KELVIN’S THUNDERSTORM THESIS REPORT

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Factors that spark an interest in science

Abstract

Renewable energy is the use of natural resources to generate electricity. Similarly, Kelvin's Thunderstorm which is an electrostatic concept, uses nothing more than running water to generate electricity. However, the current generation is not high enough to power an actual device, so it does not necessarily operate to the full capacity of a renewable energy source. Due to static electricity being a topic of science and not enough students are interested in science, research is done to figure out *What factors of design attract individuals to the science behind of technology?* The main reasons as to why there is a lack thereof, are that students personally feel that the content of science is too difficult to comprehend, that the educational institution fails to implement the STEM program properly or that the engagement with science professionals is not optimal. There are two factors that can resolve these problems, namely the "Setting" and "Collaboration".

An experiment was developed that used the Kelvin's Thunderstorm concept as a prototype to verify if these two factors were accurate. After 57 participants were recruited for the experiments, where 35 were female and 22 male, it became apparent that the data in relation to gender would be biased. Likewise, the age proportions did not have a coherent distribution, so the notion to compare the data based on age was eliminated. The resulting comparisons were made based on the total amount of participants. First, the total amount of technical participants were determined which resulted to 20 (35%). When participants were asked on the functionality of a battery and electricity, surprisingly over 50% knew how they operated. However, when asked about renewable energy, 43 (75%) knew what it was. Therefore approximately 25% more knew what it was and this could be the result of it being a visual object. So, the experiments revealed that approximately 90% knew that water was powering the device, whereas 98% thought that electricity was a part of the concept. By comparing these two findings with the previous ones, it can be seen that the knowledge gain in the concept increased with a visual model (prototype) of the concept. However, to confirm this assumption, the other results show that 81% needed guidance throughout the experiment and 82% were visual thinkers. Therefore, designing a visual concept, testing its functionality with participants and asking them questions to test their understanding, are essential to increase interest in science.

Acknowledgement

Foremost, I would like to express my sincere gratitude to my supervisor Dr.ir. Wouter Eggink, who has supported from day one, by showing me how to sketch my first 2D drawing into a 3D perspective one, for his quick responses to my emails and elaborate feedbacks, for his patience and guidance through the assessment of the different chapters of this research report and for his continuous encouragement. I am really grateful to have gotten to work with my supervisor and could not have asked for a better one.

Besides my supervisor, I would also like to extend my gratitude to Mr. Clemens Mensink, who have guided me through the prototyping processes and allowed me to work at his home on numerous occasions. I would not have been fully able to resolve the technical problems without his technical insights and enthusiasm.

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I thank my fellow 62 participants, who have taken the time out to contribute to my research project, chosen times that were appropriate to my time zone schedule, bared with me through technical difficulties and even shared helpful tips that could be integrated in certain parts of the research report, next to the results. Moreover, I would also like to thank those who did not get back to me or participated in my research again, for they gave me the motivation to go out of my comfort zone to recruit participants from around the world.

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Chapter 1 Introduction

Society today encourages students to study science and to pursue a career therein [1,14]. However, not many of them go through with it, due to a lack of interest in science. For example, research done by Anderhag et al. [2] indicates that students who barely receive any practical experiences in science at an early age, will find science to be more *impersonal*, *transmissive* and unrelatable later on in life. Furthermore, there are other factors that directly or indirectly influence the disinterest of science amongst students. These have been divided into three categories, namely personal experiences, curricula deficiencies and entity impacts.

Next to science, advanced developments of technology are also valued within society. Science is defined as the acquisition of knowledge and is integrated into technological tools that are used to craft methods or techniques that solve problems or create artistic perspectives [5]. Hence, science and technology go hand in hand, and the combination of the two can make a concept or system more complex [3,5]. Therefore, the company Menperium transforms such complex systems into simplified visual sculptures to capture the essence of those systems [3]. Moreover, their goal is to attract youngsters and seniors to scientific concepts with such sculptures or other types of visual representations. However, the target group for the project that is discussed in the third paragraph, will primarily be students from elementary school up until university.

The name "Menperium" is derived from both "Men" and "Imperium", where *men* represents the totality of all individuals and *imperium* which defines "someone or something rising to greatness" [1]. This company hosts lectures and workshops, both in Dutch and English, to inspire individuals to pursue their passions and aspirations. Thus, these individuals are given insights [3] that can help them with their personal development. Menperium has two team members, namely Clemens Mensink, PhD Electrical Engineer and founder of the company, and Fabienne Heijne, a creative product developer.

Kelvin's Thunderstorm is a visual representation of an electrostatic system [8,13] that generates an electric spark at a high voltage. Menperium who proposed this concept, will only use two streams of water, two metal inductors [5] and two collection containers [13] to conduct the abovementioned operation. Additionally, an explanation on the workings behind the spark generation will be given by first defining what electricity is and how static electricity is derived from it. Subsequently, this complex system will be transformed into a simplified sculpture that can be displayed at an event, an educational institution or in an exhibition hall. Thus, the sculpture will at most be one meter long, two to three meters high and approximately thirty to fifty centimetres wide.

Therefore, the main goal of this paper is to discover if such a practical concept can actually spark the interest of individuals in science. This process will be achieved via three assessments. First, the lack of interest in science will be determined by exploring the three aforementioned categories. Next, the factors that attract individuals to science will result in two findings, namely the "setting" and the "collaboration". Finally, the way how design can influence attraction to science will be assessed, to find an answer to the research question: What factors of design attract individuals to the science behind of technology? It is expected that the interest gain in the science topic or concept can be increased by allowing an individual to engage with a physical or visual concept.

This report will cover a range of concepts and/or systems that will give a general idea of what the project concept is. Thereafter, ideas generated through different processes and interactions will be combined to design the first prototype concept which will be optimized over time. The focus will then shift from the designing process to the functionality realization of the prototype, which will be

[1] Statement made by Clemens Mensink

accomplished through experiments. Collected data will then be processed for further optimization of the project concept or suggestions.

Chapter 2 State of the Art Review

The graduation project topic "Kelvin's Thunderstorm", is based on an electrostatic device that generates an electric spark from running water. The following section will first sum up some state of the art technologies or scientific concepts relative to the project topic, then similar ones will be given. Next, a description of what electricity is and how static electricity occurs will be given. In the last part of this section, the research question along with three sub-questions, a start to the literature research will be presented and it will end with a Stakeholder analysis.

2.1 Electricity

Every single organism and non-living thing in the universe, are made up of atoms. The centre or nucleus of an atom consists of protons which are positively charged particles, and neutrons which are neutral or do not have any charges. Orbiting around this nucleus are electrons – the negatively charged particles – in an electron cloud. Since protons and electrons have opposite charges, they attract to each other. Contrarily, charged particles with like charges will repel each other. Therefore, the constant attraction-repulsion force causes electrons to break free. These free electrons latch onto other atoms, expelling electrons from those atoms, and create a constant flow of electrons known as electric current. Thus, electricity is generated by the constant movement of an electron from one atom to the other and can be defined as the flow of electrical charge. [6,7,14]

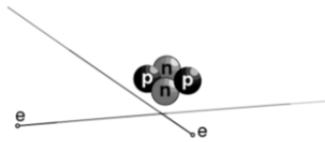


Figure 1. An atom construction with protons, neutrons and electrons [6]

2.1.1 Static Electricity

As stated in section 2.1, electricity is simply electrons moving from one atom to the other. Static electricity is defined as an imbalance of electrical charge in objects and is caused by the friction of two objects. By rubbing two objects against each other, some electrons from one object become free and move or jump to the other object. Upon separating these two objects, one of them will become more positively charged by releasing electrons from itself, whereas the other one will become more negatively charged by taking on these free electrons. Therefore, if an object takes on static electricity, charges that are the same will repel each other and move towards the surface of the object to get away from each other. These repelled charges will stay at the surface of the object and only move to another area when the object becomes grounded. A good example of this phenomena is when an individual scuffles their feet on a rug and attempts to touch a doorknob thereafter. This results in a zap or shock as the charge build-up in the individual discharges. [6,7] Similarly, the project proposed by Menperium [3] should be able to generate an electric spark from running water which consists of positive and negative charged particles. The next section will introduce systems that uses natural resources to generate energy and concepts that generate static electricity.

2.2 Renewable Energy & Sources

Static electricity can easily be generated through the rubbing of two objects against each other. When the built up charge is finally grounded, a shock will be seen or heard. So, this is an example of electricity being naturally generated. Kelvin's Thunderstorm is an electrostatic device that generates static electricity and its functionality will be discussed in a later section of this chapter. Since it uses a natural resource to generate electricity, it may be viewed as a renewable energy source. Therefore, this chapter will also introduce the topic of renewable energy and some main energy sources that contribute to renewable energy.

2.2.1. Renewable Energy

Some examples of fossil fuels that are still being used as energy sources are coal, natural gasses and oil. Due to these fuels not being in abundance and the growing population, there are speculations that these resources will soon be exhausted. Moreover, fossil fuels contribute to air and water pollution. Therefore, these energy sources are substituted by resources that are infinite and hardly have any negative impact on the environment. Such substituted resources are called "renewable energy" that can use the sun, wind and/or water to generate clean energy continuously. Other sources that can also generate renewable energy are biomass energy (e.g. plant) and geothermal energy (heat). [23,24] In the following sections, these sources will be briefly discussed.

2.2.2 Solar Energy

A solar photovoltaic system as can be seen in figure 2, uses sunlight to produce electric energy. After the solar energy from the sun is converted into electricity, the electricity is then converted into alternating current (AC) in order to power a home or building. In most cases, if the stored energy is in excess, the homeowner will be able to trade it in for cash at their energy provider. [25]

Figure 2. Solar Panels used to convert solar energy into electricity [25]

2.2.3 Wind Energy

Figure 3 shows a closeup of a few windmills on a wind farm. Windmills or wind turbines first harness wind energy, then they convert this energy into electricity. There are three steps to the conversion process [25]:

1. Angled blades on the turbines begin spinning when wind blows on them
2. Spinning causes kinetic energy which is then transferred into mechanical energy
3. Mechanical energy is converted into electricity through the generator that the turbines drive

Figure 2. Wind Mills used to convert wind energy into electricity [25]

2.2.4 Water Energy

Hydroelectric energy is considered more reliable in generating electricity than solar and wind energy. The dam that can be seen in figure 3, is a barrier harnessing a large reservoir of hydroelectric energy. Hereby, water flow can be controlled in order to drive water turbines that similarly generate electricity as the wind turbine mechanism in the previous section. [25]

Figure 3. Dam used to convert hydroelectric energy into electricity [25]

2.2.5 Biomass Energy

Figure 4. Plants used to convert biomass energy into electricity [25]

Since there is energy stored in plant-based or organic materials, they are burned to produce electricity. Even though wood might be an organic material, it does not fall under the category of biomass energy. Additionally, the conversion of organic materials into gas, liquid and solid fuel is economically and environmentally lower in cost. [25]

2.2.6 Geothermal Energy

The natural heat that lies below the surface of earth is called geothermal energy. This energy is brought to the surface by water and/or steam and is harnessed to either heat up homes or generate electricity. Contrarily, geothermal energy can also be used as a cooling mechanism. [25,26]

Figure 5. Energy generated from heat below earth's surface [25]

2.3 Similar Technology or Scientific Concepts

Several devices that use or generate static electricity are air filters or dust removers, conductors (capacitors), paint sprayers, photocopiers (xerography and printers) and the Van de Graaff generator. These are being summed up in this section to give a general idea of how such devices or systems work. This is done in order to gain a better understanding on the functionality of the project topic.

2.3.1 Air filters or dust removers

Air filters or cleaners are used to purify the normal air from ash, dust, pollen, smoke, soot and other impure particles that pass through the air. [9,10] When this particle passes nearby the device, it will get sucked into it. Thereafter, an excessive amount of positive charge, which is the electrostatic part of the operation, will be exerted onto the particle. The particle will continue through the device with the air until it reaches a grid consisting of opposite (negative) charge. This grid will attract the particle to it, since opposite charges attract, and will retain it while fresh, clean air blows out the opposite side of the device. An illustration of such a device can be seen in figure 6.

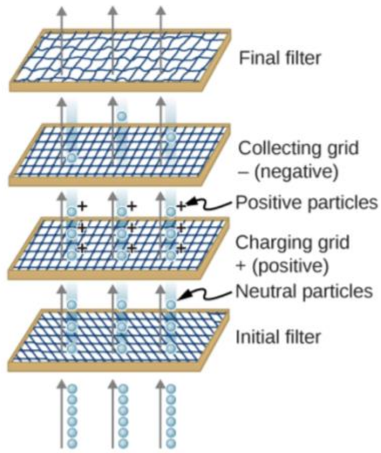


Figure 6. Schematic of an air filter/cleaner [10]

Another example of an air cleaning device is an ion generator [9]. The only difference between this electrostatic device and the previous one is that this one does not have an opposing grid that retains the impure particles. Thus, these particles will first polarize the surface that they come into contact with, then land on it. Constant accumulation of these particles on these surfaces, will result in them becoming dirty. [9] So, the first option has a better cleaning function than this one.

2.3.2 Conductors

Capacitors are examples of conductors that consist of two or more conductive plates parallel to each other. These plates are separated electrically by air or any other types of insulating materials (e.g. ceramic, glass, plastic, etc.). Capacitors have the ability to store energy (electrical charge) in an "electrostatic field" that lies between the two plates. However, this only occurs when there is a power source connected to it. Therefore, this device needs external power to drive its operation. As current begins to flow through the capacitor, it will charge up and cause the electrostatic field to become stronger, so that it can store more energy between the plates. This ability is known as the "capacitance" of the capacitor. [9]

2.3.3 Paint Sprayers

An electrode is placed at the tip of the paint sprayer to generate a high potential difference to cause the paint to slowly move through the head of the sprayer. There is usually friction between the paint and the sides of the sprayer which causes the paint to become negatively charged. As was mentioned in section 2.1.1, the friction of two objects causes a loss of electrons from one object onto another, which is exactly what is happening here. The sides of the sprayer is giving off electrons and the paint is taking on these electrons, thus becoming more negatively charged. By applying this negatively charged paint to positively charged metal surfaces or any other conductive surfaces, the charges will attract and result in a perfect finishing coat of paint. [11]

2.3.4 Photocopiers

The process of photocopying was initially called electrophotography [12] and was based on two phenomena: materials will attract to each other if they consist of opposite electrical charges and some of these materials can become better electricity conductors when they are exposed to light. This concept can split into two parts, xerography and printers. [10,12]

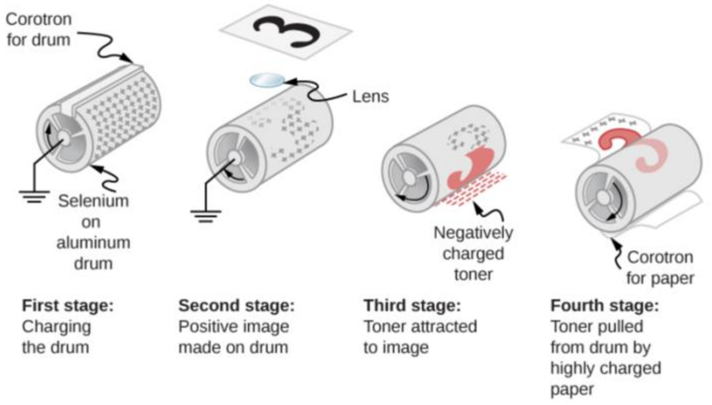


Figure 7. The process of Xerography [10]

Figure 7 displays the xerography process of copying an image onto a piece of paper. First positive charge is sprayed onto the negatively charged selenium [2] -coated aluminium drum. Next, the drum is exposed to the image that is supposed to be copied. The light areas of the image will conduct and the positive charge will neutralize, whereas the dark areas will remain positively charged. This is how the image transfers onto the drum. Then, toner is sprayed with negative charge to attract to the positively charged areas of the drum. Finally, a good amount of positive charge is placed on a blank piece of paper, with a greater charge than the positive one on the drum, then the paper will extract the toner from the drum onto itself. [10] Additionally, laser printers apply the same process as the xerographic one, but the only difference is that they use a laser to get a higher quality image from the drum. The laser, thus increases the precision of the output quality. [10]

[2] Selenium is a photoconductive substance that insulates when it is dark and conducts when light fall on it.

2.3.5 Van de Graaff Generator

This is one of the biggest static electricity generators that can produce high voltages of up to fifteen million volts. It was named after Robert Van de Graaff who built the first model in 1931 to do research in nuclear physics. In figure 8 an illustration of this generator can be seen, where A shows a battery supplying positive charge in excess, to a pointed conductor. This conductor then sprays the charges onto the belt, which will be moving upwards in reality. These charges will be taken up by the other pointed conductor in B and they will flow through it until they reach the outer surface sphere of the device. The ion source will also produce positive ions and because of the sphere also being positive, these ions will avoid coming into contact with the sphere and accelerate away from it to high velocities. [10]

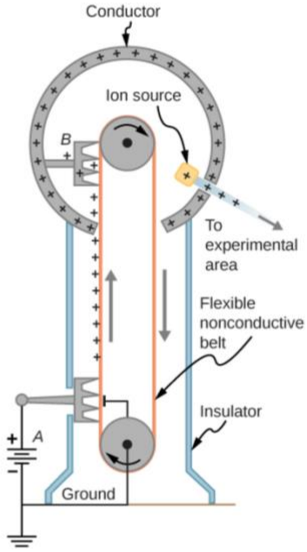


Figure 8. Van de Graaff Generator [10]

2.3.6 Similarities & Differences

The examples from section 2.2.1 to section 2.2.5 all generate static electricity with an external power source. The Van de Graaff generator as well as the photocopiers, the xerographic process in particular, both use an excess of positive electrical charge in order to enhance the output of the devices or systems. For the Van de Graaff generator, this excessive amount of positive electrical charge was used to generate the movement of the belt and to exert positive ions out of the ion source at high velocities. The xerographic process applied this method to extract the image from the drum onto the paper. So, even though both examples had a different outcome or reason for using an excess of positive electrical charge, they both manipulated the workings of the devices in the same way.

2.4 Project Concept

The basics of static electricity and electrostatic concepts were explained in the previous chapter. Now, the operation of Kelvin's Thunderstorm will be explained in this section along with how it relates to one of the renewable energy sources and some technologies or scientific concepts similar to it. At the end of this section, a preview of the research question and sub-questions will be presented.

2.4.1 Kelvin's Thunderstorm

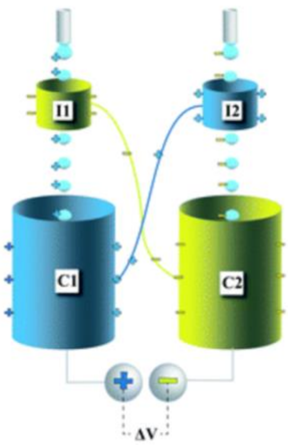


Figure 9. Kelvin's Thunderstorm configuration with two streams, inductors and collection containers [8]

One of the current sculptures Menperium is working on is Kelvin's Thunderstorm, also known as Kelvin's Water Dropper [8]. This sculpture is meant to translate the scientific concept of static electricity into a visual representation in order to spark an interest for science in students. Its standard configuration can be seen in figure 5, where two streams of water [8,13] originate from a water reservoir at the top and flow through two cylindrical metal objects into containers at the bottom. The cylindrical metal objects [8] are representations of inductors [13] (I1 and I2) and are cross-connected with the containers (C1 and C2), which are representations of electrodes. This cross-connection is what triggers the charge build-up. Moreover, the two streams of water are electrically connected by an electrode [8] or conductive wire and generate the ionization in the water. For example, if the ions in the left water stream become imbalanced and the inductor takes on negative charge, positive charged droplets will fall from inductor I1 into container C1. Seeing that container C1 is connected to inductor I2, this inductor will take on positive charge and produce negative charged droplets [8,13] that will fall into container C2. Consequently, charge will build up across these containers, eventually causing a spark [8] to jump from the negatively charged side (C2) to the positively charged one (C1). This spark will carry 10-15kV and a few nanoamps.

As simple as this configuration may seem, Kelvin's Thunderstorm faces four challenges which can be viewed in the proposal presented in appendix A. These challenges are: How to present the concept in an attractive way; how to explain the concept such that it will inspire people; how to implement a water pump maintaining functionality; and how to maximize the spark length to make it most spectacular. The first two challenges are a commodity to the concept, whereas the last two are luxury requirements. Therefore, the following sections will investigate why there is a lack of interest in science, how individuals attract to science and how design influences attraction to science. These aspects combined form the research question: What factors of design attract individuals to the science behind of technology?

2.4.2 Comparative Renewable Energy Source

Water is the power source of Kelvin's Thunderstorm just as a large water reservoir is the power source to a dam. Kelvin's Thunderstorm can thus be compared to the energy source of section 2.2.4, where hydroelectric energy is converted into electricity. Although Kelvin's Thunderstorm produces a high voltage, the current can be rendered as negligible and can only power a small LED lamp, whereas the water turbines in the dam generate a much higher amount of voltage as well as current in order to power homes or buildings. Even if the Kelvin's Thunderstorm concept was scaled up, it would not change the outcome of the amount of voltage and current that it produces. There was a study done on the implementation of external power to boost its energy generation, however it is still in the developing progress.

2.4.3 Comparative Technologies or Scientific Concepts

The air cleaner as is mentioned in section 2.3.1, was specifically designed to attract particles of opposite charges. Likewise, when the stream of water falls too close to the metal inductor, it will try to pull or extract the opposite charge out of the water. Since the distance between the stream and coil is too far, the coil will end up dropping this particle through the inductor, hence producing water droplets. Contrarily to the operation of the air cleaner, as the stream of water from the Kelvin's Thunderstorm concept becomes imbalance at some point in time, the charge that the inductor takes up will repel the exact same charges and as was stated earlier, allow the droplets with the opposite charge to flow through. Thus, even though these two concepts are modelled differently, there are still similarities between their functionalities.

Some functionality of the photocopier operation in section 2.3.4, can perhaps be applied to the Kelvin's Thunderstorm concept to produce a better output experience, since the spark is about 0,5 cm long and emits a small buzzing sound. If additional sound could be used to exaggerate the spark effect, when the spark is sensed by a photodiode, perhaps it can add to the user experience. The photocopier concept works similar to a photodiode by conducting when exposed to light and insulating when it is dark. So, there can be a possible implementation of such a mechanism in the project concept.

By comparing all of the devices from section 2.3 to Kelvin's Thunderstorm, it became clear that the greatest distinction is that Kelvin's Thunderstorm is more sustainable than the rest since they all use external power to drive their operations. Kelvin's Thunderstorm only uses running water. However, by integrating external power to the concept, this can perhaps increase the spark length, the amount of current flowing through the concept or the accuracy of the droplets falling through the coils. Alternatively, the integration of external power can probably turn Kelvin's Thunderstorm into a miniature water dam that can power a device or multiple ones.

2.5 Literature Research On Science Interest

In order to know how the Kelvin's Thunderstorm concept should be designed, research has to be done to first figure out What factors of design attract people to the science behind of technology. This will further be analysed by Why there is a lack of interest in science, What attracts individuals to science and How can design influence attraction to science.

2.5.1 Lack of interest in science

The lack of interest in science amongst students are caused by a number of factors. The first set of factors will describe how science personally affects students in a negative manner; the second set of factors will discuss the various deficiencies that the curricula in science have; and the last set of factors will target *who* plays a role in students losing interest in science.

Firstly, when science personally affects a student negatively, they experience difficulties with comprehending the concepts or contents being offered by the specific science topic [2,22]. Science is viewed by most students as critical and lacking of creativity, since the topics are strictly related to the science curricula and textbooks. Furthermore, it is regarded as unrelatable [2,21], especially when a student develops a negative view or image of themselves [1,21] by experiencing the negative effects of science. Science can also be perceived as nonbeneficial when the curriculum demands increase and result in poor performance of other curricula activities, due to it being very time consuming [1]. On the other hand, students who may have already acquired a certain level of knowledge in the science topic, might find the repetitive participation or engagement unchallenging and tedious [20]. This factor can also lead to a lack of interest in science if the student is hindered to develop themselves more.

Secondly, science can be difficult to grasp if there is a lack of explanation or elaboration on the content [20]. This factor caters to how poor the content is transmitted [2] into the learning environment. Moreover, sticking to traditional learning methods such as the use of textbooks [2,21,22], or being bound to subjects without any interactive functionalities, can result in inappropriate integrations of the STEM courses as was discovered in the research paper of Braund and Reiss. These courses are Science, Technology, Engineering and Mathematics. [21]

Lastly, there are a few entities that play a role in students losing interest in science. These entities are the educational institutions, the teachers and some science experts. An educational institution can value everyday objects of interests[3] over the scientific ones [2], or fail to integrate the STEM concept as was mentioned above. As a result, teachers will also fail to understand the STEM concept [21] and barely add any valuable contribution to the scientific knowledge [20] development of the student. This could in turn add additional strain on the teacher-student relationship, causing it to become more impersonal [2]. Therefore, also resulting in a reduction of the quality of the educational experience [22]. Similarly, if a student should undergo a bad experience with a scientist, for example, not receiving any responses to their emails or handed in reports from the scientist, it can result in them losing their interest in the topic and person altogether. After all, the scientist is supposed to be the bridge between the student and science. [1]

Thus, lacking interest in science comes from negative personal experiences, deficiencies in the educational system and inappropriate preparations with the science content or bad experience with people in the context.

[3] The interest a person acquires by, for example, their upbringing at home

2.5.2 Attraction to science

Next to the factors that play a role in the lack of interest in science, each or a group of students all have different opinions on what attracts them to science. From these opinions stem two main factors that influence this interest, namely the “setting” and “collaboration”.

Setting

In order for students to learn and gain knowledge comfortably [20,21], it is essential to create an informal setting [1,20,21,22] and place them therein along with the support from their significant others. Parents and peers are referred to as the significant others in the study conducted by Hall et al. [22]. Alternatively, students can take up role-plays, which is a form of the arts, to act out specific scientific concepts to improve their learning skills. For example, a set of students can “portray molecules, components of biological cells or model processes such as energy or behaviour of electrons in circuits” [21], in order to grasp a better understanding of these scientific topics.

Apart from this, providing the students personal engagements with scientists or experts [1,20,22], can add value to the informal setting as well [1,20,21,22,15]. Even though in the previous paragraph this type of engagement had a negative impact on some students, not all experiences suffer the same outcome. Furthermore, this engagement does not only lie in the setting domain, but also crosses over to the collaboration domain.

Collaboration

Multiple researchers, namely Masson et al. [1], Anderhag et al. [2], Mcmeeking et al. [20], Braund and Reiss [21], and Hall et al. [22], discovered that there is one common factor that allows the students to develop a distinctive taste for science [2], that is participation in specific scientific activities. This type of participation give students the opportunity to interact with physical objects or relevant experts [1,20,22,15], such as scientists. In addition, these different interactions cater to their level of engagement in discussions or inquiries [2,20,22,15].

Aside from the aforementioned factors, there are two others that independently play a role in the interest development of students towards science. Firstly, ensure that the subjects are properly structured or that the curricula is organized in such a way that it accommodates both the science and the arts [21,15], for example, role-playing as was mentioned previously. Finally, provide the students with a variety of options that can help them study for these science subjects. An option can be to give the students a local problem to solve and let them draw a solution from the arts, humanities and STEM content [21].

2.5.3 Design influencing attraction to science

As the previous section discussed the different factors that play a role in what attracts students to science, this section will now examine how design can influence this attraction aspect to science. Before one can design for an audience or a specific user, the following conditions must be taken into consideration: effect of visual art on public [16], empathic design [17], elements of a well-designed object [19] and examples of visual designs [18].

Effect of visual art on public

Visual art forms such as graffiti, installations and sculptures may be viewed by the general public in a passive way. For example, if these art forms are intentionally placed in areas where crowds of people pass by or through, they are intended to engage participation. However, the passers-by might quickly take a look at them, then go about their business. In addition, these art forms may not cater to all the groups involved at these crowded areas. Thus, different age groups with different knowledge backgrounds can have an effect on whether individuals engage with these art forms or not. [16]

Marcus and Wang emphasize that the experience of the audience or user(s) should be taken into account when designing for them. Study in the cognitive development theory indicates that two fundamental processes are relevant for this type of designing approach, namely "Assimilation" and "Accommodation". Assimilation is the process of incorporating new information into a cognitive structure that already exists, whereas accommodation forms a new cognitive structure to incorporate the new information. Therefore, gaining a better understanding of this theory will help the designer produce a better product for the audience or end-user. By incorporating this theory into design, the user will have a better participatory experience. Nevertheless, the best approach to designing for others is to apply the human centred design method. [16]

The human centred design method places the user at the centre of the design, which allows the designer to get a better understanding of the behaviour of the user and what the user needs. Furthermore, this method has two objectives where one focusses on making the user happy and the other on applying empathy to the design. [16]

Empathic design

Being empathetic means being able to stand beside another person and understanding their situation or what they are going through, however, not experiencing their situation as your own. So, empathic design [17] can be defined as identifying oneself with a user and trying to understand what the user wants. There are two empathy components that play an important role in the designing process: the affective component and the cognitive component. The affective component refers to the designer being able to relate to the emotions of the user, whereas the cognitive component refers to the designer gaining an understanding of the user. [17] Thus, to be able to design for a user, one must first empathize with the user(s) they are designing for.

Elements of a well-designed object

The first step to better understanding the user is to develop a Persona [19] which describes specific user groups that consists of demographics (age, educational level, gender), goals (set accomplishments), limitations (obstacles in the way), motivations (driving forces) and the environment (where or how the product or service will be used). Thereafter, various fields of study should be implemented to produce a good design according to the findings of Rosenzweig [19]. These are cognitive science, human factors, human memory, human perception, accessibility/disabilities and learning styles.

Cognitive science focusses on what information the mind processes and how it is processed. Human factors investigates the limitations of individuals through biomechanics, cognitive abilities, engineering, industrial design and psychology. Human memory is similar to a processor that can store and retrieve current and past events upon request. Human perception translates information through all the human senses. Accessibilities/disabilities refer to physical and visual disabilities, where in the physical case an individual is limited to using certain tools, such as a computer, and in the visual case, reading a computer. Learning styles are complicated to integrate into a single product that is designed for multiple user groups, when the requirement is to feed a diversity of information to individuals using the device or system in order for them to learn. After going through all of these steps, the designer can make a start on the physical designing process. [19]

Examples of visual designs

In this section, different visual designs will be discussed. Camburn et al. defined a prototype as "…a pre-production representation of some aspect of a concept or final design." [18]. Prototyping has the goal of enhancing performance and the experience of the user in relation to the final product. Four objectives must be taken into consideration when designing a prototype, namely refinement, communication, exploration and active learning. Refinement is known as adapting the design gradually. Communication is when information based on the design is shared to the users or to the members within the design team. Exploration refers to searching for new concepts of design. Active learning can be defined as gaining new knowledge either about important phenomena or about the design space. Next to these objectives, there are also seven guidelines for the incorporation of prototyping in a design process and these are displayed in the table of figure 6 along with their design heuristic. [18] This overview gives a clear structure on how ideas can be translated into visual designs to give the audience or the users a better vision of what the product might look or feel like.

Variable	Design Heuristic
Testing	Construct a clear testing objective
Timing	Early prototyping is the most critical
Ideation	Prototypes lead to functional ideas
Fixation	Fast prototyping reduces fixation
Feedback	Feedback may induce corrections but also increase fixation
Usability	End-user testing may enhance performance assessment accuracy
Fidelity	Higher fidelity representations lead to accurate interpretation of the design

Figure 10. Seven guidelines for incorporating prototyping in design process. [18]

Moreover, there are two types of design prototyping methods: iterative prototyping and parallel prototyping. Iterative prototyping is a crucial method when it comes to prototyping a design at an early phase, for it helps with the management of great uncertainty, the simplification of parts, the identification of errors and gaining insight on difficult situations. Research done in the paper of Camburn et al. indicates that the application of the ideation guideline in prototyping will increase functional ideas. Additionally, according to some empirical studies from "the evaluation of the self-efficacy and design requirement satisfaction" [18], teams who apply iterative prototyping surpass teams who do not apply it. Thus, this prototyping method strongly relates to the increase in performance which is relevant to meeting difficult requirements. Similarly, parallel prototyping also correlates to an increase in performance when it comes to discovering new ideas. However, both these prototyping methods can be strenuous on the design team. Therefore, mock-ups are good alternative methods to relieve the design team of the strain. Mock-ups are high-level, abstract demonstrations of a feature or features of product concepts or systems. Some examples of mock-ups are product mock-ups (e.g. paper mock-ups), system mock-ups and service mock-ups. Furthermore, they enable communication within the design team and to the users, and initiate rapid exploration of concepts. However, the only disadvantage is that they can give misrepresentations of actual physical concepts, so they should be cautiously evaluated. [18]

2.6 Stakeholders

Seeing how empathetic the designer has to be while designing a product for the end user, this section will discusse who these potential stakeholders are or could be.

There are two sets of stakeholders involved in this project, namely the shareholders and testers. The client from the company Menperium and the study program Creative Technology fall under the shareholders, since the project is being done for them. All participants in the experiments, whether technical or non-technical, fall under the testers. An overview of the stakeholders can be seen in figure 11, including potential candidates such as an educational institution or a renewable energy company as additional shareholders. Since the system is more valuable at the bottom where the spark is generated than at the reservoir, the most valuable stakeholders are placed at the bottom and the least at the top. In addition, the shareholders are more financially invested in this project than the testers, therefore the profit meter is placed at the bottom of the graph. In the cross-section of the device, “Empathic Design” is emphasized to indicate that the values from both testers as well as shareholders will be taken into account when developing the prototype model.

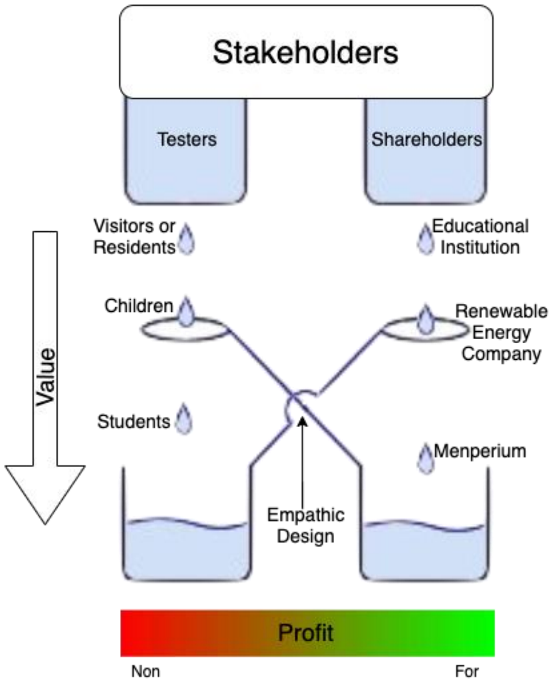


Figure 11. Measure in Value and Profit amongst Stakeholders (Made by Ikmareka)

Chapter 3 Methods & Techniques

The various methods used to accomplish this project are discussed in this chapter. These are the experimental concept design, the techniques used in establishing the concept's functionality, the user testing, the dependent and independent variables from this user testing, the comparisons between the different user testing stages and how the data is collected and analysed.

3.1 Experimental Design

This section will link the experiments to the researched information from section 2.6 and give the three stages of the experiment.

3.1.1 Prototype Description

As is mentioned in section 2.3, this concept will be a simplified structure of a complex system called Kelvin's Thunderstorm. In addition, a depiction and description can be found in the same section about the various components needed for this concept. The initial goal of this project was to design a concept large enough to attract a crowd of students. However, due to the spark size not matching the massivity of the concept, the prototype has been scaled down to an appropriate size, thus targeting a smaller group of individuals. Initially, the size was 1x0.5x3 m^3 and has now been scaled down to 38x9x43 m^3. Illustrations of both sizes can be found in chapter 4.

The designed experiments are based on the research results of section 2.6. It is stated that students who are placed in a desirable setting, is more likely to feel comfortable engaging with science. In addition, collaboration between a student and a scientific concept, or even a scientist, can increase their interest in the science topic. So, in order to ensure that the project concept has a similar effect on the participants, it will consist of two interaction methods: one which will allow the participant to freely explore the concept and another which will allow the participant to observe the concept thoroughly. Thus, there will be both exploratory and observational interactions between the participants and the prototype.

The recruited individuals for these experiments are both *Live* and *Online* participants. Live as in participants that are physically present and Online as in participants that are virtually present. Online participation will be considered the low fidelity (lo-fi) prototype method, since the participant will only be able to explore and observe the concept through the researcher: The researcher will pose as an Avatar for the participant in the virtual environment and follow the instructions given. On the contrary, Live participation will be considered the high fidelity (hi-fi) prototype method, since the participant will be able to physically see the true representation of the concept model.

3.1.2 Experimental Stages

Stage One: Exploratory Interaction

In this stage, the participants will be free to explore the concept however they like. The only objective for the Live participants, is for them not to come into contact with it. So, as is also mentioned in the information brochure in appendix B1, a sign will be placed on or next to the concept. The only requirement that is requested of the participant, is to verbally describe their thoughts while observing the concept and its functionality. This stage is meant to trigger the participant to start thinking about what is going on.

Stage Two: Observational Interaction

In this stage, the researcher will ask the participant specific questions to guide their thinking process into understanding the concept based on their background knowledge, regardless of them being technical or non-technical. By doing this, the participant can voluntary use their background knowledge to discover underlying processes that seem familiar to them. Moreover, they can also discover the usefulness of the design in relation to the system itself. Three clues are given in the background questions document in appendix C1, where the participant is asked about a battery, electricity and renewable energy. With this in the back of their minds, they can probably relate their knowledge of these aspects to the concept in order to find the answers to the questions being asked.

Stage Three: Functionality Comprehension

In this stage, the participants will first receive a clear explanation on how the system/device works. Next, if any parts are unclear or the participants want further explanation, the researcher will provide additional explanation to them. After the participants are satisfied with the explanation given, they will receive the final question of the experiment and determine whether or not seeing the actual model helped them gain a better understanding of the science concept. They will also be given the choice to state whether the explanation was clear enough to imagine how the concept could be modelled.

3.2 User Testing

The collected data from the experiments will be divided into two categories, namely the Dependent Variables and Independent Variables.

3.2.1 Testing Procedure

Participant Experiment

Each participant will be given an information brochure that informs them about the concept topic, rights and rules of the experiment, and the corresponding consent form that should be filled out before participation. In appendices B1 and B2 these documents can be found, where two versions of consensus are given: a consent form for independent participants that are of legal age and another one for the parents or guardians of underage children. The final document that the participants have to fill out is the Background Questions, which is given in appendix C1. This will give the researcher more insight in the technical or non-technical background of the participants and determine the independent variables of this research.

As is mentioned in section 3.1.1, the experiment will first start off with the participant naturally interacting with the concept, then the researcher will ask a few questions to guide the participant into a thinking process and deeper exploration of the concept. Both sessions will be recorded on camera and documented on paper for further analysis. At the end of the experimental session, the researcher will ask the participants questions about the looks of the concept (design), whether they understood it on their own or with the guidance of the researcher (background knowledge) and if the concept model made it easier to understand the functionality of the system (visual comprehension).

3.2.2 Dependent Variables

From the experiments of the user testing procedure mentioned in the previous section, both functionality interpretation and design comprehension will be considered the dependent variables. The recorded and documented data will first be converted into qualitative data, then coded in order to get quantitative data.

3.2.3 Independent Variable

On the other hand, pre-screening will be one of the techniques used to determine the independent variables. Some examples relevant to this research are gender, age and background. Moreover, pre-screening is done to establish homogeneity between the participants. However, concept appearance is also an independent variable, but unrelated to pre-screening.

Chapter 4 Ideation

This chapter combines all the previous sections that enabled the first brainstorming session of the researcher. It also summarizes a secondary brainstorming session between the researcher and the client, which then lead to the final brainstorming session that determines the hazards that can occur throughout the project or with the project concept. Finally, all the brainstorming and research done will result in the three initial prototype models/sketch at the end of this chapter.

4.1 Brainstorming Ideas

Upon reading the “Graduation Proposal Form” in appendix A, a brainstorming session could already begin on how the model could be built and what materials could be used. However, ways to tackle the challenges were a bit harder to think up on the spot, so research had to be done for this part. This part is further elaborated on in the next chapter. Next to this initial brainstorming session, a secondary one between the researcher and client was done. The combined ideas of both parties are summarized below.

4.1.1 Model Mechanisms

1. One recognizable detail from the first round of brainstorming, was that the majority of the existing models use a water reservoir as a base for the two streams. During the secondary brainstorming session, different ideas were explored on how to optimize the looks of the reservoir. Two things had to be taken into consideration, the pressure in water flow and the amount of water that can be used. In the report of Xie et al. [13], it has been stated that the way to achieve a consistent result of the spark generation and system itself is to create a jet-effect. However, that jet-effect was achieved by the use of external voltage. Since this project is supposed to be as sustainable as possible preferably without the use of external power, a more natural jet-effect has been thought up. So, the idea of using two long narrow columns filled with water to increase the pressure at bottom of the column was put into motion.
2. When the water from the streams fall through the metal inductors, it can easily come into contact with the sides of the inductors. Therefore, check if the concept will work if an insulator is attached to the inside of the metal.
3. Another recognizable detail from the current models, is that the water always flow through a metal object. If a ramp is made in such a way that the water drops start forming midway down the ramp, that can change the designing outcome of the concept. It can also be a testing moment to check whether the metal really does help in the formation of waterdrops.
4. Since a larger spark length is desired, there is an experiment that produces a climbing spark called Jacob’s Ladder. However, it should first be checked whether the amount of voltage produced by the Kelvin’s Thunderstorm concept is enough to trigger the climbing effect of the spark. Although the concept might generate a high enough voltage, Jacob’s Ladder calls for a continuous power supply, whereas the spark only occurs every few seconds.
5. In addition to the previous mechanism, use an external power source to pre-provide voltage to the Jacob’s Ladder experiment. When the spark occurs, have it trigger the remaining voltage needed to allow the system to work.
6. Another way to ensure that this system is as sustainable as possible, is to have a recycling system built into it or around it. An example of such a recycling system is a water-pump. If the water is used to drive the pump’s operation, there will be a chance that water will be wasted. If no form of loss is desired, then use an electric pump.
7. Test if by adding more substances to the water to increase its viscosity, if this has any effect on the size of the water drops. In addition, test if this also can influence the spark occurrence.

4.1.2 Materials

1. For the two long columns that replaces the reservoir, perhaps PVC pipes, hoses, or two tall, narrow metal/plastic containers can be used. If a small test version is used, use water bottles as miniature representations of the long columns.
2. The metal inductors can be metal cans, conductive wires wound in a cylindrical form, any other cylindrical metal object. Plexiglass or plastic can be used as insulating material for the inside of the metal inductor. If a plexiglass cylinder can be used instead of the metal inductor, either attach or spray a metal layer onto it.
3. The ramp will either be plexiglass or plastic with a metal layer under it or metal screw attached to it or screwed into it.
4. PVC pipes or wood can be used for the frame of the concept. However, plastic is a better option since it does not cause any voltage leakage like wood can, especially if it gets wet. Therefore, plastic or plexiglass should be used as the ultimate insulating material. They are also cheaper than glass or ceramic.
5. For the Jacob's Ladder experiment, use two firm metal wires that can be bend with a tool at the desired angles and distances from each other. As tool, use a pliers.
6. If a non-electric pump is used, it can be easily made with PVC pipes. The only additional supplies will be PVC pipe couples, valves, a hose, a drill and a saw.
7. The substances that can be used to increase the viscosity of water are salt and/or sugar.

In section 4.3, two long PVC pipes are used as columns, which fulfilled the first hypothesis of this brainstorming session. The long tubes did help to create a jet-effect. However, the insulating material on the inside of the metal inductor and a ramp were ideas ignored during the assembling and testing procedures. Moreover, since the Jacob's Ladder required a constant power supply in order to operate, it was also neglected in the model set-up.

4.1.3 Hazards

Pre-Mortems

Another important part of the brainstorming session was the determination of the possible dangers or risks that the project and/or project concept can entail. This was done to establish the ethical implications that the project and project concept can have towards other individuals, such as the stakeholders, or the environment. Moreover, since the project concept is being designed for an end user, their ideas, values and wishes should be taken into consideration when designing the prototype for them, as was determined in the research of section 2.5.

Figure 12 gives an overview of the hazards that can occur throughout the execution of this project. First, the type of hazard and how or why it occurred is determined, then who can be affected by these hazards were taken into account. Thereafter, the location or time in which the hazard took place was established. Finally, an evaluation on the independent outcomes or a combination of the aforementioned factors, was done in order to define the pre-mortems as seen in the last column.

Hazard Types	How/Why?	Who is/are affected?	When?	Pre-Mortems
Undesired End Product	Poor communication Lack of empathy in design Lack of diversity in group	Designers & Stakeholders	Throughout the entire project	The combination of these hazards may lead to fallacies, such as groupthink and/or bubble mentality
Delay in Product Development	By cancelling or not showing up to meetings Tardiness Late Delivery of Materials	Designers & Stakeholders	During scheduled meetings	These two hazards may cause stakeholders to feel as if their needs and desires are neglected
Inadequate Measurable Data	Unable to recruit sufficient users for user testing	Designers	Before, during and after the testing phase of the project	May lead to inconclusive results
Privacy Violation	Not handling the user's sensitive acquired data with care	Stakeholders	During the analysis phase of the project	This can cause scepticism in the end user(s)
Getting Shocked by Device	If no safety measures are taken to prevent users from touching the device, since it produces a high voltage of ~15kV	Stakeholders	Before and during the testing phase of the project	In this manner, the designer violates the safety of the user, which can lead to distrust
Functionality Failure	Due to the lack of specified dimensions The theory not matching the practice Voltage leakages caused by poor isolation and/or unsuitable materials	Designers	Throughout the entire project	All these hazards combined can cause unnecessary stress on the designer
Loss of Interest	Due to functionality failure or demo-defect	Designers & Stakeholders	Throughout the entire project	Meetings will have to be rescheduled
	The operation of the device not being clear			Some users may cancel due to loss of interest which leads to loss of viable data
	The size of the device not being in proportion to the spark length			The user may also be disappointed with a tiny spark coming from a huge device
	If either the science behind the operation of the device or its structure (or both) is too difficult to understand			This can lead to the confusion or interest reduction of the user during the user testing

Figure 12. Risk Assessment Report including the Pre-Mortems

Post-Mortems

The independent hazards from figure 12 were combined in order to form the two major post-mortems as can be seen in figure 13. The post-mortem 'Participation Reluctance', is derived from the combination of independent hazards in the *Loss of interest* hazard. The blue colour gradient relates to the amount of factors that make up for each hazard. *Loss of interest* contains the most and *Getting Shocked*, *Privacy Violation* and *Inadequate Measurable Data* contains the least. All the other hazards contain relatively the same amount. Moreover, another post-mortem titled 'Termination of Project' is present in the diagram and indicates that the corresponding factors combined can result in the termination of the project.

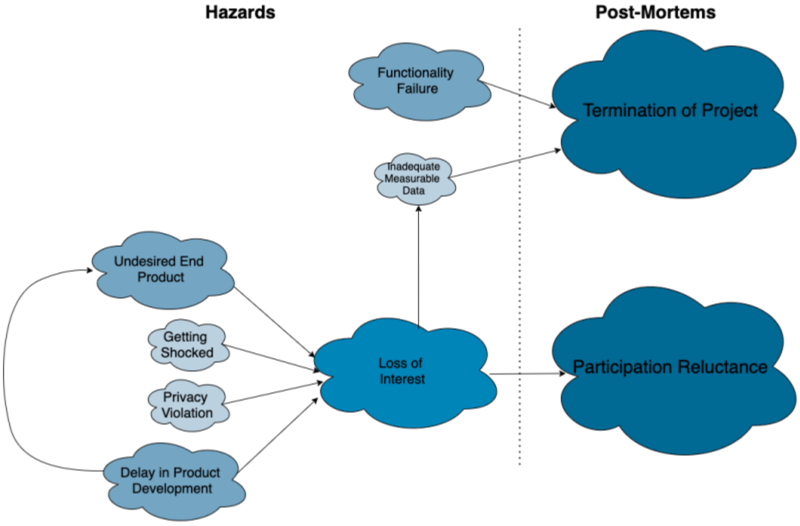


Figure 13. Cascade model of hazards into Post-Mortems (Made by Ikmareka)

On the contrary, *Loss of interest* can be seen as a sub-hazard to the *Inadequate Measurable Data* hazard, which is the primary hazard for the post-mortem 'Termination of Project'. Thus, this primary hazard is actually the greatest of them all, but only in this cascaded model. Therefore, figure 14 gives an adapted cascaded model of these hazards as a better representation of the quantity of hazards incorporated into another.

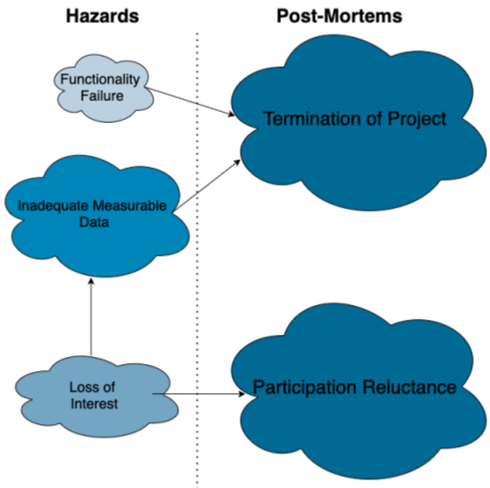


Figure 14. Adapted cascade model of hazards into post-mortems (Made by Ikmareka)

4.2 Design Concepts

This section introduces the initial prototype model, the initial prototype sketch, then the actual attempt at building the first prototype model.

Figure 15.. First Prototype Concept of Kelvin's Thunderstorm

Figure 15 shows the very first prototype version before any skecthes were made. It consisted of a wooden frame with two PVC pipes fastened at the outerends which are above two floating cans that are mounted onto copper steels and fastened to the buckets by zipties. In the middle of the cross-section, two small flexible copper wires are placed to make the spark gap. At the bottom of the two buckets are ceramic isolators.

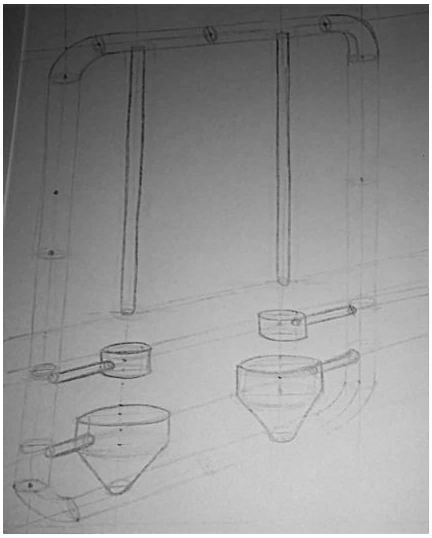


Figure 16. First Sketch of optimized model version (Made by Ikmareka and P14)

An improvement version of this prototype was sketched out and can be seen in figure 16. Unfortunately, the prototype in figure 15 could not be optimized to look like the one in the sketch, due to the researcher returning back to Sint Maarten when the Corona Pandemic occurred. Thus, a new one was constructed as can be seen in figure 17. As is mentioned in section 3.2.1, this new concept was a quick mockup that lacks proper materials and it can also be seen that a lot of duct tape was used.

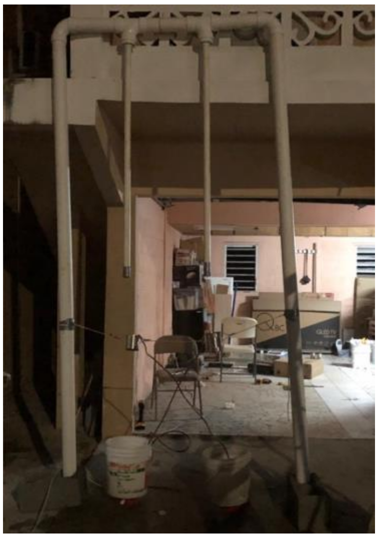


Figure 17. Quick Mock-up of the concept with at-hand equipment

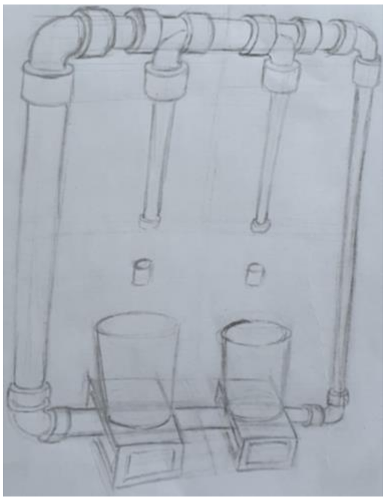
A base PVC pipe is missing, the isolators at the base were inconveniently small and uneven, which sometimes made the buckets fall, plus the cans are dangling while being pulled down by the two copper pipes. These inconveniences resulted in inconvenient results, so an improved concept model had to be developed. This version along with more optimized versions can be seen in Chapter 5 which gives the prototype's specifications.

Chapter 5 Specification

In the previous chapter, the initial prototype models were shown. Now in this chapter, the development of the intermediate prototypes will be given along with some sketches. A brief explanation on the optimization of these models will also be summarized in the following sections.

5.1 Prototype Improvements

Due to the prototype in figure 17 being incomplete, the device did not work properly and caused a lot of inconsistencies in its operation. Thus, the sketch of it was improved to the one in figure 18 and the prototype modified to the one in figure 19. All parts were available in this concept, but the cross-section was still not stable enough to produce a functioning operation. So, the cross-section was modified from these two soft wires, to firm electric wires with insulating coverings. Even though, the plastic buckets were fine, they were also changed to metal buckets to optimize the conductivity of the system. This adapted model can be seen in the sketch of figure 21 and the image in figure 20.



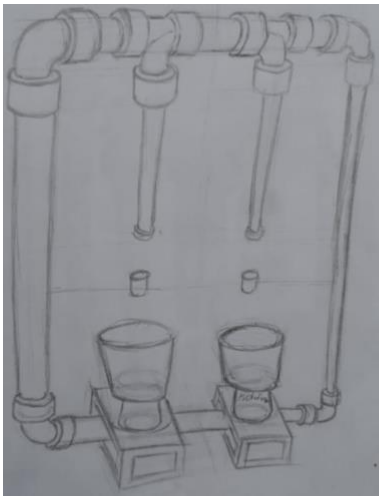


Figure 18. a) Adapted sketch of newer model prototype. (Made by Ikmareka and P14) **b) Remodeled version including isolation plastic objects**

Figure 19. 1st Improved big prototype with soft wires

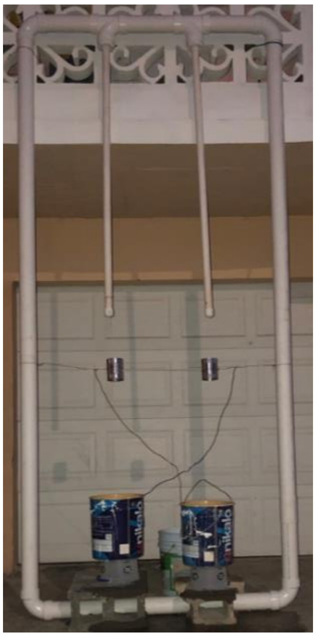


Figure 20. 2nd Improved big prototype with metal buckets and electric wires

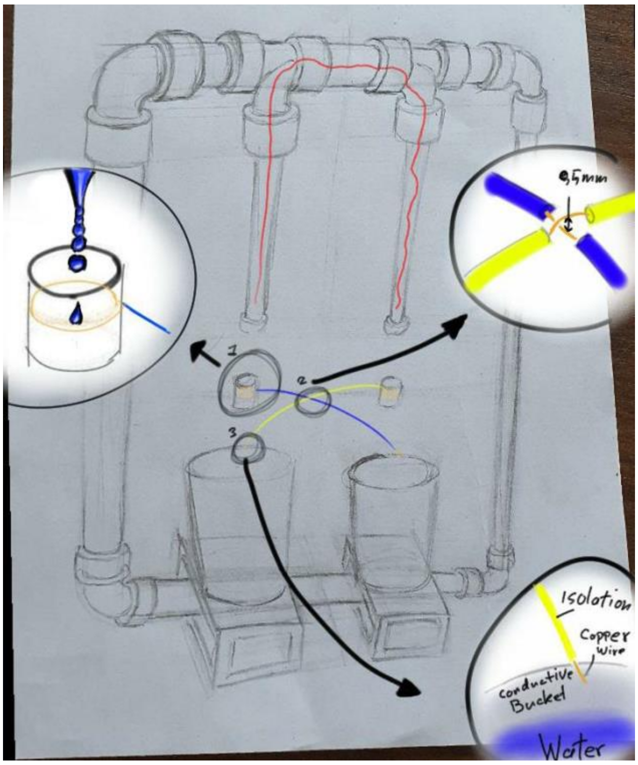


Figure 21. 2nd Improved sketch of prototype (Made by Ikmareka and P14)

Although these changes did improve the stability of the system, they did not improve the functionality of the system. So, a medium prototype was developed to find the necessary dimensions that can later be upscaled again, or downscaled to a desktop version. This medium version is given in figure 22. Even this experimental mockup had to be adjusted a few times from its initial version and the version seen in this figure was the best option that was used as a reference for the sketches in figures 23 and 24. The first downscaled model is displayed in figure 25, which was approximately 48x51 cm^2. It caused too much inconveniences where a lot of components and parts had to constantly be replaced or glued back into place. So, after this version worked it was scaled down to 38x43 cm^2 using the same structure. This smaller version can be seen in figure 26.

Figure 22. Medium Scaled Prototype for Experimentation purposes

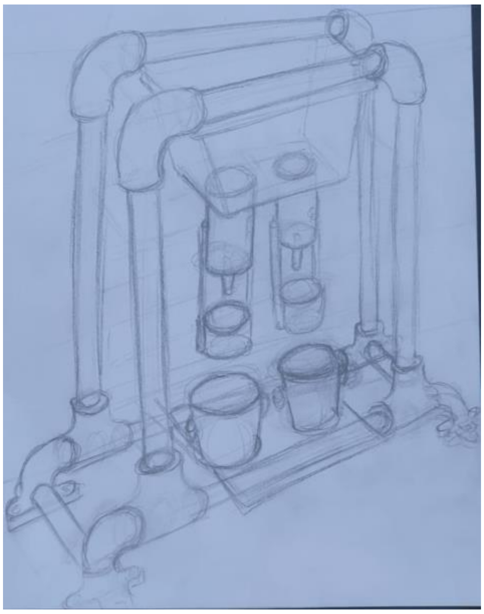


Figure 23. 1st sketch of 1st downscaled prototype version (Made by Ikmareka and P14)

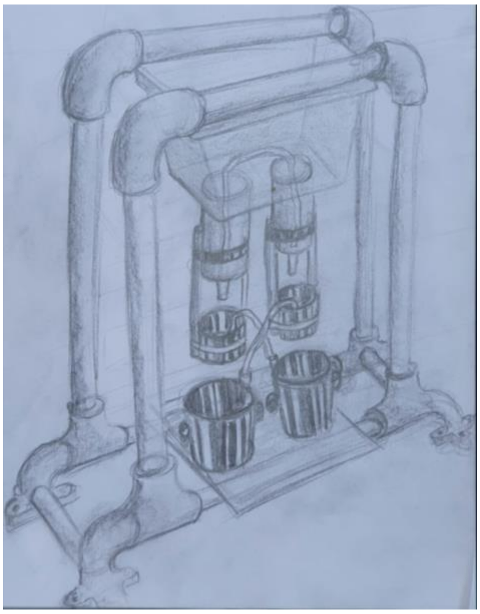


Figure 24. 2nd sketch of 1st & 2nd downscaled version (Made by Ikmareka and P14)

Figure 25. 1st downscaled prototype model with metal reservoir

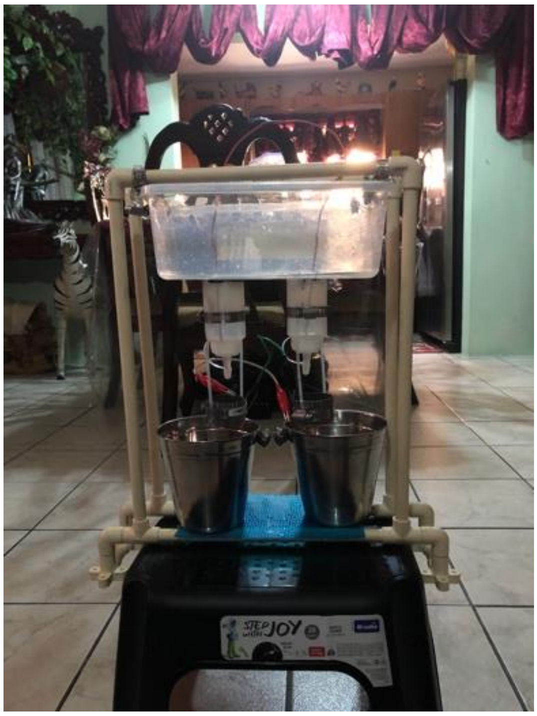


Figure 26. 2nd downscaled prototype model with plastic reservoir

Chapter 6 Realisation

In this chapter, the realization of the final prototype will be built up from the smallest detail to the biggest one. So, by first discussing the components chosen for the prototype, then by the way these components combined either worked or failed to work as a whole, and ultimately describing which prototype choice worked the best and was used for the remainder of the project.

6.1 Component Choices

This section gives a closer look on how the different components of the prototypes in chapters 4 and 5, were chosen.

6.1.1 Frame

There were a variety of components chosen to reach the final prototype of this project. In the first prototype that can be seen in figure 15, a wooden frame was used instead of the miniature PVC piped frame version as is seen in figures 25 and 26. The wooden frame prototype as well as the mock-up in figure 22, were both quickly done. No thought went into the designing process other than producing a quick model that generates desired results. Another distinction between the model in figure 25 and that of figure 26 is the blue plastic base that was placed on the lower frame. Initially, the two metal pails were glued directly onto the frame and would constantly unstick or topple over. So, adding the plastic plate really stabilized the structure.

The initial frame that was designed in the sketch of figure 16, had some more thought put into it than the previous two that were discussed. Some flaws in the actual realization of this design were that it was too big to manage and could not stand on its own. That is why the mock-up in figure 22 was quickly done in order to get a grasp on what framing type and size would work best, hence the smaller frame design. The initial size of the frame was 1x0.5x2 $\mathbf{m^2}$ and this was scaled down to 38x9x43 $\mathbf{cm^2}$.

In the end, a PVC piped structure was chosen since it did not require any drilling and nails to assemble the frame together. Therefore, only PVC junctions were needed and used. Additionally, the size could easily be adjusted in the PVC structure which was more difficult to accomplish in the wooden one. So, the PVC structure was ultimately the best option that could hold the weight of the components and produce no strain transporting it to the different experiment sites or locations.

6.1.2 Isolators

The base isolators in the wooden structure were ceramic pots. Ceramic pots are in theory good isolation materials. However, the pots consisted of porous designs on the outside which could absorb water and cause a voltage leakage. So, when water spilled on the buckets, they probably conducted electricity to the ground. After testing the prototype in figure 20 with two plastic base isolators, there were sparks in the first round of testing. Thereafter, the prototype did not work anymore. So the testing continued on the mock-up version also with plastic base isolators, where the results were optimal. However, some issues were faced before the sparks actually occurred. First, there were no sparks due to poor isolation between the inductors (metal cans) and water bottles. The first isolation option was tape and just as the ceramic pots, they probably conducted electricity when they got wet. So, the tape was swapped with plastic straws which worked pretty well and produced a series of sparks.

In the first downscaled model of figure 25, rubber was used as isolation between the plastic tubes/bottles and metal inductors (metal circular objects). However, the rubber was not pure and had threading inside of it which could have probably conducted electricity causing a voltage leakage. So, it was swapped with plastic straws as can also be seen in figure 26. These firm plastic straws were the best option and were fastened onto the plastic tubes and metal objects with (metal) rings. Since the stream is supposed to stream close to the metal (~ 1¼ cm distance) and not directly on it, this adjustment method was convenient for changing the angle in which it flows through the metal inductors.

6.1.3 Water Reservoir Container

In the initial model of figure 25, a frail metal container was used which resulted in a lot of inconveniences. Due to the large amount of water being poured into it that would flow to one side of the container, the strain would cause deformity in its built and cause leakages. So, it was optimized to a plastic container. Although this option was more stable, water would still sit in the container after the testing and experimental rounds, since it did not have a funnel effect.

Conductive wise, the metal container was the better option and gave promising results such as a longer spark at a further distance (~ 0,5 cm), whereas the plastic container gave a shorter spark at a shorter distance (< 0,5 cm). These two distinctions can be seen in figures 27 and 28. If the two metal knobs from the plastic container model were placed at a further distance as is displayed in figure 29, then there would be a weak spark. Thus, the reservoir material actually had an influence on the conductivity.

Figure 27. Metal Container Resulting Spark

Figure 28. Plastic Container Resulting Spark

Figure 29. Resulting Spark at Larger Distance

6.1.4 Wires

It can be seen in figure 19 that the wire used was really flexible and loopy, which resulted in a non-functional concept. Due to these wires blowing easily in the wind, they could not be fastened at a fixed position in order to generate or detect a spark between them. Therefore, these wires were replaced with electric wires that can be seen in figure 20 and figure 21 as a detailed sketch. These wires were more firm and could be shaped into any desired form. As can also be seen in figure 22, these wires were a part of the mock-up and were separated with plastic water bottle covers to prevent any contact between them that could immediately discharge the concept.

The red wire that is visible at the top of the mock-up and the downscaled prototypes, was also in the large PVC piped prototype as is drawn in the sketch of figure 21. This wire was then shortened for the experimental prototype. In addition, it is also an electric wire with hard copper inside of it, whereas the wires used for the cross-section are electric wires with soft copper on the inside. So, clamps are placed at the ends of the wires (see figure 30) in order to get a solid connection between the metal pails and inductors (metal circular objects). These wires were initially a length of approximately a meter long and had to be shortened to stimulate the charge build up in the cross section. At first the inconvenience of using the lengthy wires resulted in them not being able to create this cross-section and no spark generating. Thus, it soon became clear that the cross-section does indeed need to be crossed in order to generate a spark.

Figure 30. Soft Copper Electric Wires

6.2 Prototype Functionality

In this section, next to the individual component issues that were mentioned previously, the functionality of the prototype as a whole will be discussed.

6.2.1 Combined Components

After combining the separate parts and following guidelines on building this model, it became apparent that the theory does not always match with the practical results. One of the major struggles was centring the stream in the metal cans, especially in the first prototype models. Coincidentally, while working on the mock-up model, it occurred that the stream did not need to be centred within the diameter of the can in order for the concept to work. It actually had to stream at most 0,5 cm away from it. So, in order to accomplish this, an offset had to be made between the isolating straw and the can in order to bring the stream in a closer range to the inner can. This offset was fixed by adding a small PVC pipe in between the two components.

The difference between figures 19 and 20 is that one uses plastic buckets while the other uses metal ones. Similar to the metal container in section 6.1.3, the metal buckets served as a better conductor than just placing the wires inside of the plastic buckets. There was absolutely no spark when testing the version with the plastic bucket, even after changing the cross-section. However, there was a spark during one test with the metal buckets. Unfortunately that was the first and last time that the spark ever occurred on the large model.

Another issue that occurred was there initially not being a wire between the two long columns as is illustrated in figure 21. This showed how easy an essential part of the prototype can be forgotten and cause unnecessary stress. Moreover, this was not the last time that this occurred. At least in the mock-up model, the red wire was taped to the top of the bottles, but in the downscaled prototypes, while transporting the wire from different locations, the wire could easily be forgotten or misplaced. In theory if the streams originate from the same reservoir or water source, then they are automatically connected and the concept should not need an extra wire to electrically connect both streams. However, in practice that is not the case. The concept was tested both with and without the wire along with the streams originating from the same reservoir and only generated a spark with the wire present in the concept. Therefore, the wire is crucial for the system. Although water is conductive, in order for it to travel, there needs to be some sort of conductive medium that helps carry the charges to their rightful destinations.

At certain moments, the final prototype model would work perfectly and even though nothing has changed when tested again, it would stop working. One of the reasons for this is that if the clamps are not closed properly or makes proper contact with the metal objects, then there will be no charge built up and no discharge of an electric spark. A tight clamp that might be troublesome to detach after it has been clamped, is highly recommended instead of a hobby version which can become loose very easily.

Distance caused the most amount of the inconsistencies in all of the prototypes. The prototype from figure 20 worked once and never again, which could be the cause of the large distance in height between the buckets and cans. For example, if the charged water drops take a longer time to reach their destination and come into contact with the air, then this might interfere with the charge in the drops and discharge them before they reach their destination. Even though this was discussed and determined, it still had to be tested out. So, by switching to the mock-up version and testing this claim out on it, the results confirmed this claim. There were two small plastic base isolators that were used and no spark was generated. Then, these small isolators were replaced with larger (higher) ones that lifted the buckets closer to the cans and it worked. There were sparks! That is also another reason why the smaller prototype was made even smaller, because it eliminated this issue and became a continuous functional prototype.

Additionally, mentioned earlier was how the stream had to flow as close to the metal inductors as possible in order for the concept to work. So, when the straws were fastened unto the metal pails and plastic bottles creating an adjustable mechanism, it provided the prototype with an on hand solution. If during an experiment or testing procedure the stream should either come into contact with the metal objects or be centred therein, they can easily be manipulated to the desired position.

6.3 Chosen Prototype

This section summarizes why the prototype in figures 24, 26 and 31 were chosen, and what disadvantages this prototype can possess.

As was mentioned in section 3.2.1, each one of the models produced inconveniences. Ten models in total were made and only half of them actually worked. However, the very last prototype that can be seen in figure 31 below, worked the best due to a number of factors:

- It eliminates the dimension inconsistencies of height and distance that the larger prototype provided;
- It provided a series of continuous results (sparks);
- It had a more firm and stable frame than the initial one from wood, and no ceramic base isolators. In fact it did not need any additional base isolator since it sat on a plastic plate attached to the lower frame;
- The metal pails and metal circular objects can be easily moved around to obtain the best result in the moments when the prototype does not seem to work;
- It is transparent to a certain degree which can be interesting to see what is actually going on, unlike the larger prototype models;
- The wires with the clamps can be placed on the objects and removed easily, whereas that was not the case with the initial and follow-up larger models;
- It is transportable and not heavy;
- It can be used both in and outdoors;
- Does not use up much space and can be stored anywhere;
- The components that make up the prototype can be recycled or reused, after the project;

- The structure is easy to assemble and dissemble.

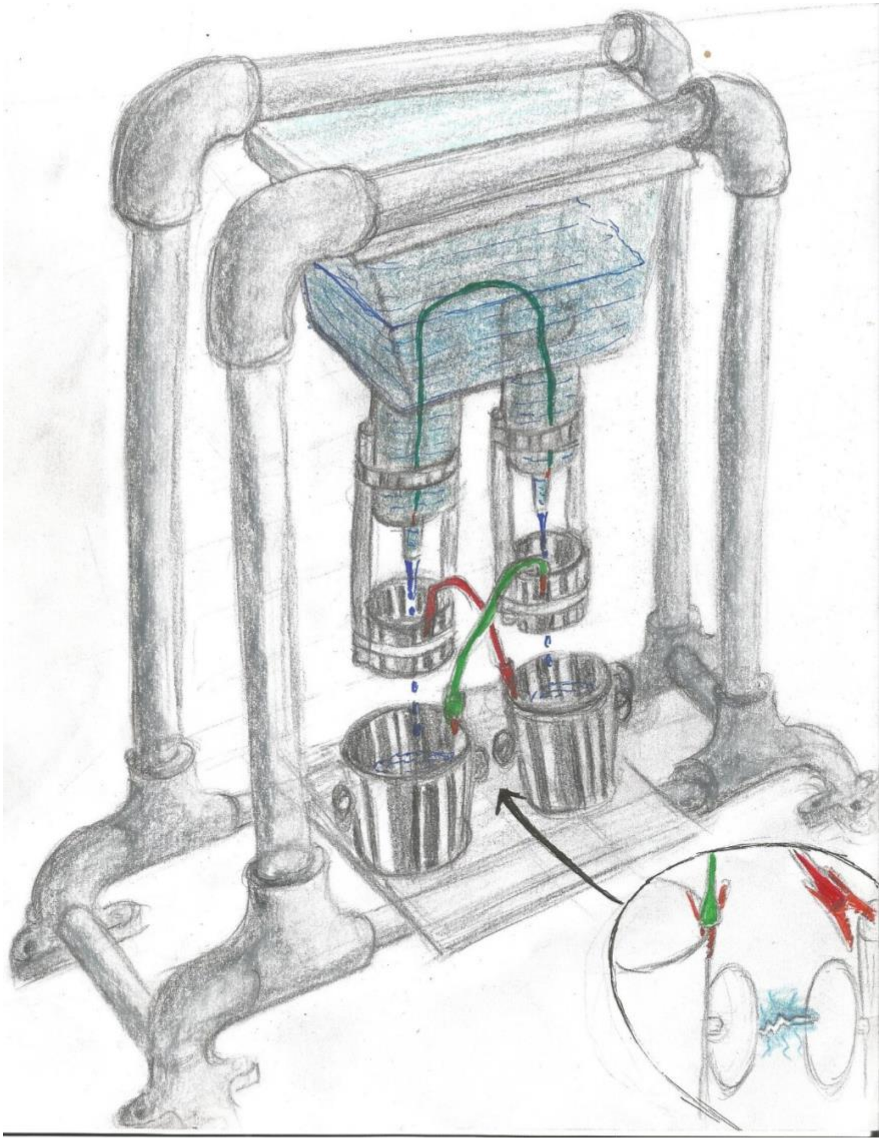


Figure 31. The Functioning Final Prototype Model (Made by Ikmareka and P14)

The only inconveniences that can be summarized are:

- It can fall apart easy, since some of the essential parts are glued on instead of fastened;
- The metal starts to rust after a while;
- Once a hole has been punctured in the nozzle of the plastic tubes/bottles, there is no way to close it up or make the hole diameter smaller;
- The wire can cause a blockage at the nozzles or distort the stream from falling straight down;
- Since there are no joints connecting the two upper pipes of the frame, there is a chance that the prototype can lean forward or backward or tumble over, if it is not positioned properly;
- It does not funnel all the water through the plastic tubes/bottles. Some of it stays in the top container.

Chapter 7 Evaluation

The different ways on how data was collected, processed, graphed and discarded will be discussed in this section. It will first describe and reflect on an earlier section (chapter 3), which introduces the terms on safety measures taken to ensure no injuries during experimentation and how the data collected from the participants will at no time be used for misconduct. Next, the procedure on how the relevant data was selected, processed and graphed will be given. Finally, the results will show the outcome of the research where comparisons and distinctions will be drawn amongst them.

7.1 Data Acquisition

The two different methods in which the data was collected are described in this section.

7.1.1 Consent & Background Discovery

Consent

In section 3.2.1, it has been stated that forms were given to the participants in order for them to give their consent for the use of their data. Retrieving the forms from the *Live* (in person) participants was more convenient than getting them back from the *Online* participants. Thus, leniency was loaned to the *Online* ones, where they were told to hand it in whenever they could. This lead to constant back-tracking of who actually handed it in or not. A total of 57 participants, out of the 62, gave consent. So, the data from the missing five will be shredded, trashed and deleted as soon as the project is officially over.

Background Discovery

Next to the consent forms, background questions as can be seen in appendix C1, were also given to the participants. The information from these questions, was the first set of data collected. These questions hint what the experiment will be about and may even set the participant in a thinking process that can trigger him/her to do some research on the experiment topic or questions. On the other hand, the questions can jog the memory of the participant and reveal his/her forgotten knowledge. A total of 11 questions were asked, where three of them were closed and the rest open.

Data collected from these questions, especially the age, gender and background knowledge ones, will play a substantial role in the data analysis where linking data to specific age groups or a specific gender class is essential.

7.1.2 Exploratory & Observational Discovery

Exploratory Discovery

The second set of data is collected during the different stages of the experiments. *Live* participation grants the participant the opportunity to pour the water into the prototype and physically move around it. On the contrary, *Online* participation limits the participant to truly grasp the actual size of the concept or to engage in that single interaction option (the pouring of water). There is thus a small chance that details may be overlooked by the *Online* participants, while they are more evident to *Live* ones. To avoid such an inconvenience, a video of the concept can be taken and sent to the participant for a better visual on how it looks, operates and sounds like.

The very first question of this part is: *Can you verbally describe to me what you are hearing and seeing?* In this way, the participant will visually engage with the prototype. If the participant discovers what is occurring, thus the spark generation, the experiment will proceed to the next stage. Since this first stage allowed the participant to observe the prototype as a whole, this stage will allow him/her to look at the smaller parts of the prototype. However, if the participant does not see or even hear the sparks, the researcher will lead their focus to the focal point of the prototype.

Observational Discovery

Another part of this data collecting session, will include a live interview where there will be a back and forth conversation between the researcher and the participant. The answers and expressions of the participant will be recorded and noted down. If any noted down information is unclear during the data analysis, the researcher will have the opportunity to look or listen back to the recording. The interview will start with the question: *What do you think the power source is of this concept?* This question intends to see if the participant paid attention to when the sparks started occurring. Water is the power source of the concept and it is expected that the majority of the participants will answer this question with ease. If the participant should answer differently, then the next question will be: *What do you think the water is used for?* In this way, the participant may be able to realize that the water is in fact the power source. If both questions are answered poorly, then the researcher has no choice but to move on. The first set of questions focus on the operation of the prototype, whereas the next set focuses more on the design (appearance) of the prototype. Coming down to the final stage of the experiment, the researcher will give an explanation on how the concept works, then ask the final question. It is up to the participant to now determine whether the functionality of the prototype could be understood without a visual representation. It is also expected that the majority of the participants will prefer a visual representation rather than only receiving a description on how the concept functions. After this is determined, the experiment will conclude and the data will be stored in a folder for further analysis.

7.2 Data Analysis

After all the necessary files have been filled out, signed and delivered, and the experimental data collected, they will be archived and registered. Thereafter, the necessary data will be selected for further analysis which will go through a qualitative process first, before being coded and converted into quantitative data. These processes are elaborated on in the following sections.

7.2.1 Data Registration

The data registration starts from the moment the first experiment is booked. After the exchange of files from the researcher to the participant, the researcher has to trace when files are sent or given back. Therefore, it is necessary to use a log book or create a log page to keep the "tracking" process organized. Next, after the consent has been confirmed, the data analysis can start immediately. Start off by processing the background information first, before analysing the experimental one. However, the analysis processes will be the exact same. The next section will describe how the data is analysed qualitatively.

7.2.2 Qualitative Data Analysis

Even though raw data can be very informative, it does not give a clear overview of what needs to be portrayed. Therefore, in order to convey the message behind of the raw data, it has to first be converted into qualitative data. The table in appendix D1 gives an overview on how the raw data from the background questions was converted. It shows:

- The 11 questions that were asked, where the relevant ones are selected for further analysis and the irrelevant ones disregarded;
- How the questions were answered by the participants;
- How these answers were abbreviated accordingly.

If the tables in appendices D1 and D2 are compared with each other, it is clear to see that the experimental data analysis had more complexity to it than the background one. The difference between the two sets of questions is that the background analysis does not check whether the participant answers the question correctly or not, whereas in the experimental one it does check the validity of the answers. This is done in order to test the technical knowledge of the participant, regardless of their educational background. Due to this level of complexity, another table (which has been split into two separate tables) had to be made to show the defined answers created by the researcher and the given answers from the participants. These tables can be seen in appendices D3 and D4. The "*" and "~" symbols indicate that the answers are repeated in other questions.

This is but only the beginning of the data analysis process. Appendices D5 and D6 show two other example tables that give an overview of both data analyses. It was mentioned earlier that the raw data itself does not give a clear overview of what is needed to be portrayed. Thus, these examples show how the raw data can be minimized and organized. These tables were accomplished by first establishing the type of question that was being asked: Is it a YES/NO question or is it an Open question. If YES/NO, then the column for this question will only consist of two variables or symbols. Even though there were Open questions, the structure of the questions made it possible to recycle the "✓" and "–" symbols. Since there were pre-defined answers for the experiments, they were used to measure if an answer could be true or false, which can still be interpreted as YES or NO. Answers that fell out of the scope of the research were classified as Other. If absolutely no answer was given, then the slot in the table was left blank. Now that the qualitative data has been established, it can be converted into code that can generate a measurable value. The following section will discuss the quantitative analysis of the qualitative data.

7.2.3 Quantitative Data Analysis

Converting the qualitative data into quantitative data may seem difficult to do, however that is not the case. Per question, a separate sheet was made and the independent variables along with their corresponding values, as described in section 3.2.3, were copied into the sheet along with the answers from the question. Subsequently, a new column was made and placed next to that of the answers. In this column, a code (in this case a single letter) was assigned to the answers individually, similarly to the abbreviation column that can be seen in the tables of appendices D1 – D4. Due to EXCEL being the platform used to analyse the data, the formula COUNTIF(REF, "") was used to calculate the amount of times a specific code repeated itself. After placing the answers under each other, similar to the layout in figure 32, and assigning them the value determined by the formula, these values were then summed to find the total amount of participants that answered the question.

The next step was to transform these values into percentages to get the proportions of each answer. An example of the quantitative data analysis can be seen in appendix D7 and an example of the different proportions thereof in figure 32. The table with the heading "Frequency", shows the amount of participants per age group that answered the question. Section 7.1.1 had already indicated that 57 out of 62 participants were legitimate participants in this research and this table confirms that.

Proportions	
Child	5%
Adolescent	65%
Grown-up	30%
TOTAL	100%

Figure 32. Different proportions in age amongst participants

7.3 Data Findings

Results from both data analyses that are related to the topics in the earlier chapters of this report, will be shown and explained in this section. Comparisons will be drawn between specific data results as well as distinctions. These results will also be compared to previous findings.

7.3.1 Results & Discussion

Background Findings

After analysing the data in accordance to the data analysis processes discussed in section 7.2, the first challenge was to discover how many of the participants actually had a technical course in their life. Figure 33 shows the amount of participants that took a technical course or not. The result shows that a total of 20 (35%) participants out of the 57, followed a technical course. In order to find out who exactly these participants were, two other graphs were plotted that show the relation between the genders with a technical background and the different age groups that have a technical background. Thus, figure 34 shows that there are more female participants than male ones with a technical background, which is quite impressive. However, the majority of the participants was in fact female, so this result is not that surprising after all. A total of 35 females and 22 males participated in the experiments. One surprising result is that the gender proportion between participants that took a technical course and the gender proportion between female and male participants are exactly the same, as can be seen in both figures 34 and 35.

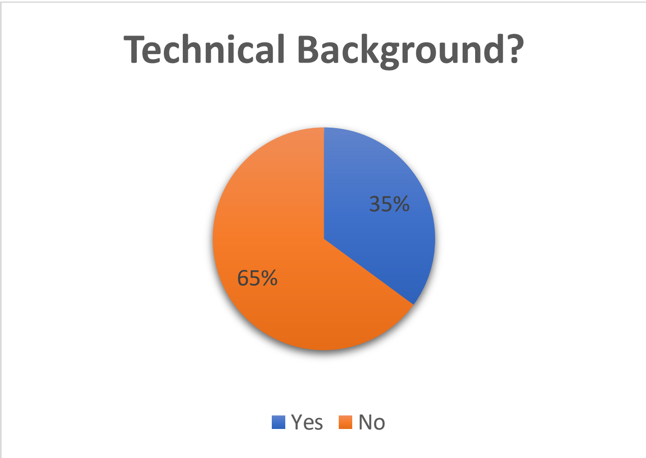


Figure 33. Proportions between Technical and Non-Technical Background

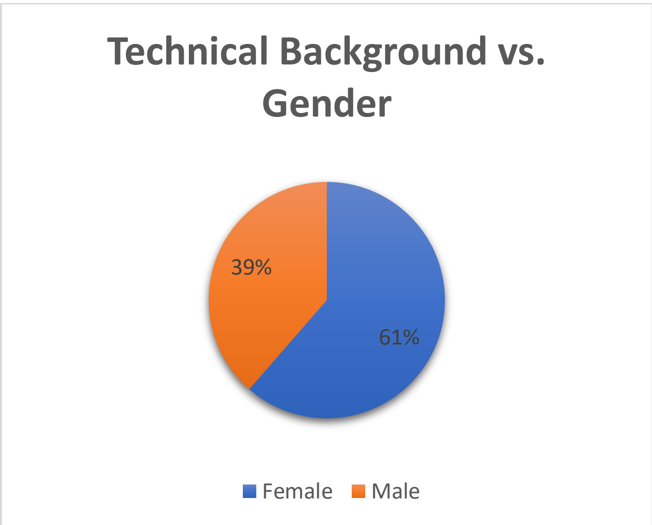


Figure 34. Proportion Tech & Non-Techs in relation to Gender

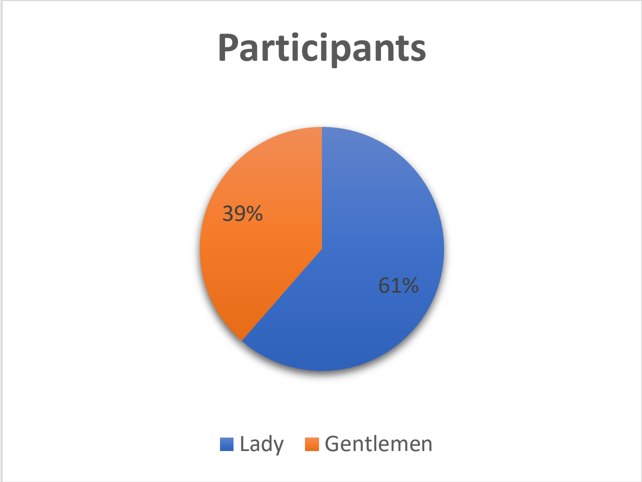


Figure 35. Proportion between Female and Male Participants

Next to gender, the proportions between the different age groups in figure 36, show that most participants are between the ages of 18-25. Just as the previous result, there were more females in this category than males with a ration of 8:5. Another interesting observation that can be noted, is that even though there are 3 different distributions in this figure, it still somehow resembles that of figure 33. However, the results from both graphs should not relate to each other since the one in figure 36 is zoomed in on one criteria (With Technical Background) from the graph in figure 33.

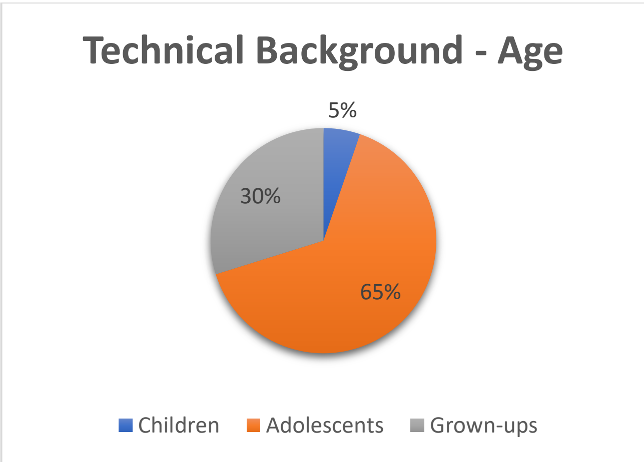


Figure 36. Proportion between Tech & Non-Techs in relation to age

There were two questions asked that could set the thinking process of the participant in motion. These questions were:

- Do you know how a battery works?
- Do you know how electricity works?

Mentioned previously is how these questions hint what the project concept is about and they can relate well to the sections 2.1, 2.2, 2.3 and 2.4 of chapter 2. Section 2.4 introduces the Kelvin's Thunderstorm concept which is the prototype that can be seen in chapters 4 and 5, which functions as an electrostatic generator. Another important question that hints what the project might be about is:

- Have you ever heard about renewable energy?

This question is strongly related to section 2.2 that covers the topic of renewable energy. A renewable source converts energy from a natural resource, such as sun, wind or water, to electric energy.

Similarly, Kelvin's Thunderstorm generates energy from a renewable source (water), so it can be seen as some form of renewable source. Therefore, when the electric sparks are generated during the experiments from running water, the participants may be able to link these occurrences to a renewable source or renewable energy. So, the answers to the three questions above are discussed in the next sections.

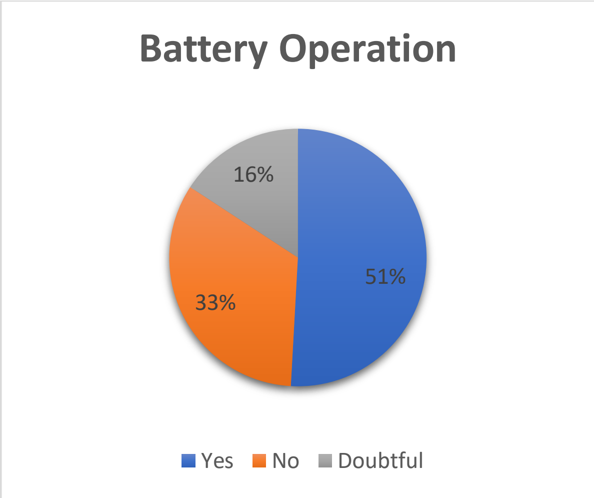


Figure 37. Proportion distribution on battery operation

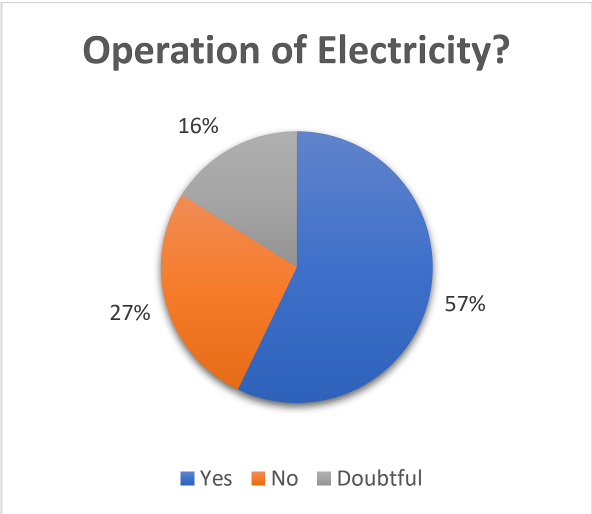


Figure 38. Proportion distribution of electricity operation

It is not a surprise that the proportions between figures 37 and 38 are relatively the same, since a battery goes hand in hand with electricity, just as science does with technology. The only aspect that improved in figure 38 is that there were a few more participants that understood the workings of electricity better than a battery. "Electricity" is not an easy topic, so the fact that about 60% of the participants grasped how it works, is quite impressive. There was the expectation when designing these questions, that since a battery is something that human beings work with more often than electricity, it would be understood better than electricity. However, the results in these figures proved this assumption wrong. Contrarily, since these questions were asked one after the other, the participant could have been stimulated to think about it a little more from the battery question, and gotten a better idea of the working of electricity when they reached that question. Thus, resulting in a few more grasping the concept of electricity.

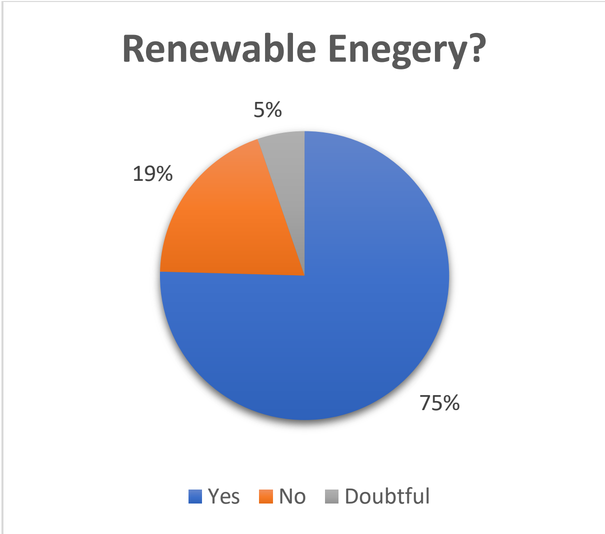


Figure 39. Proportion distribution on renewable energy

Moreover, comparing figures 37, 38 and 39 with each other, it seems as if participants are being enlightened just by answering the questions. Concepts or objects that existed longer than the term "renewable energy", are less understood which raises the question: *Why is renewable energy better known amongst the participants, rather than batteries and electricity?* Renewable energy is a concept that generates electricity, but with the inclusion of visual objects, such as solar photovoltaic panels and windmills. Perhaps, that is the reason why it is better known than electricity. However, a battery is a physical object, yet it is understood the least. The only explanation that would suffice is that although a battery powers a device, its functionality cannot be seen with the naked eye. A windmill, on the other hand, is a visual object that is known as a spinning wheel and can be seen from miles away. Therefore, it could be possible that the visual representation of the concept is what makes it more popular than the functionality it embodies. The next section will dive deeper into this speculation.

The calculations on how these figures were achieved, can be found in the EXCEL file titled "Participant Log".

Experimental Findings

In section 7.2.2, it has been established that the analysis for this part will consist of pre-defined answers and answers that can still use the YES/NO approach as an alternative for true or false. Since the first stage of the experiment allows the participant to see and hear the spark, there is no right or wrong answer that can be given. Should the participant struggle to detect it, then the researcher would offer some guidance. On the other hand, it is more interesting to find out if the participants understand that the prototype is self-powering once water is added to it. In figure 40, it shows that about 10% (6) of the participants thought otherwise. Thus, that there was either an external power source or that another component or other components powered it. This was quite shocking, because the participants were placed in front of the prototype before it was working, saw the water being poured into it or in certain cases poured it in themselves, and only after the water was poured in, did it start to work. At least 2 out of the 6 participants stated that it is the wires that power the prototype, which is not entirely correct, but a good attempt. It is actually the friction between the hydrogen and oxygen elements in the water that causes the charges to separate and flow. Then the wires are used to carry or transfer these charges throughout the circuit. So, had they stated that it could be the combination of water and wires, then the answer would have been registered as correct.

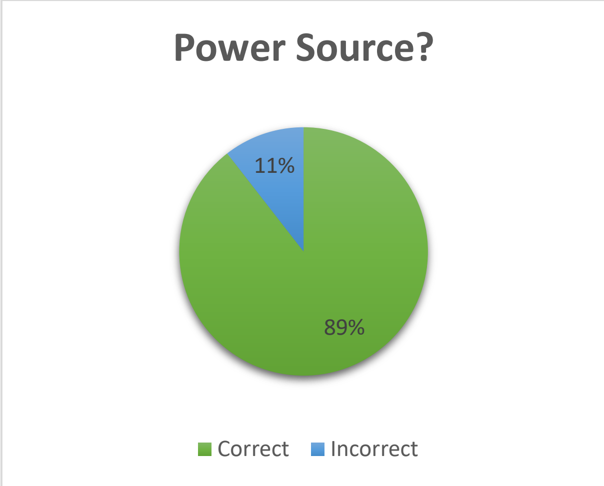


Figure 40. Water Powers the prototype concept

On the contrary, the majority realized that it was indeed water powering the prototype. So, even though 65% (37) of the participants had no technical background, 89% (51) understood this part of the operation. Since there is no fair proportion between male and female, and the majority participants who had a technical background were females, comparing the distribution of this topic based on gender would be disproportional. The same goes for making comparisons between the different age groups. There were only 3 children that participated, so if data were to be compared per age group, then it would be more fairly distributed. However, to avoid any biased results, the further examination of the measured data will focus on the total amount of participants rather than a selective group.

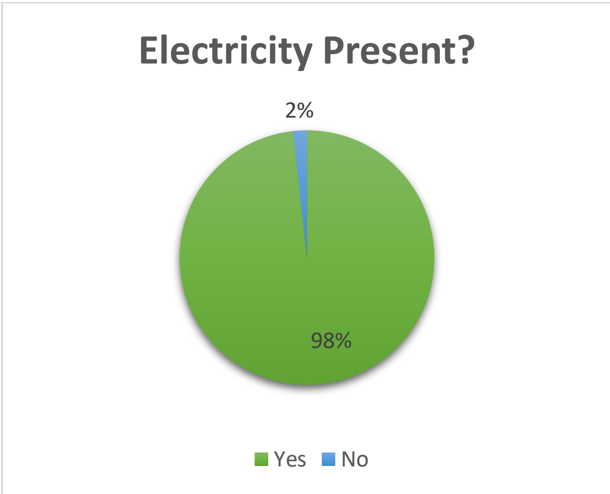


Figure 41. Yes, it is being generated

The results from figure 41, are quite good. It was also expected during the designing of this question, that the majority of the participants would choose that “electricity is present” in the prototype, due to the electric sparks and zapping sounds. So, even though one participant did not think so, the vast majority did. Figures 40 and 41 were the results on the functionality of the prototype. Now, the part where the design is observed will be shown next. It will reflect on the speculation from the previous section and section 2.5.

The first question that related to the design of the prototype was:

- *How does this concept look to you?*

As can be seen in the graph of figure 42, there were 42 (74%) participants who thought that the concept looked simple, whereas 31 (54%) either thought that it looked complicated or that the functionality behind of it was complicated. The participants who thought it looked simple, either found it “sustainable”, “symmetrical”, “easy to make” or even “creative”. The expressions and reactions from the various participants are summarized in the table of appendix D3 – D4 in the row of question 6. Additionally, there was a total of 47 (83%) participants that expressed their interest in the prototype verbally. These expressions can be found in the EXCEL file titled “EXP CODE BOOK” along with the calculations that contributed to the production of these various figures. Moreover, there were also 20 (35%) participants who chose both options. For them, the concept “looked” relatively simple, but the process behind getting it to work or putting it together seemed “difficult” or “complicated” in their opinion. Unexpected responses on what it looked like were: “Ben 10 Watch”, “Kitchen sink to wash dishes”, “A cow’s utter or a cow making electric milk”, “Ancient chemistry experiment”, “Two kidneys” and “Water robot”. This really showed how the model tapped into some of these participants imagination.

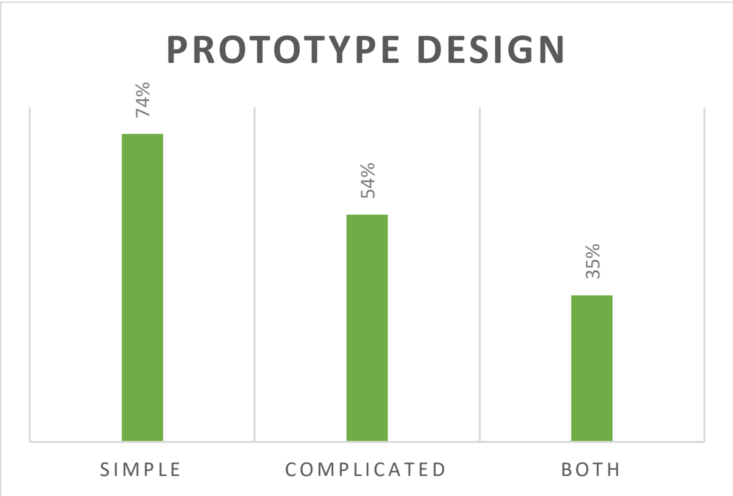


Figure 42. Proportion between the concept looking simple or complicated

Next to whether this prototype seemed simple or complicated, the participant was asked questions on the technical design of the prototype. So, figure 43 shows a graph where the participants had to determine whether the prototype was easy to understand on its own, or if they needed guidance to understand it better. The majority of the participants, in this case 46 (81%), felt that they either needed guidance to see where the spark was, or that the follow up questions were some sort of guidance to help them focus on specific parts more closely. These questions were intended to be a guidance tool for the participants when trying to understand how the prototype actually works. At least 29 (49%) of the participants thought they could have managed on their own or understood it pretty well without guidance. However, similarly to the previous case (prototype design), there were participants that could manage on their own, but realized that the questions helped them to pay closer attention to the components that could easily be overlooked.

On the contrary, the results also showed that the question could be interpreted another way. For example, there were participants who related the functionality of the prototype to real life experiences or occurrences. High school played a huge role in this perception, where the majority could relate it to the science topics they learned. Then, there were also a few who related what they saw to analogous systems that can generate static electricity, such as a “A loose wire” or “A loose wire in water”, “A broken breaker box”, “Using a hair dryer too close to the shower or water”, “A Powerplant”, “Experiments to generate light”, “Connecting jumper cables to a car battery” and actual “Thunderstorms”. All in all, even though some of them stated that their science courses were either too boring or difficult to follow, due to it strictly sticking to textbooks with no experimental courses (e.g. Italian participants), they did indeed like this experiment. The word “Cool” came up at least 12 times along with other derivations of it, which expressed how interested the participants were to participate. Previously, it was mentioned that 47 participants expressed their reactions towards the experiment and prototype verbally. Approximately 35 (61%) of them verbally expressed their interest in the prototype design and the electrostatic concept. Although the remaining 22 (49%) participants did not verbally express their interest, they did exhibit signs of interest through facial expressions, conversations on technicality, design (component or frame) choices or by just engaging in a sort of Q&A (questions and answers) session in between the experiments or thereafter. Thus, it was clear that both the technical and non-technical participants were interested in it. In addition, there were three participants that had no clue what was going, but still found the experiments fun to do. However, the next part will examine whether the presence of the prototype was necessary to understand the functionality of the concept or if it could be understood without a visual representation.

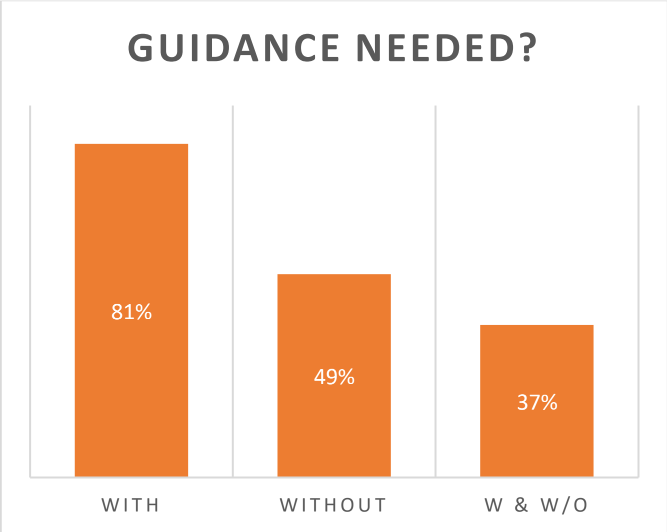


Figure 43. With, without, with & without guidance

In figure 44 it is clear to see that the general majority, thus 47 (82%) participants, thought that the use of a physical model is better than an explanation when it comes to science. Most of them claimed to be a “visual learner” or “need to see it in order to understand it”. The few participants that claimed that they would be able to understand it even without a visual model, explained that it might take them a bit longer to mentally visualize the image in their mind, but that they would eventually get it. Just as the previous two cases (prototype design and guidance needed?), there were 2 (4%) participants who chose to either have a physical model or not. One participant claimed that if the model was described in detailed, that she would have been able to visualize it in her mind. The other participant also agreed that it would have taken him some time to mentally visualize the prototype, but that the physical representation did help a lot. Thus, to now figure out whether these participants were truly enlightened by this science experiment, the results from both the background questions as well as the experimental questions will be compared to each other in the following section.

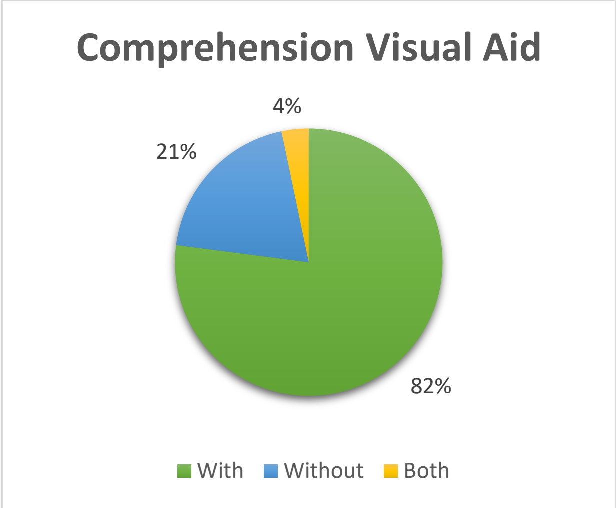


Figure 44. Comprehension on functionality clear with visual representation

In the background results, < 60% of the participants know the operation of electricity and how a battery works. However, during the experiments, about 90% of the participants knew that water was powering the prototype and 98% of them thought that electricity was present or being generated with the prototype. So, it can be assumed that this huge increase in knowledge gain may have come from the participants witnessing the occurrences in real-time off of a visual model. The questions they had to fill out on the “Background Questions” form, did not present any kind of visual representation of electricity or a battery, which could have resulted in the low amount of participants grasping the concepts. However, the actual engagement with the prototype, show that the participants became more interested in the functionality of the concept and understood it better. Furthermore, figure 33 from the background analysis showed that 65% of the participants were non-technical, but in the end at least 90% of the participants understood the two main functionalities of the concept. Thus, there was a 25% increase in knowledge gain due to the experiments, which goes to show that a visual model and real-time occurrences can improve the technical comprehension of non-technical participants. Moreover, the experiments were not performed in the traditional setting and the participants were given the choice to either participate online from the comfort of their homes or meet with the researcher in person also in a domestic setting. It was also stated that most of the participants learned science from High School textbooks, where some of them never engaged in experiments, which dismissed their interest in the topic of science. However, since this experiment was performed as mentioned above, in an informal setting, it helped the participants to enjoy it from the comforts of their homes and increase their interest in science altogether.

Chapter 8 Conclusion

This final chapter will summarize all the previous information from the different chapters and reflect on them with aid of the experiment findings. The research question will also be answered during this process and a discussion will share the advantages and disadvantages of the whole project process.

This research shows how Kelvin's Thunderstorm resembles a renewable energy source, but does not perform as powerful as one. In addition, relatable systems that use the same electricity generation technique as Kelvin's Thunderstorm, namely static electricity, use external power to drive their operation. On the other hand, Kelvin's Thunderstorm uses nothing more than water to drive its operation. Therefore, it is more sustainable than the others. Since static electricity is a science topic and science is not liked by many students, research was done to discover why there is such a lack of interest in the science topic. First, the reasons for the "lack of interest" were examined, which provided three results. Students can have negative personal experiences with the science topics due to the content being too difficult to understand, the school and teachers failing to implement to the STEM standards or students undergoing bad experiences with people (e.g. scientists) in the science context. Second, the different aspects that can attract students to science were examined which resulted into two factors, namely "Setting" and "Collaboration". It is recommended to have the student engage in science in an informal setting along with the peers, family and/or with a scientific concept or scientist, in order to increase their interest experience with science. Third, the way how design can influence the attraction to design was investigated and covered three areas: empathic design, elements of a well-designed object and prototypes. The end-user should be placed at the centre of the designing process in order to develop an empathic product that reflects the needs of this user. This end product can be realized through prototyping.

Thus, by taking these different points into consideration, the project experiments will be designed to determine if "Setting", "Collaboration", "empathic design" and "prototyping" can indeed enhance the interest in science. After coming up with designing and functionality ideas, the first set of prototypes were made and tested. Due to functionality inconveniences, a mock-up was developed to further test the concept's functionality. When the mock-up worked, two down-scaled versions were developed where the prototype in figures 26 and 31 was used for the experiments. So, individuals were then recruited to participate in the experiments and could freely choose how they wanted to participate (Setting). The experiments were designed to first see how participants would initially understand the concept's operation without any visual representation, then to further see the change in their responses during and after the conduction of the experiments. Since the majority of participants were female, which could make the data gender biased, it was decided to eliminate this independent variable. The main focus was aimed on the total amount of participants instead of the individual group as mentioned in chapter 3. A total of 35% of the participants followed a technical course, whereas 65% did not. Surprisingly, over 50% (less then 60%) of the total amount of participants, knew how both a battery worked and electricity operated. Another noticeable factor, was that 75% of the participants knew what renewable energy was, which contradicted the low amount that knew how a battery and electricity worked. However, renewable energy sources are visual concepts. Thus, it can be presumed that this factor (visuality) is the reason for the participants knowing renewable energy better than a battery and electricity.

The experiments further revealed that about 90% of the participants thought that the Kelvin's Thunderstorm concept was powered by water. Then 98% of them actually thought that electricity was either being generated or present in the concept. Thus, in comparison to the previous findings where over 50% of the participants understood the battery/electricity operation, it is clear that the experiments did improve the knowledge gain in the science concept. Next, a total of 74% of the participants thought the prototype looked simple, where 54% of them thought it to be complicated. These results were followed by reactions that indicated that the participants were very engaged with the experiments and the design of the prototype. For example, a total of 82% of them suggested that they are “visual learners” and preferred the visual representation of the concept over an explanation thereof. Similarly, 81% of the participants thought the guidance throughout the experiments was valuable. So, to answer the research question:

What factors of design attract individuals to the science behind of technology?

The answer is as follows:

- First, design a prototype that can be tested on the level of functionality comprehension;
- Then, design an experiment or experiments where participants can freely choose how they would like to participate in it or them;
- In addition, design questions that can help enhance the knowledge gain in the science topic;
- Next, allow the participants to see at least the input (water being poured in) of the prototype and have them discover the output (sparks generating) for themselves;
- Lastly, ask them questions on specific parts of the prototype to find out if they are paying attention to its operation. (Also ensure that participants can ask questions.)

Thus, simply discussing the science topic without any form of visual or physical engagement, will result in a decrease of interest in science. Therefore, all of the factors mentioned in the list above are essential to increase this lack of interest in the science topic or concept. Fortunately, this answer also coincides partially to the expectations of this project as is mentioned in chapter 1. What was missing in this expectation is that by receiving questions throughout the experiment(s), the participant can be guided to discover the functionality of the concept. There is no point in engaging with a prototype (or scientific concept) without 100% understanding what is happening right in front of you. So, provide some sort of guidelines or guidance as a tool to help the participant understand what is going on.

Chapter 9 Future Work

In this chapter, a couple of methods will be mentioned on how the current concept could be improved for future research and functionality results. These methods are either still in a working progress or are wishes for the next researcher that may take on this sort of project.

9.1 Pump Implementation

Since the Kelvin's Thunderstorm concept is symmetrical, but the water from the bottom containers should not come into contact with each other throughout the operation process, two separate small pumps will be used to recycle the water. The pumps that will be used are two 12 DC aquarium pumps that can suck up water and transfer it. Unfortunately, these pumps require the use of a power supply, thus instead of using a battery or power outlet, a 12 DC power bank will be used to power both pumps. Since the pumps require twice the amount of voltage, a power booster (voltage regulator) will be used. The tubing that will go from the metal container at the bottom to the pump, then from the pump to the top container, will either be a hose or flexible plastic tube. However, since the aquarium does not have an automatic timer on it and will suck the water even after there is none left to suck up, a timer switch will be connected between the power bank and the aquarium pump in order to set a time when the pump should start sucking and when it should stop. The suction function should only start when the water has reached half of its initial volume. That way, the cycle or recycling mechanism can be a continuous one until the power bank has run out of juice.

9.2 Water Test Procedure

In any future analysis of this project, the researcher should test the conductivity of the water with four different types of water. These water types should be any choice between mineral water, filtered water, rain water and/or saltwater from the sea. This should be done in order to collect measurements that can be graphed and compared with each other to find out if the salinity in each water type has a huge effect on the spark generation. The speed of the water flow versus the time of the spark occurrences should be plotted against each other in the graphs or diagrams for clear comparisons. After figuring out which water type produces the best waterdrops along with the quickest spark generation, the next section can then be designed.

9.3 Final Prototype Design

The current prototype design as can be seen in chapter 5, is built from PVC pipes and easy accessible objects. However, since this project is based on a sustainability as was mentioned in chapter 2, the prototype or final product should be made out of recyclable objects as well. In order for the viewer to get a good understanding of what is happening or where to look, have the different components be shaped in organic forms that direct the attention to the middle bottom part of the device. In at least five cases of the User Testing experiment, the participants realized that since water was being poured in at the top that they should follow it to the bottom to see what happens there. Thus, by applying this approach and taking these tips into consideration, the end product can be made in such a way that it self-guides its operation. Unfortunately, the majority of the results or participants had to be guided to the focal point of the design which indicates that improvement is needed in the structure design. A few of these participants only became aware of where they had to look if the room was relatively dark or if they saw me observing it in a certain area to first check if it was working before placing them in front of it.

The new prototype should be transparent but have a protective covering in order for the viewer to see its full operation and admire its functionality. Therefore, the use of plexiglass as a casing, smaller metals with an anti-rust layer sprayed both inside and out of them, a plexiglass transparent isolation material placed on the inside of the metal inductors, a transparent plastic base, enough room should be under the device in order to attach the plastic tubing or hoses to the bottom containers that go up to the pump, a place to fasten the pump and the power bank to and a better reservoir construction that has a funnel like operation should be implemented in the new model.

9.4 Spark Length Elongation

One of the challenges as is given in the graduation form of appendix A, is to find out how the spark length can be elongated. One known way that had already been tested was the use of a syringe in order to create under pressure between the spark gap in order to lengthen it from approximately 0,5 cm to 1,0 cm. During this process, the initial yellowish/white spark became a blueish colour, due to the energy being distributed over a longer distance. Figure 45 shows the relation between the pressure and the breakdown voltage and was the key representative to this method. Additionally, the future researcher should also look up other ways to accomplish this with on a bigger scale with the same yellowish/white light intensity that the spark displays.

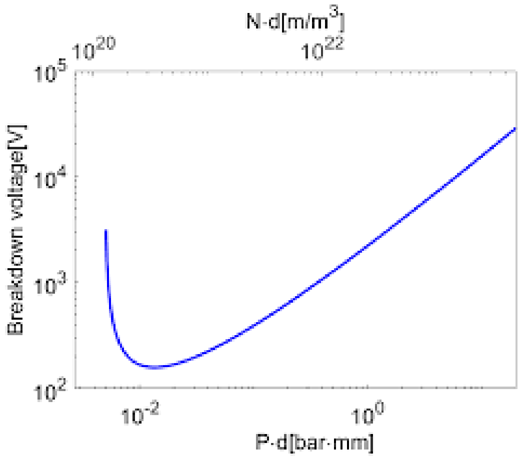


Figure 45. Breakdown Voltage plotted against the Air Pressure [27]

9.5 Attach Load Between Spark Gap

Earlier in this report, it was discussed that Kelvin’s Thunderstorm does not produce enough current to work as the known renewable sources do. However, it does generate enough voltage that can power a lightbulb, for example. In the future or if someone researches this concept further, the use of a small LED lamp or component that does not call for much current, can be added in between the spark gap as an alternative confirmation method to show that energy is being generated. Especially for those who struggled to see what was happening when the sparks were occurring. This can also be another solution to guiding the viewer’s focus to the focal point of a device or system, instead of creating a concept with an organic form to steer them in the right direction.

9.6 Measure Amount Of Voltage

In section 2.4.3, it was mentioned that a photodiode can probably be used to detect the spark occurrences. Since Kelvin’s Thunderstorm is very prone to voltage leakages and it would not be wise to use a multi-meter or any device that is grounded on it to determine the amount of voltage being produced. So, if there is a way that the spark detection can be converted into light intensity measurements and those values can be converted into voltage measurements, then this could also add value to the current prototype model. In the same way, if the detected sparks can be converted into current to give the exact or estimated values of the generated current, then it will be useful in knowing what experimental components can be attached as load between the spark gap.

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Appendix

A. Graduation Proposal Form

Creative Technology - Graduation Project proposal
V1.3 171012

Kelvin's Thunderstorm

Client name	**Clemens Mensink**
Client contact	**06 20 26 25 28**
Client website	**www.menperium.com**
CreaTe contact	Wouter Eggink (w.Eggink@utwente.nl)
Period	Sep. 2018 - Jan. 2019

Client Information (100 words)

Any great ambition starts with passion and only thru action it can lead to successes. The underlying principles are personal vision and self-confidence, in short, personal leadership. Menperium provides tools to inspire you to build your vision and work deliberately towards successes.

To help you finding your way, Menperium provides lectures about fundamental mechanisms of achieving, of which building a strong character is an important factor. In addition, Menperium creates sculptures to show the essence of a concept, contributing to the discovery of personal interests. Understanding the essence is crucial since it is the root of any other creation.

Project Background (200 words)

Nowadays a lot of information comes to us and we are easily caught up in the flow of daily life. This is all fine as long as you know what your values are, what is important to you, and what goals you are after. Only then you can work towards something and experience personal growth. Discovering your values is not necessarily easy, it is not written in a personal user manual, and can be a long process.

Technology evolves fast. Just realize how the world was 20 years ago, the smartphone was beyond our dreams. It is almost certain that the world will be quite different 20 years ahead where we will have self-driving cars and many more new inventions. At the root of any invention are physics and timeless principles, that will never change.

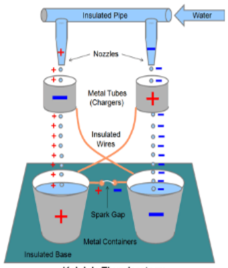
One of Menperium's activities is to create sculptures that show fundamental principles, the essence of a concept. Why sculptures? A sculptures enables a live experience. It are the experiences that will be remembered. Experiencing a sculpture will also stimulate creativity. The viewer will think "how can it work for me". Whatever the answer is, it contributed to one's personal discovery.

Project (150 words)

There are almost an unlimited number of fundament principles. For this project static electricity has been chosen using a Kelvin Dropper or Kelvin's Thunderstorm. Water is polarized and therefore a voltage is build up across the containers. When the voltage is high enough a spark fires, typically every couple of seconds. The only thing needed to get it going is running water. By using a water pump it can be a closed system.

Challenges:

- How to present the concept in an attractive way?
  What dimensions, extra light, audio, ...
- How to explain the concept such that it will inspire people?
  Maybe a multi-level explanation might be useful.
- How to implement a water pump maintaining functionality?
  Collect water from the buckets without and electrical path.
- How to maximize the spark length to make it most spectacular?
  There is more to it that you might think initially.



Kelvin's Thunderstorm

Constraints & Practical Aspects (100 words)

The project should result in a physical implementation. preferably in show model that could be placed right away somewhere at the campus. This draws up on your building skills. Initial thoughts are to use Plexiglas with brass (messing). A limited budget for these materials is available. Menperium has a simple Kelvin Dropper with 1 liter plastic buckets and tin cans, and can be used for experiments.

Menperium would like to have weekly or bi-weekly progress meetings to align mutual expectations. Furthermore, optimizing the spark length requires an understanding of leakage paths, resistance, capacitance, breakdown voltage of air, etc.

B. Information Brochure & Consent Forms

1. Information Brochure: "Kelvin's Thunderstorm"

Dear participant,

In this letter, we would like to inform you about the research you have agreed to participate in. The research will take place on multiple days where you have the choice to either participate live (being physically present) or online (being virtually present). Can you please select a suitable date and participation option?

☐ *dd-mm-2020*	☐ *dd-mm-2020*	
☐ *dd-mm-2020*	☐ *dd-mm-2020*	
☐ *dd-mm-2020*	☐ *dd-mm-2020*	
☐ *dd-mm-2020*	☐ *dd-mm-2020*	☐ *Live*
☐ *dd-mm-2020*	☐ *dd-mm-2020*	☐ *Online*
☐ *dd-mm-2020*	☐ *dd-mm-2020*	
☐ *dd-mm-2020*	☐ *dd-mm-2020*	
☐ *dd-mm-2020*	☐ *dd-mm-2020*	

In the proposed research, entitled "Kelvin's Thunderstorm", you should observe the object and try to explain what you think is happening. Your interaction and observation with the object will be recorded on camera. A short interview will follow thereafter, which may also be recorded to collect both visual and verbal data that can contribute to the evaluation of the research. The main goal of this research is to establish whether the design of the object influences an individual's perception of the science behind of the concept and whether this aspect sparks an interest in that individual.

First, Kelvin's Thunderstorm produces a high voltage that can generate a spark in thin air. However, ***this spark will only distribute a slight shock to the participant(s) and not cause any serious damage.*** *So, as a safety measure a sign will be placed either on or next to the concept to ensure that participants avoid touching it. Should there be any first attempts to touching it, a warning will be given. Thereafter, the participant(s) will immediately be disqualified from participating further in the research. All collected data will also be terminated.*

Second, in the first experimental round, the natural interaction of the participant(s) will be documented: the participant(s) will freely explore the concept either Live or Online (with researcher as Virtual Avatar) and will be asked to verbally describe their thoughts. In the second round, a few questions will be asked to help the participant(s) explore the concept more deeply. In this way, an answer for the research question can be found.

Third, parents who want to be present and/or participate alongside their child(ren), are allowed to do so. The only objective is for them not to interfere or influence the natural and authentic thinking process of their child(ren). The parent(s) should only ensure that the child(ren) heed(s) the instructions properly. If at any moment the parent(s) change(s) their minds about their child(ren) participating, they are allowed to stop the participation. If useful data have been collected, despite the ending of the participation, the parents will be asked whether the data can still be used in the research. The data will be dealt with accordingly to ensure no violation of privacy or consent.

Fourth, participants between the ages of 10 to approximately 55 can participate in this experiment. Individuals younger and older than this age range will be kindly asked not to participate. Children younger than 10 years might risk touching the concept or just see it as a fun toy to play with, rather than exploring it critically. Individuals older than 55 years are at high risk for COVID-19, so to ensure their safety and the safety of others, they will not be permitted to participate.

Fifth, if a participant wishes to be anonymous, please fill in and sign the following declaration:
I, ……………………………, hereby declare that I would like for my identity to stay anonymous in this research and that my information should not be disclosed to any third parties without my permission.

____

Participant's signature

Finally, all Live participants will receive specific timeslots to avoid anyone coming into contact with each other. The break between participant exchanges will be at least 5-10 minutes. On the other hand, if the participant feels offended or uncomfortable at any given moment, he/she can stop participating without having to give a reason or an explanation. Should a participant not want to participate again, the researcher should be notified at least a day (24 hours) in advance. If a participant does not want his/her data to be used for the research again after the experiment has been conducted, he/she should notify the researcher within 24 hours so that the data can be discarded. The experiment along with the interview will last no more than ***an hour****. After the entire research has been done and all the results have been obtained, if you would like you can receive information about these results by means of a debriefing.*

Kind regards,

Coordinator: Richard Bults
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E-mail: ikmareka@gmail.com

2. Informed Consent for Standard Research

'I have been given the main goal of this research, the topic of what the research is about and the manner in which this research will be carried out in the "Information Brochure Kelvin's Thunderstorm".

I agree that my questions have been answered to my satisfaction and that I freely choose to participate in this research. I understand that I have the right to withdraw this consent and my participation at any time without having to give any reasons or explanations, and without there being any consequences.

If I do not permit for my information to be used in the research or to be disclosed to third parties, I am aware that my information will be discarded. I know that I will be recorded on camera during the experiments and interview, and that these recordings will only be seen by the researcher. I know that my name will be mentioned in the research unless I choose to be anonymous.

If I have any further questions about the research, now or in the future, I may contact Ikmareka Hunt via e-mail at ikmareka@gmail.com. *If I have any concerns or complaints about this research, I may contact the Secretary of the Natural Sciences and Engineering Sciences Ethics Committee at the University of Twente, P.O. Box 217, 7500 AE Enschede (NL), telephone: +31 (0)53 489 2547; email: m.c.kamp@utwente.nl.*

Signed in duplicate on ……/……/……:

…………………………	*…………………………*
Name Participant	*Signature*

I have provided notes that explains what this research is about. I declare that I am willing to answer any questions that arise about this research, to the best of my ability.'

…………………………	*…………………………*
Name Researcher	*Signature*

3. Informed Parental Consent for Research Involving Children

'I have been given the main goal of this research, the topic of what the research is about and the manner in which this research will be carried out in the "Information Brochure Kelvin's Thunderstorm".

I agree that my questions have been answered to my satisfaction. I understand that my child's involvement in this research is voluntary and I agree to allow my child to participate in this research. I also understand that I have the right to withdraw this consent and the participation of my child at any time without having to give any reasons or explanations, and without there being any consequences. I am aware that my child has the right to withdraw from participating at any time as well.

If I do not permit for the information of my child to be used in the research or to be disclosed to third parties, I am aware that my child's information will be discarded. I know that my child will be recorded on camera during the experiments and interview, and that these recordings will only be seen by the researcher. I know that my child's name will be mentioned in the research unless I choose for my child to be anonymous.

If I have any further questions about the research, now or in the future, I may contact researcher Ikmareka Hunt via e-mail at ikmareka@gmail.com*. If I have any concerns or complaints about this research, I may contact the Secretary of the Natural Sciences and Engineering Sciences Ethics Committee at the University of Twente, P.O. Box 217, 7500 AE Enschede (NL), telephone: +31 (0)53 489 2547; email: m.c.kamp@utwente.nl.*

Signed in duplicate on …../……/……:

………………………	………………………
Name Participant	*Signature*
………………………	………………………
Name Parent/Legal Guardian	*Signature*

C. Interview Questions

1. Background Interview Questions

B1. What is your name?

____

B2. How old are you?

☐ 10-17
☐ 18-25
☐ 26+

B3. What is your gender?

☐Male
☐Female

B4. What is your profession? (student, teacher, architect, etc.)

____

B5. What are you studying? Or, what have you studied?

____

B6. Did you ever follow a technical course? If yes, which?

____

B7. Do you know how a battery works? If yes, please explain.

____

____

B8. Do you know how electricity works? If yes, please explain.

____

____

B9. Have you ever done any type of electric work before? If yes, what kind?

____

____

B10. Have you ever gotten shocked from touching a metal object, such as a door handle?

☐Yes
☐No

B11. Have you ever heard about renewable energy? If yes, what do you know about it?

____

____

2. Observational Interview Questions Part I

Stage 1: Exploratory Question

O1. Can you verbally describe what you are hearing and seeing?

Stage 2: System/Device Observational Questions

O2. What do you think the power source of this system/device is?

O3. How do you think the spark is being made?

O4. Do you think electricity is present in this system/device? If yes, what makes you think so?

O5. What do you think the water is used for?

O6. Why do you think the red wire goes from one bottle to the other or from one water stream to the other?

O7. Why do you think these green and white wires are cross-connected?

O8. Can you please list the materials that you see?

O9. Which material(s) do you think contribute to the generation of the spark?

O10. How does this system/device look to you?

O11. Does it look complicated or simple to you?

O12. Was it easy to understand what was happening when exploring the system or device?

O13. Did it become more clear after the follow up questions (O2-O9)?

Stage 3: Functionality Explanation of System/Device

First, give an explanation of the functionality.

O14. Did the functionality of the system/device become easier to understand with this visual example/model?

3. Observational Interview Questions Part II

Stage 1: Exploratory Question

O1. Can you verbally describe what you are hearing and seeing?

Stage 2: System/Device Observational Questions

O2. What do you think the power source of this system/device is?

O3. Do you think electricity is present in this system/device? If yes, what makes you think so?

O4. What do you think the water is used for?

Guidance 1: The red wire at the top goes through the two plastic bottles and is stripped at its ends, which exposes the copper inside to the water. So,

O5a. What do you think the purpose is of this wire?

O5b. Why do you think these green and white wires are cross-connected?

O5c. Can you please list the materials that you see?

O5d. Which material(s) do you think contribute to the functionality of the system/device?

O6a. How does this system/device look to you?

O6b. Does it look complicated or simple to you?

Guidance 2: When you first explored/observed the system/device and described what you heard and saw,

O7. Was it easy to understand what was happening, or did it become more clear after the follow up questions (O2-O5d)?

Stage 3: Functionality Explanation of System/Device

First, give an explanation of the functionality.

O8. Did the functionality of the system/device become easier to understand with this visual example/model?

D. DATA Analysis

1. Background Code Book

BACKGROUND CODE BOOK			
Number	**Question**	**Answer**	**Abbreviation**
		YES	✓
		NO	–
1	Name	**Irrelevant**	
2	Age	10-17 (Minor)	MIN
		18-25 (Legal)	LEG
		26+ (Mature)	MAT
3	Gender	Female	F
		Male	M
4	Profession	**Irrelevant**	
5	Study/Studied	**Irrelevant**	
6	Technical Background		✓/–
7	Battery Operation		✓/–/Other
8	Working of Electricity		✓/–/Other
9	Done Electric Work Before		✓/–/Other
10	Experienced Shock	Closed	✓
			–
11	Renewable Energy		✓/–/Other

2. Experiment Code Book

<table>
<tr><th colspan="9">EXPERIMENT CODE BOOK</th></tr>
<tr><th>Number</th><th>Question</th><th>Answer</th><th colspan="6">Abbreviation</th></tr>
<tr><td>1</td><td>Listen and Watch</td><td colspan="7">Open</td></tr>
<tr><td>2</td><td>Power Source</td><td colspan="7">Open</td></tr>
<tr><td>3</td><td>Electricity Present</td><td>✓
–</td><td colspan="6">Yes
No</td></tr>
<tr><td>4</td><td>Purpose Water</td><td colspan="7">Irrelevant</td></tr>
<tr><td>5a</td><td>Purpose Red Wire</td><td colspan="7">Open</td></tr>
<tr><td>5b</td><td>Purpose Cross-Connected Wires</td><td colspan="7">Open</td></tr>
<tr><td>5c</td><td>List Materials</td><td colspan="7">Irrelevant</td></tr>
<tr><td>5d</td><td>Choose The Essential Materials</td><td colspan="7">Open</td></tr>
<tr><td rowspan="6">6</td><td rowspan="6">Prototype Design Appearance</td><td rowspan="6">Open</td><td>ANC</td><td>COOL</td><td>ELAB</td><td>INS</td><td>SAFE</td><td>SYM</td></tr>
<tr><td>BTW</td><td>COW</td><td>EPIC</td><td>INT</td><td>SCL</td><td>BOT</td></tr>
<tr><td>BBOX</td><td>CREA</td><td>EXP</td><td>KIDN</td><td>SIMP</td><td>WRD</td></tr>
<tr><td>CUP</td><td>CUR</td><td>FLT</td><td>NEW</td><td>SML</td><td>WOW</td></tr>
<tr><td>COMP</td><td>DIFF</td><td>GHET</td><td>PUMP</td><td>STR</td><td></td></tr>
<tr><td>CONC</td><td>DRN</td><td>GOOD</td><td>PPLT</td><td>SUS</td><td></td></tr>
<tr><td>7</td><td>Comprehensive with/without Guidance</td><td>Open</td><td colspan="6"></td></tr>
<tr><td>8</td><td>Comprehensive with/without Model</td><td>Open</td><td colspan="6"></td></tr>
</table>

3. Description Codes Part I

DESCRIPTION OF CODES I		
Question	**Defined Answer**	**Abbreviation**
Exploratory Experimental Round		
1	*Water Spark	WAT SPK
Observational Experimental Round		
2	*	
3	Yes	✓
4	**Irrelevant**	
5a	Close Circuit Connect Water Charges	CLC CWC
5b	Charge Buildup Negative-Positive Connection	CBU NPC
5c	**Irrelevant**	
5d	Metal	MET

4. Description Codes Part II

DESCRIPTION OF CODES II		
Question	**Given Answer**	**Abbreviation**
6	Ancient Ben Ten Watch Breaker Box Can Use Paint Complicated Concept Cool Cow Creative Curious Different Drain Elaborated Epic Experimental Filter Ghetto Good Inspirational Intriguing Kidney New Pump Powerplant Safe Scalable Simple Small Structured Sustainable Symmetrical Robot Weird Wow	ANC BTW BBOX CUP COMP CONC COOL COW CREA CUR DIFF DRN ELAB EPIC EXP FLT GHET GOOD INS INT KIDN NEW PUMP PPLT SAFE SCL SIMP SML STR SUS SYM BOT WRD WOW
7	~With Without Other	W W/O O
8	~	

5. Example Background Analysis Chart

	2	3	6	7	8	9
P#	Age	Gender	Technical Background	Battery Operation	Electricity	Electric Work
P1	MAT	F	✓	Other	Other	✓
P2	LEG	F	–	Other	✓	–
P3	LEG	F	✓	Other	✓	–
P4	MAT	F	✓	Other	Other	–
P5	MAT	F	–	–	–	–
P6	MAT	M	✓	–		✓
P7	MIN	F	–	✓	✓	–
P8	MAT	M	✓	Other	✓	✓
P9	MIN	F	✓	–	–	–
P10	MAT	F	✓	–	–	–
P11	LEG	M	–	✓	✓	–
P12	MIN	M	–	✓	✓	–
P13	LEG	F	–	–	–	–
P14	MAT	M	–	✓	✓	✓
P15	LEG	F	–	✓	✓	✓
P16	LEG	M	–	✓	–	–
P17	MAT	M	–	✓	✓	–
P19	LEG	F	✓	Other	–	–
P20	LEG	F	✓	–	✓	–
P21	LEG	F	✓	✓	✓	✓
P22	MAT	F	–	✓	✓	Other
P23	LEG	F	–	–	–	–
P24	LEG	F	–	–	–	–
P25	MAT	F	–	Other	–	–
P26	LEG	F	–	–	–	–
P27	LEG	F	–	✓	✓	–
P28	LEG	F	✓	✓	✓	✓
P29	LEG	F	–	–	–	–
P30	MAT	F	–	–	Other	–
P31	LEG	F	–	✓	✓	–
P32	LEG	M	–	✓	Other	–
P33	LEG	M	–	✓	Other	✓
P34	LEG	F	✓	Other	Other	–
P35	LEG	F	✓	✓	✓	✓
P37	LEG	F	–	–	✓	–
P38	LEG	F	–	–	✓	–
P39	LEG	F	–	✓	Other	–
P40	MAT	M	–	✓	✓	–
P41	LEG	M	–	–	✓	–
P42	LEG	M	✓	✓	–	✓
P43	LEG	F	–	–	✓	–
P44	MAT	M	✓	✓	✓	✓
P46	LEG	M	–	✓	✓	–
P49	LEG	M	✓	–	✓	–
P50	LEG	M	–	✓	✓	–
P51	LEG	M	✓	✓	✓	✓

6. Example Experimental Analysis Chart

	1				2	3	
	Hear		See				
P#	WAT	SPK	WAT	SPK	WAT		CLC
P1	✓	✓	✓	✓	✓	✓	✓
P2	–	–	✓	✓	✓	✓	✓
P3	✓	✓	✓	✓	✓	✓	✓
P4	✓	–	✓	✓	✓	✓	–
P5	–	✓	✓	✓	✓	✓	–
P6	✓	✓	✓	✓	✓	✓	–
P7	–	✓	✓	–	–	✓	
P8	✓	–	–	✓	✓	✓	–
P9	✓	✓	✓	–	–	✓	✓
P10	✓	✓	✓	✓	✓	✓	
P11	✓	✓	✓	✓	✓	✓	
P12	✓	–	–	✓	✓	✓	–
P13	✓	–	–	✓	–	✓	–
P14	✓	–	–	✓	✓	✓	✓
P15	✓	–	✓	✓	✓	✓	✓
P16	✓	–	✓	✓	✓	✓	–
P17	✓	–	–	✓	✓	✓	–
P19	✓	–	✓	✓	–	✓	–
P20	✓	✓	✓	✓	✓	✓	–
P21	–	✓	✓	✓	✓	✓	
P22	✓	–	–	✓	✓	✓	✓
P23	✓	–	–	✓	✓	✓	–
P24	✓	–	–	✓	✓	✓	–
P25	–	✓	–	✓	✓	✓	–
P26	–	✓	–	✓	✓	✓	
P27	–	–	–	✓	✓	✓	–
P28	✓	–	–	✓	✓	✓	✓
P29	–	✓	–	✓	✓	✓	–
P30	✓	✓	✓	✓	✓	✓	–
P31	✓	✓	–	✓	✓	✓	✓
P32	✓	–	–	✓	✓	✓	–
P33	✓	–	✓	✓	✓	–	–
P34	✓	–	–	✓	✓	✓	–
P35	–	–	–	✓	✓	✓	✓
P37	–	–	–	✓	✓	✓	–
P38	✓	–	✓	✓	✓	✓	–
P39	✓	✓	✓	✓	✓	✓	
P40	✓	–	–	✓	✓	✓	
P41	✓	–	✓	✓	✓	✓	✓
P42	–	✓	–	✓	✓	✓	–
P43	✓	–	–	✓	✓	✓	–
P44	–	–	–	✓	✓	✓	–
P46	✓	–	–	✓	✓	✓	–
P49	✓	–	✓	✓	✓	✓	
P50	✓	–	✓	✓	–	✓	–

7. Example Conversion Chart

Q2. How old are you?

Sub-table from DATA sheet

P#	Age	code
P1	MAT	g
P2	LEG	a
P3	LEG	a
P4	MAT	g
P5	MAT	g
P6	MAT	g
P7	MIN	c
P8	MAT	g
P9	MIN	c
P10	MAT	g
P11	LEG	a
P12	MIN	c
P13	LEG	a
P14	MAT	g
P15	LEG	a
P16	LEG	a
P17	MAT	g
P19	LEG	a
P20	LEG	a
P21	LEG	a
P22	MAT	g
P23	LEG	a
P24	LEG	a
P25	MAT	g
P26	LEG	a
P27	LEG	a
P28	LEG	a
P29	LEG	a
P30	MAT	g
P31	LEG	a
P32	LEG	a
P33	LEG	a
P34	LEG	a
P35	LEG	a
P37	LEG	a
P38	LEG	a
P39	LEG	a
P40	MAT	g
P41	LEG	a
P42	LEG	a
P43	LEG	a
P44	MAT	g
P46	LEG	a
P49	LEG	a

Set themes & assign relat

Themes	Codes
Child	c
Adolescent	a
Grown-up	g

ive codes	Data Analysis	
	Statistics	
	Frequency	
	Child	3
	Adolescent	37
	Grown-up	17
	TOTAL	57
	Proportions	
	Child	5%
	Adolescent	65%
	Grown-up	30%
	TOTAL	100%