	23
Qatar. (Bangladesh)	18	Albania - Peru - Bangladesh	22

Albania and Canada. (The Netherlands)	20	Canada - South Africa - Qatar	24
Qatar and South Africa. (South Korea)	20	Peru - South Africa - South Korea	20
Sweden and The Netherlands. (Canada)	21	New Caledonia - Sweden - Albania	21
Sweden. (New Caledonia)	22	Albania - Peru - Qatar	24
Sweden and The Netherlands. (Canada)	23	South Africa - South Korea - Bangladesh	25
Peru and South Korea. (South Africa)	21	Canada - Albania - South Africa	20

DT6		**DT7**	
Qatar - Peru - Albania	19	South Africa, South Korea, Qatar (Peru and Bangladesh)	18
Albania - Sweden - New Caledonia	22	The Netherlands, Albania, Peru, South Africa (Canada and South Korea)	22
Peru - Canada - Sweden	22	Peru, South Africa, South Korea, Qatar (Albania and Bangladesh)	20
South Africa - Albania - Canada	24	Sweden ,Canada, The Netherlands, Albania (New Caledonia and Peru)	19
Qatar - South Africa - Canada	18	Peru, South Africa, South Korea (Albania and Qatar)	17
Qatar - South Korea - The Netherlands	21	Canada, The Netherlands, Albania (Sweden and Peru)	18
South Korea - South Africa - Peru	20	The Netherlands, Albania, Peru, South Africa (Canada and South Korea)	16
Bangladesh - South Korea - The Netherlands	25	The Netherlands, Albania, Peru (Canada and South Africa)	20
Qatar - Albania - New Caledonia	22	Canada, The Netherlands, Albania, Peru (Sweden and South Africa)	19
Bangladesh - South Korea - South Africa	21	Peru, South Africa, South Korea (The Netherlands and Qatar)	18

South Korea - South Africa - The Netherlands	19	Sweden, Canada, The Netherlands (New Caledonia and Albania)	16
Bangladesh - Peru - Albania	18	Albania, Peru, South Africa (The Netherlands and South Korea)	21

AT1	**AT2**
Cool!	Yes, pretty much. At first it was kind of difficult because you can be pretty precise with the marbles. But then it clicked and it was pretty cool.
Funny because it used marbles and that was pretty fun to use.	Yes.
Fun.	Yes.
Cool.	Yes.
Interesting. I have never used anything like this.	Yes.
Cool.	Yes, quite.
Pretty fun.	Yes.
Very nice to try and use.	Yes.
Fun.	Yes.
Fun to use..	Yes.
Different to how I normally learn, but in a good way.	Yes.
Cool.	Yes..

AT3	**AT4**
Better understand how much bad stuff there is in the air in some countries.	Definitely.
To understand where on earth the air has to get better.	Yes.
In order to know where the air is good, and where the air is bad.	Yes.
Then you know which countries have good air.	Yes.

To better understand how much good and bad air there is.	For sure!.
So that people can know which countries are worse for the health of the world. And that way everyone can convince these countries to improve their air.	Yes!
To see where in the world most of the bad air quality originates from.	Yes.
To show where in the world the air is good and bad. That way people will think of it more.	Yes.
To make sure more people are aware of how the air around the world is doing.	Yes.
To better understand where in the world the air is bad so that less people will go here. So it might suggest to these countries to try and improve the air in these areas.	Yes.
So that people can see where the air is bad and do something about it.	Yes.
To show that air isn't of the same quality all over the world.	Yes.

AT5
Why were these countries chosen?
No.
No.
How can the countries change when I change the amount of marbles in the tub?
When is the air bad? Because The Netherlands isn't as high up as I thought it would be while I have never had trouble with the air here?
Why is the air in these (points to Bangladesh and Qatar) so bad?
No.
No.
No.
No.
How is the air in Europe so good, because isn't it a lot of countries close together?
No.

PR1	PR2
That it was fun to use the marbles to change the lights of the countries.	Europe all had pretty good air. Asia all had worse air. New Caledonia had the best air and South Africa also had some pretty bad air weirdly enough.
That I was wrong about Australia and that the air near Australia was actually the best.	The Netherlands had a lot less good air quality than I thought. Qatar, South Korea and Bangladesh had the worst air.
That you could walk all the way around it and sometimes you had to look for the countries.	Essentially all countries with good air quality were in the upper half of the world except for New Caledonia, which is an island in the middle of the sea.
The fact that I could use the marbles to change the air quality was cool.	The country next to India had the worst air quality and New Caledonia had the best, followed by Canada and the rest of Europe.
It all went pretty fast.	Countries being on the coast have no influence on the air quality, some countries on the coast had good air quality and some had bad. There was a difference in the general location though.
It was fun!	I think the countries near The Netherlands and the upper part of continents had good air. And that the counties that were on the lower parts of continents had bad air.
There were quite a few countries with bad air at the coast..	South Africa and Peru had a lot worse air than I thought. But Canada had a much better air than I thought.
The marbles were fun, so it didn't feel like I was doing a task or something, which was nice.	New Caledonia had the best air quality, Bangladesh had the worst air quality and The Netherlands, Sweden, and Albania were all in the better half of the countries, but not as good as New Caledonia.
It was pretty easy to use the marbles in order to change their quality.	That the countries that were more to the north all had better air than those in the south. And that the island had the best air out of all of them.
The filling of the tub was fun to do, and it all looked nice.	That the air in South Korea was not good, but that the air in Bangladesh and Qatar was even worse.
That I was wrong about where the air would be the worst.	That the air in Europe was pretty good, even though it is so many countries.
The marbles were a fun way to change the countries.	That the air in the area of Australia was good instead of bad, just like in Europe and Canada. And that Asia did not have good air.

PR3	PR4
More time to use the device.	–
Use more countries.	Fun!
Nothing.	–
A bigger tub for more marbles.	–
Nothing.	–
No.	–
Nothing.	–
Use something other than marbles. Because I dropped a few and they rolled away pretty quickly.	–
More tasks. This was over so quickly.	I wish we could learn like this more often.
Nothing.	–
More time.	–
Nothing.	–

Method 3: Filling up the tub for **bad** AQ:

PT1	PT2
Yes.	No.
Yes.	I watched a documentary about Asia with my parents once. There they mentioned that the air in cities was getting worse and worse than in nature because it stays there.
Yes.	No.
Yes.	Not really.
Yes.	No.
Yes.	No.
Hopefully yes.	No.
Yes.	No.

Yes.	No.
Yes.	Maybe a little bit. But I like people who do good things for the world and watch youtube videos about it too.
Yes.	No.
Yes.	No, not actively at least.

PT3	**PT4**
China.	Yes.
India. In the movies they always show how many people live there and that there are so many cars in the cities that there is almost no place to go.	Yes.
America.	I think so.
America.	Yes.
China.	Yes.
The Middle East.	Yes.
Russia.	Yes.
India.	Yes.
America.	Yes.
Africa.	Yes.
Australia.	Yes.
Asia.	Yes.

DT1	**Time(sec)**	**DT2**		**DT3**	
Bangladesh	11	New Caledonia	13	Sweden > Peru.	23
Bangladesh	14	New Caledonia	13	South Africa < Albania.	19
Bangladesh	10	New Caledonia	14	Albania > South Korea.	20
Bangladesh	11	New Caledonia	13	Qatar < South Africa.	17
Bangladesh	10	New Caledonia	14	Sweden > Canada.	22

Bangladesh	9	New Caledonia	11	Sweden > The Netherlands.	23
Bangladesh	12	New Caledonia	11	Canada > Qatar.	21
Bangladesh	9	New Caledonia	11	Qatar < South Korea.	18
Bangladesh	13	New Caledonia	12	Canada > Peru.	18
Bangladesh	11	New Caledonia	13	South Africa >South Korea.	24
Bangladesh	13	New Caledonia	11	Albania > Peru.	23
Bangladesh	14	New Caledonia	13	The Netherlands > Peru.	18

DT4		**DT5**	
New Caledonia and Canada. (Sweden)	23	The Netherlands - South Korea - Qatar	21
The Netherlands and Peru. (Albania)	21	Sweden - Canada - Peru	22
Albania and South Africa. (Peru)	20	The Netherlands - South Korea - Bangladesh	24
Peru and South Korea. (South Africa)	22	New Caledonia - Qatar - Albania	20
Bangladesh and South Korea. (Qatar)	25	The Netherlands - South Africa - South Korea	26
Qatar. (Bangladesh)	20	Albania - Peru - Bangladesh	20
Albania and Canada. (The Netherlands)	25	Canada - South Africa - Qatar	22
Qatar and South Africa. (South Korea)	24	Peru - South Africa - South Korea	23
Sweden and The Netherlands. (Canada)	19	New Caledonia - Sweden - Albania	25
Sweden. (New Caledonia)	21	Albania - Peru - Qatar	27
Sweden and The Netherlands. (Canada)	19	South Korea - South Africa - Bangladesh	24
Peru and South Korea. (South Africa)	18	Canada - Albania - South Africa	20

DT6		DT7	
Peru - Qatar - Albania	21	South Africa, South Korea, Qatar (Peru and Bangladesh)	18
Albania - Sweden - New Caledonia	23	The Netherlands, Albania, Peru, South Africa (Canada and South Korea)	21
Peru - Canada - Sweden	21	Peru, South Africa, South Korea, Qatar (Albania and Bangladesh)	19
South Africa - Albania - Canada	21	Sweden, The Netherlands, Albania (New Caledonia and Peru)	22
Qatar - South Africa - Canada	25	Peru, South Africa, South Korea (Albania and Qatar)	19
Qatar - South Korea - The Netherlands	18	Canada, The Netherlands, Albania (Sweden and Peru)	23
South Korea - South Africa - Peru	25	The Netherlands, Albania, Peru, South Africa (Canada and South Korea)	21
Bangladesh - South Korea - The Netherlands	22	The Netherlands, Albania, Peru (Canada and South Africa)	21
Qatar - Albania - New Caledonia	26	Canada, The Netherlands, Albania, Peru (Sweden and South Africa)	20
Bangladesh - South Korea - South Africa	22	Albania, Peru, South Africa, South Korea (The Netherlands and Qatar)	17
South Korea - South Africa - The Netherlands	22	Sweden, Canada, The Netherlands (New Caledonia and Albania)	19
Bangladesh - Peru - Albania	25	Albania, South Africa (The Netherlands and South Korea)	22

AT1	AT2
The marbles were fun to use.	At first it was a bit weird because the more marbles you used the worse the air was, but once I got used to that it was fun!
I liked it.	Yes.

I did like the marbles but the globe was a bit hard to see because it was all one color.	Yes.
I don't know really.	Yes.
Confusing at first but very fun.	Yes and no, the goal was clear but it was difficult sometimes as I wanted to get a better air value, but that meant I needed to take out marbles instead of putting them in.
It was nice to use the marbles to change the country, and it was fun to watch the countries change.	Yes.
It was fun.	Yes.
It looked cool.	Yes. The marbles were also pretty easy to use.
I liked it.	Yes.
I think it was very fun to use. And I like that it is about our planet.	Yes.
Having to use the marbles in order to select the countries was fun to do!	Yes.
Fun.	Yes.

AT3	**AT4**
To get an idea of what the air is like all over the world and not just here in The Netherlands.	Yes!
To know which countries do and do not have rules for the air quality.	Yes.
To learn more about the world.	No.
So that you know which countries have bad air, so you can help them get it better.	Yes! For sure.
To raise awareness in people who are in countries where the air is bad.	Yes.
To show that there is a big difference in air quality around the world.	Yes.

To understand that there are countries where the air is good and some where the air is bad. And that the countries with bad air need to fix it.	Yes, I think it was fun.
I don't really know, maybe to get more people to help with the air in the countries with bad air.	Yes.
To see that air is not good everywhere, there are places with bad air.	Yes.
To show that air quality is not something that is equal everywhere. Kind of like the same thing with water.	Yes! I would love to have something like this, and for a lot of other people to have one too as I think more people need to look after our world.
To convince people to take action and to make the air good everywhere in the world.	Yes.
To stop people from doing more harm to the world and show that there are places where air is not good yet.	Yes.

AT5
No.
Why is it that some countries have a bad air quality?
No.
No.
No.
No.
Is the air in the bad countries getting better or worse?
Is there a way to help the countries with bad air?
No.
How can we help people get better air to their country? Water and earth you can hold and clean but you can't do that with air.
No.
No.

PR1	PR2
That you had to use marbles to change the air quality and other countries would light up if you used more or less marbles.	South Korea had pretty bad air, just like South Africa, which I did not expect. And the island above Australia had the best air, followed by Sweden and Canada.
It was pretty fun to use the marbles to change the countries.	I think that there was a division in the location on the globe. A lot of the counties in Europe had good air while those more in the south had worse.
The globe looked very cool with it being made like that.	There was a big difference between Peru and Canada even though they are on the same side of the world. And most countries in Europe were very good. But I do like that I was kind of right with India, because the country next to it was the worst one.
I thought it was cool. But I did have a bit of trouble with the marbles.	It was weird to me that South Africa had bad air quality, because it is such a nice country. And that Canada had such good air was a surprise.
I liked it. It was fun to use and it was nice.	That was kind of like I expected. But it was cool to see how a lot of countries that were similar were kind of close to each other.
Weird but fun to use.	I remember New Caledonia being the best, Bangladesh being the worst and Qatar being close to Bangladesh. So I am happy that I was almost right.
I think that it was fun to learn about something in this way instead of the chromebook.	The air in South Korea was not good, but the air in Bangladesh and Qatar were even worse.
Kind of fun.	I think my prediction was right. And that the country next to Australia had the best. Followed by Canada and I think Albania.
I liked it but I don't understand why more marbles meant that the air in the country was worse.	The Netherlands, Sweden and the other countries in Europe all had good air, and the countries in the lower part of Asia and Qatar all had bad air.
I like that we had to use marbles to change the countries and I like that the countries we're all over the world so that you could see more of the air around the world and you had to walk around it which was fun.	New Caledonia was the best, then came Canada, then Sweden, then The Netherlands, then Peru, South Korea, South Africa and Bangladesh. I know I missed a few but I can't remember those now.

I like that I was able to walk around it and use the marbles. It felt like I was controlling the globe.	The countries with bad and good air all were kind of close to each other.
I think it was cool.	The country with the worst air was Bangladesh and the one with the best air was New Caledonia.

PR3	**PR4**
Maybe make it so that it is the other way around. So more marbles make the air quality better. That would make more sense to me.	–
Nothing.	–
Maybe change something with the marbles, that's the only thing.	–
Nothing.	–
Nothing.	–
Nothing.	–
Nothing.	–
Nothing really.	–
Change it so that more marbles means better air.	–
Nothing.	–
Nothing.	–
Nothing.	–