An demonstration device for electrical engineering

Sietze Huisman
Creative Technology

Supervisor: Cora Salm
Critical observer: Jorien Berendsen
EEMCS
University of Twente
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abstract

This graduation project has the goal of developing an interactive demonstrator that excites and educates future students about electrical engineering. This was done to develop a demo that is specifically engineered for outreach purposes which can be used on open days or school visit days.
Starting with background research, finding the stakeholder, and setting up a list of requirements. A brainstorm was held to generate a list of ideas. These ideas were evaluated and the best idea was elaborated and constructed.
This resulted in a platform simulating multiple ways of generating electricity interactively together with an information sheet that elaborated on how they were connected with electrical engineering.
The design was evaluated using three different methods, user evaluation, handler evaluation, and expert evaluation. The demonstrator was well-received and both excited and educated the participants of the user evaluation. The handler and expert evaluation resulted in a lot of feedback on the demonstrator that was turned into a list of future improvements.

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1 Introduction

The University of Twente organizes open days in order to attract students to the studies they provide. Many studies have a stall where they show off the things they do as well as answer questions about the study itself. The electrical engineering study does this too. They usually use projects done by students during the study but would like some additional demonstrators for both the open days as well as show days at schools. Those who visit/see the demonstrator will thus be a mix of interested people and those who might not be interested in the specific workings of the demonstrator. The challenge is then to design a demonstrator that is interesting and educational to both the ones who are already interested in the electrical engineering field as well as those who might not be as interested. Since the main target demographic is those that are interested in electrical engineering, the research question will be reduced to target just those people with the additional bonus being that it is fun to look at for those not necessarily interested. The main question becomes then: What are the components that make an interactive demonstrator with the purpose of exciting and educating prospective students aged between 16 - 18 about the field of electrical engineering? based on this question sub-questions were constructed:

1. What are the subfields and applications of electrical engineering? Since the demonstrator is specifically about the electrical engineering field and not just the bachelor, it would be good to have an idea of the different directions students can head in order to better generate ideas.

2. How can these subfields and applications be shown practically? Same as the last question, in order to get a good grasp on the potential directions this project can go in and what the demonstrator can show, there will be research to find visualizations that will help get an idea for the final design.

3. How can a demonstrator be made interactive? As it would be appreciated to have the demonstrator be interactive, multiple ways to make it interactive will need to be researched in order to get more inspiration.

4. How can the effectiveness of the demonstrator be evaluated? The designs need to be evaluated and part of that evaluation will of course be how well the demonstrator works as a demonstrator.

Additionally, an academic literature review will be conducted with a focus on the educational aspect of demonstrations. This is slightly different than an object called a demonstrator and usually also includes a person to explain everything. This review can be helpful with the project as the philosophies used in demonstrations can potentially be used in demonstrators as well. The research question for this review is: how to educate people about intangible and theoretical concepts in an engaging way using demonstrations. with the sub-questions:

1. What are different types of demonstrations.
2. How to make demonstrations engaging.
3. How to effectively educate using demonstrations.
4. How to show intangible and theoretical concepts physically.

2 Background Research

2.1 museum visits

There are museums that focus on teaching science in an interactive way. These museums do this through the use of display pieces and information boards but also with the help of demonstrations. Since the goal of this graduation project is the design of an interactive demonstrator, it would be good to visit these museums in order to learn what they have and how they use it as well as to potentially get inspiration that can influence the final design.

2.1.1 universiteitsmuseum Utrecht

The Universiteitsmuseum Utrecht is a small museum with the focus on getting people in contact with the scientific method, with different rooms for different types of research and different stages in a research project.
The main way they did this was using a mystery cube, the cube was a hollow opaque box with a mystery item in the middle. The visitors can then go through the museum and could at some places test the cube using different methods that researchers use. You could for example use a magnet to see how magnetic the item in the box was. Or there was a space where they asked you to shake the cube to see if the thing inside was a single object or multiple objects.
After doing these tests you could then go to the entrance of the museum where multiple displays were visible with the potential objects inside. You could then drop a coin in the slot pertaining to what you thought was in the box. This is a very involved and interactive display that demonstrates the nature of research and the different methods that researchers can use to find out about the unknown. This kind of setup is very fun and very involved and would be great to integrate into a design. However the nature of the setup requires a lot of space to set up, it would be great for something like an open day where you can set it up once at the start of the day and not have to interact much with it. It is not that great for visiting days since those usually only last for a couple of hours, the potential setup and breakdown time might be too much for those purposes.
Other than that there were a lot of interactive screens with quizzes or small games that showed some current research being done. The biggest drawback of these is that they could only be used by one person at a time and the quizzes and the small games usually took up around 2 to 5 minutes. It works in a museum or on an open day but again not very well in a school visit

situation.
The next interesting thing I saw was a giant board with a projector and an infrared camera pointed at it. To interact with the board you had to put planks of wood with different pictures on the board, the infrared camera then picked up reflective dots on the planks of wood and the placement and amount of the dots determined the position, rotation and content of the planks of wood. This installation was very large but also very interesting, since the only important parts are the planks of wood and the projector + camera it could be very easy to store and set up since all you need is a flat surface. It was also an interesting way to interact with the installation with the physical interaction of picking up and placing the wooden planks.
One of the coolest things I saw was a very simple setup of three giant buttons that were see-through, with an object underneath that signified the choice. This is a nice way to get people to press a button without having to label it. All in all the installations in the museum were very large, this is due to them being almost permanent and thus do not need to be moved often. Museums also use multiple large open rooms for their installations so, the need for small devices and the like is not very needed. The last thing I noticed is that most interactive things were very simple, one action resulted in one result or there was only one variable that you can change.

2.2 science education youtube

On YouTube many youtubers talk about multiple different STEM subjects, this of course also includes electrical engineering. YouTube is a visual medium and many YouTubers use this to their advantage to show easy-to-understand demonstrations and models to aid them in their videos.
YouTuber Steve Mould [1] for example has made a lot of 2d see-through representations of interesting objects that use water. This 2d representation of a Pythagorean siphon for example [2]. He also has a couple of videos on electricity where he shows some simple experiments one of which being a very simple motor [3]. The most interesting for this project is him showing [4] a product from a company called spintronics [5]. This company made a modular circuit-building product that uses analogous components like a spinning weight for inductance and a harder-to-turn component for resistance to show electricity practically.
Another interesting video this time from the channel AlphaPhoenix [6] shows electricity going through the path of least resistance using a maze made out of aluminium foil and a thermal camera. Putting electricity through the maze resulted in the quickest path through the maze heating up and showing on the camera, He also built an analogous maze using water where the correct

path was shown using the water current flowing through the maze.

2.3 open days

Since the demonstrator is going to be used in the open days, it would be good to attend this year's open days and see what the structure of the open days are as well as to see what is already out on display. The UTwente open days is a two-day event that is structured in chunks, with alternating presentations from different studies and free time to go around the campus and visit the tables from specific studies in order to ask more questions.
Additionally, the electrical engineering study has a small space where they display a project for every module. The electrical engineering presentation was also visited in order to get an idea of how the EE bachelor is being promoted. This might lead to some important design wants or needs that can be integrated into the final design.

Looking at the demonstrations now being presented at the open days gave me a good idea of the general things that could be improved. The small display space for the electrical engineering study was filled with a project from every module. With some miscellaneous things sprinkled in like a Tesla Coil and a microscope with a very small chip underneath. The projects were very nicely explained on the wall behind the demonstrations but very few actively worked and of those that worked, most needed some assistance to start up the device. It would thus be good to have a design that can work entirely on its own.
One part of the presentation gave me a very good point to add to the "would like to" section of the ideation and that was that the study focused on team/group-based learning and work and it would be nice to potentially have that reflected in the final design. But that might not be feasible and that is why it is in the would-be-nice section.

2.4 sub fields and applications of electrical engineering

The research question specifically states that the demonstrator has the purpose of educating and exiting about the field of electrical engineering as a whole. It would thus be wise to identify what a student can do after their studies and how that can be integrated into the project. There are many directions that students can go after completing the electrical engineering bachelor, in order to potentially get an idea of what to show with the final design it will be good to orient on the subfields of electrical engineering. When looking online the 5 most often named subfields are: power engineering, control systems, communications, electronic engineering, and microelectronics[7][8][9][10].

Power engineering is the subfield of electrical engineering that deals with generating, transmitting, and distributing electricity. The generating part of power engineering deals with the generation of electricity. This means the conversion of different types of energy into electricity. These include but are not limited to wind energy, nuclear energy, solar energy, and energy from fossil fuels. the transmitting part does the transportation of electricity from the power stations to the general consumer, this means they are responsible for the high voltage cable system and the power grid. the distribution part is responsible for converting the high-voltage electricity from the grid into a usable voltage and distributing the electricity throughout people's homes. They are responsible for connecting the sockets and installing the fuse box.[11]

Control systems are the subfield that deals with systems where the output is in some way controlled. This is done using various inputs that can depend on the output but do not have to. A very recognizable and simple example is the cruise control of a car where the output is the target speed of the car and the inputs are the current speed of the car and the correction speed. A control systems engineer is responsible for analyzing a system and designing a control scheme that manipulates the input in order to get the desired output. [12]

telecommunications is the subfield that deals with the exchange of information over large distances, this can be done using various mediums like fiber, cable, electromagnetic radiation, and many more. The biggest example of this is the internet with its use of WIFI and fiber optic cables to connect the world together. [13]

electronic engineering is the subfield that is concerned with the design of electronic devices. This is seen in daily life with electronic devices being everywhere. Devices like coffee makers, computers, and any other device that uses electricity in some way. [14] It is also the subfield that most people first think of when they imagine electrical engineering.

microelectronics is the subfield that goes small and deals with small electronics like microprocessors and other chips, in this subfield an electrical engineer designs and makes these chips that are used everywhere these days with the most common examples being computers smartphones, and many other appliances.[15]

2.5 literature research

2.5.1 The different types of demonstrations

Two overarching types of demonstrations have been identified. The first type is the demonstration set up as an experiment as outlined by MacKay et al.[16] where the student participates in the demonstration and has to use the results of the demonstration to reach a conclusion on the subject that is taught.
This type is also used in Loren[17] where the student has to change the setup until an easy-to-work-with data point is reached and the final result, which in this case is the speed of sound, can be calculated. A variation of this comes up in T. Mimi[18] where the students are instead asked to gather data before the demonstration, this data is then used in order to demonstrate to the students how to work with the data and the results of the data analysis. Another variant of the experimentation type is the watch the experiment type as put forth by McGuire et al.[19], where the students watch an experiment being carried out but do not get data to do research or find conclusions. The students instead listen to the demonstrator explain the experiment and the results while they carry out the experiment.
This previous paper can also fit in the second type of demonstration namely what is henceforth going to be called the watch and learn demonstration. This type works by having the students watch the demonstrator doing the demonstration with no expectation on the student to do any extra work but instead learn through the talk given during the demonstration and ask questions about the lecture material or the demonstration itself.
The paper from Chan[20] uses representational models of various internal body parts to show what they look like and demonstrate how they work while talking about them, the students can then ask questions that can then be answered using the models. This way the demonstration acts as a helpful resource to aid the lecture. Similarly Vongsawad et al.[21] also uses the demonstrations to supplement the lecture, however in addition to seeing the demonstration like in the previous case Vongsawad et al. also uses other senses to have the students engage with the demonstration, in this case, for example, the participant feeling the vibration of different fundamental frequencies of sound.
Blackley et al.[22] uses this type of demonstration as an intro to the lesson after which the students will try to replicate the device demonstrated in their own way, it starts out as a watch-and-learn demonstration and turns into an interactive lesson where they have to make their own device in their way.

2.5.2 The ways demonstrations can be engaging

There are many ways to engage the students in the demonstrations. The most common way is to ask the students questions and have them do related exercises.

Chan[20] finds that the demonstration makes students more likely to ask and answer questions when the demonstration is in use. Similarly, the student's input can be used in order to change the input of the demonstration like Vongsawad et al.[21] does by using a microphone and a spectrum analyzer, the student can see the sound they make immediately, thus inviting the student to try different sounds.

Another way to use input is by the use of polling like it is used by Schmid et al.[23] where they poll the participants on their knowledge of the different kinds of ice cream. Overduin et al.[24] also ask for suggestions on what variables on their boat to change thus making the students think about what effect these changes would make and engaging them in the demonstration. Although similar Mimi[18] has the students collect data beforehand, since their data is going to be used in the demonstration the students will be more interested to see what has been done with their data.

Ahmed et al.[25]does not have specific demonstrations but does outline four different levels of engagement used in lessons. These are: individual projects, group projects, short topics that change often and hands on learning. For use of a demonstration the best type of engagement will be hands on learning and group projects as used by Blackley et al.[22] where the students engage with the demonstration by making their own version of it. While this is going on they are also asked various questions and are being encouraged to collaborate with their fellow students. Very different from these is the use of visually interesting events as used by McGuire et al. [19] where the reactions used are very fun to look at like the fire column from the thermite and a cylinder of carbon from a H2SO4 with sugar reaction.

2.5.3 Educating using demonstrations

There are many ways that demonstrations can be made educational. For example, a very effective reason to use demonstrations for education is as quoted from Chan[20]: "The mid-gut apron is a more versatile method of demonstrating mid-gut rotation than animation since the apron allows manipulation in unplanned ways, e.g., rotation in the wrong direction, to different degrees and at different speeds, thus allowing learners to explore the concept in different ways.".

The study from Loren[17] finds instead that asking questions about the

demonstration like in this case calculating the speed of sound helps a lot due to the students being active participants. Mimi[18] also finds that the students learn a lot through active participation and experience, often asking questions about their gathered data like discussing what they would say counts as a shoe to name a demonstration-specific example.
The study Ahmed et al.[25] puts forth that: "STEAM education benefits have been widely documented Taylor[26] to support student engagement in transformative learning". STEAM in this case meaning the addition of Arts in the STEM(Science, Technology, Engineering, Mathematics) field. Lastly, the use of demonstrations can be effective due to the use of already familiar objects to connect the known knowledge of these objects to the unknown of various taught topics. This can be done by using these objects in a way that connects the concepts being taught to the object at hand, using ice cream to teach participants about really cold liquid nitrogen for example since both are cold Schmid et al.[23].

2.5.4 Showing intangible and theoretical concepts physically

There is one way identified to show intangible and theoretical concepts physically and that is by visualizing them in some way, the way of visualizing however varies. Three ways have been discovered.
The First way to do this is to show the effect of the concept like in Vongsawad et al.[21] where the pressure differences of sound make a candlelight move thus showing the nature of sound through the moving candle. Overduin et al.[24] also demonstrates the effect of the underlying electric principle used by making a boat move using just electricity and magnets, the fact that the boat moves because of that demonstrates the effects of the mechanism inside.
The second way outlined in Loren[17] is to make a change in the demonstrator and show the effect of that change, the difference between the initial condition of the demonstration and the changed condition will then show the concept being taught.
The third and last way used by Chan[20] is to use a representational object to show the concept. This can then be used to show in a general way how the concept works.

2.5.5 conclusion

The purpose of this review was to find out how to educate people about intangible and theoretical concepts in an engaging way using demonstrations. Although there are many different types of demonstration the most common type was the experiment where the student had to gather data during the demonstration and use that to answer additional questions. The other common type was the watch-and-learn demonstration where except of having the students be asked and asking questions in the moment, the students only had to watch the demonstration unfold.

In order to engage the students in the demonstrations the research found that the most common way was to ask questions about the demonstration. One study found that the demonstration does make students more likely to ask and answer questions Chan[20]. Another way to engage students was to involve them in the process before or during the demonstration. Lastly, one study found that students are engaged when the result is visually interesting.

When engaged in the demonstration the student can learn a lot. One study found that due to the nature of the demonstrations, many unintended and edge cases could be performed thus increasing the potential to learn new things. Connected to the experiment type, having the students engaged in the demonstration by having them do work before or after. Increased the likelihood of asking questions and getting more experience with the subject of the demonstration.

In order to create more understanding some concepts need to be shown better as they might not be as intuitive as when someone sees them with their own eyes. The best way to do this is to visualize the concept that needs to be shown. This can be done in three ways. The first way is to show the effect of the concept being demonstrated. The second way is to show the concept by changing the demonstrator which changes the output thus showing that the concept that needs to be taught is there. The third way is to use a representational object to show the concept in the real world.

Unfortunately, only ten papers ended up being reviewed, and although they are all in one way or another relevant to the review not all of them are about demonstrations specifically. This might skew the result of the trend of the types of demonstrators in one direction like the experiment demonstration or there might be many types of demonstrations that do not show up in this review.

The results can also come out as very varied like in the sections about educating and showing intangible concepts. There were very few clear trends discovered in those sections with loads of different ways of doing things discovered.

The first recommendation for another review is thus to include more papers especially those about demonstrations that show intangible and theoretical concepts. This might make certain trends in types of demonstrators more clear and can give more ways to create a better understanding of intangible and theoretical concepts.

The papers were, for the most part, also very subjective with a lot of opinions based on anecdotal evidence without any scientific data to support the opinions given by the demonstrators. The second recommendation is then to do more scientific research on the various demonstrations found in this review and how educational and engaging they actually are.

3 Design method

The design method used was a design process for creative technology[27]. This process uses a cyclical design strategy with four distinct phases: ideation, specification, realization, and evaluation.
The first phase, ideation, is made up of research that will act as a source of inspiration. This can mean getting a better understanding of the topic of the demonstrator like researching the potential jobs or subfields one can go in after the bachelor of electrical engineering or finding similar or related work by visiting a museum since museums do a lot with installations and demonstrators and the like. All of this background research serves the purpose of generating inspiration that can lead to good ideas when brainstorming.
the brainstorming can then start after doing most of the background research. And identifying most of the requirements suggested by the stakeholders (see ideation). Brainstorming consists of combining and trying out different designs based on the inspiration gotten from the background research, an installation of the museum can for example be combined in some way with an identified subfield to create a multi-stage exercise with separate parts that combine to create a full experience that has to do with the chosen subfield.
The next phase is the specification phase where the chosen idea will be worked out more and low-level functional prototypes will be made to see if the components can work together to get the intended result. Only focusing on if the basic idea will work. If not the project will move back to the ideation phase to choose a new idea.
The phase after that is the realization phase, this phase is where the final design is built as a high-level prototype. After the evaluation phase, it is improved or changed to fit the requirements and any concerns raised by the evaluation. After evaluation, the prototype will be upgraded to an actual professional-looking design.
During the evaluation phase, the prototype will be evaluated by the stakeholders in order to get an outsider's perspective on the project. This can identify problems not seen by the student and raise concerns that might be missed during the previous phases. This is not to say that this is the only time for evaluation but it is the phase where the evaluation and feedback are more elaborate.

4 Ideation

4.1 stakeholders

During the background research, the stakeholders were also identified. These are the following:

1. the prospective students
   These are the people who are expected to interact with the device and potentially be convinced to enroll in the electrical engineering study.

2. the parents of prospective students
   As they usually accompany their children they will interact with this device too and do have some influence over the choice of their children, even if it is just as suggestions.

3. the supervisors of this project
   They represent the bachelor of electrical engineering. They want a working demonstrator. Or at least the plans to make a working demonstrator.

4. the helping students that set up and supervise the device.
   The device is only used on occasion and stored somewhere when not in use. This means that there will be people who need to get the device from storage and set it up on-site. They also need to be supervising the device to make sure that it does not break.

4.2 requirements

The ideation process started upon being accepted to start this project, using just the first prompt of an electrical engineering demonstrator and the initial requirements and limitations from the supervisors. Those being:

1. The device should be small/portable.
   The device should be easy to store and easy to take somewhere else if required. An example of a potential size is to make it small enough to store in a standard closet. since it needs to be carried places it will need to be sturdy too and not break as you pick it up.

2. The device should be interactive
   Participants are more engaged when actively participating in a demonstration. Making the device interactive then results in a more favorable impression of the EE study.

3. The device should be self-explanatory or be explained using a simple poster or piece of paper.
   This requirement lessens the need for an additional observer to explain the device every time someone comes by.

4. The device should reflect the field of electrical engineering.
   The device is for the electrical engineering study and as such it should incorporate electrical engineering in some way, shape or form.

5. The device should be safe or have safety features built in.
   Since people are expected to interact with the device, they should not get injured while doing so.

6. The device should be self-controlled, using for example an Arduino, and not require external hardware like a laptop to run.
   This decreases the needed set-up time and reduces the needed additional components that need to be sourced in the days before an open day.

Additionally, a soft requirement was added. This is a requirement that the supervisors would like to have but can be left out if needed.

1. The device should be for medium to large groups.
   The device will be used during either open days or school visit days. Both of these have the potential to attract a sizable audience, all looking at the device at once.

new requirements

After doing the background research and identifying the stakeholders new requirements were identified and added to the list. They are the following:

1. The device should be easy to repair.
   The device will be handled a lot of times. Although it would of course be best if it never broke, that is hard to make. So instead, to preserve the sanity of those working with the device, the device should be easy to take apart and use materials that are easy to replace.

2. The device should be designed with the background knowledge of the potential students in mind.
   Since the study has specific requirements of what subjects are required before being able to do the study. The prospective students will already have some knowledge about electrical engineering and do not necessarily need to have that taught to them again.

One more soft requirement was identified and is written below.

1. The device could have a multiplayer or teamwork feature built in. Since the EE bachelor uses a lot of team-based learning it would be good to have this be reflected in the final design.

4.3 idea generation

The idea generation phase started before doing the background research. These ideas mainly focused on showing what electrical engineering is and how that can be shown to people. The ideas also were designed within the initial requirements set by the supervisors (see first section requirements).
After the background research, a small brainstorming session was held where the ideas also used inspiration from the background research. The various sub-fields of EE or the museum visit as examples. These ideas also had an expanded selection of requirements that resulted from the background research (see second section requirements).
It would be useful to have at least one idea/design that could be related to every subfield mentioned in the background research. This is to get a wide variety of ideas that will be able to be refined and used in the future. This process resulted in the following list of ideas which are further explained below the list:

ideas from before the brainstorm

- Guess the appliance game (electronic engineering)
- Wireless communication installation (telecommunication)
- Transistor maze game (micro-electronics)

ideas from the brainstorm

- Power engineering diorama (power engineering)
- Sensor playground (electronic engineering)
- Analog control system (control systems)

4.3.1 Guess the appliance from the circuit board

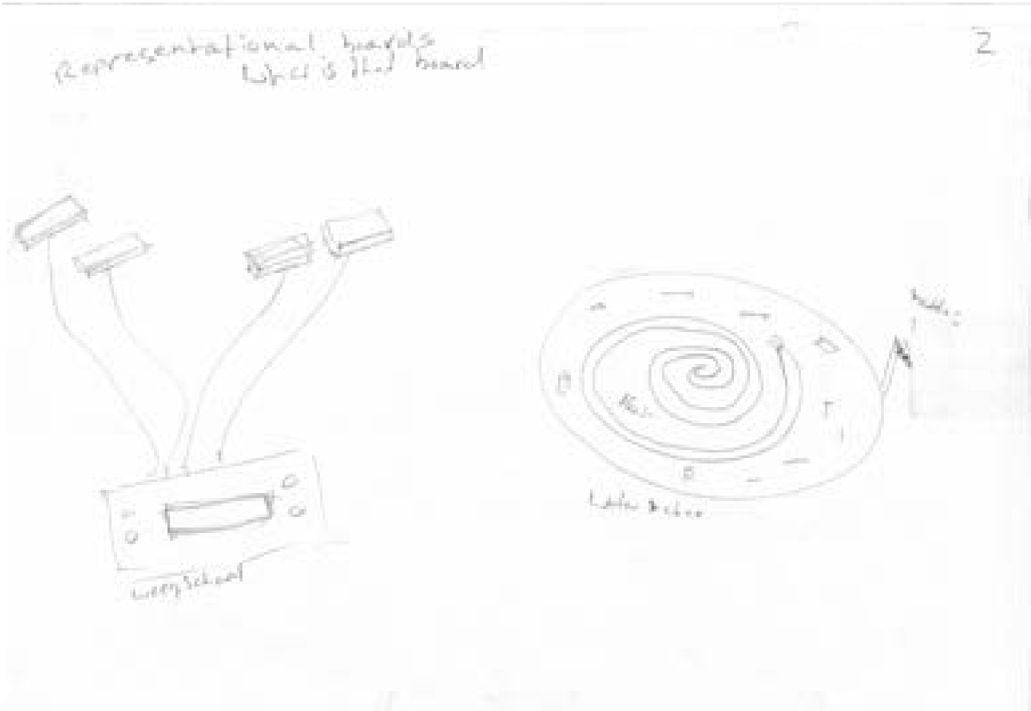


Figure 1: Initial design for a demonstrator to show the inside and working of various electrical appliances

This is an idea for a demonstrator that shows the common places you can find electrical engineering in day-to-day life via an investigating/guessing game. The demonstrator is made up of abstracted interactive circuit boards that are taken out of recognizable everyday appliances. These circuit boards still have their functionality but they are scaled down. Otherwise, some circuit boards would require high voltages which is very impractical and potentially dangerous.

As an example, on the left of the sketch in figure 1 is a taken-apart scale. Just looking at it does not tell a participant anything. When they press on the aluminum blocks, however, the scale will output a number on the display. The participant should then realize that this is the circuit board for a scale.

4.3.2 Wireless communication installation

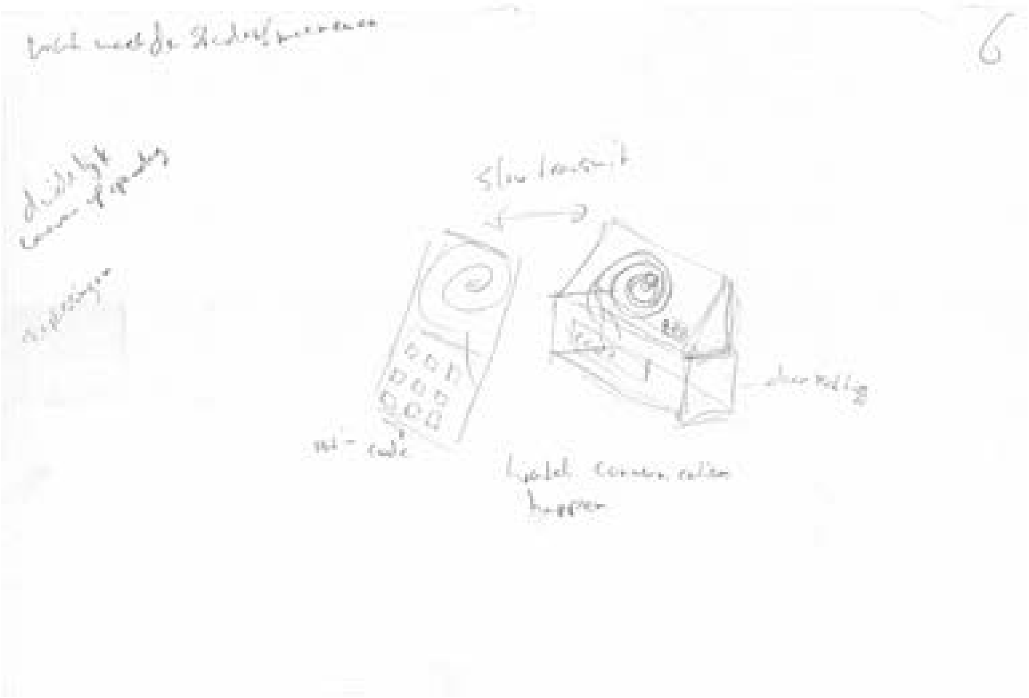


Figure 2: initial design for a demonstrator to show how wireless communication works

The idea for this installation is to show wireless communication in action. This can be done using a wireless keyboard or any other input device. Pressing a key on the chosen input device shows the information that gets transmitted when someone does that using an array of LEDs.

4.3.3 Transistor maze

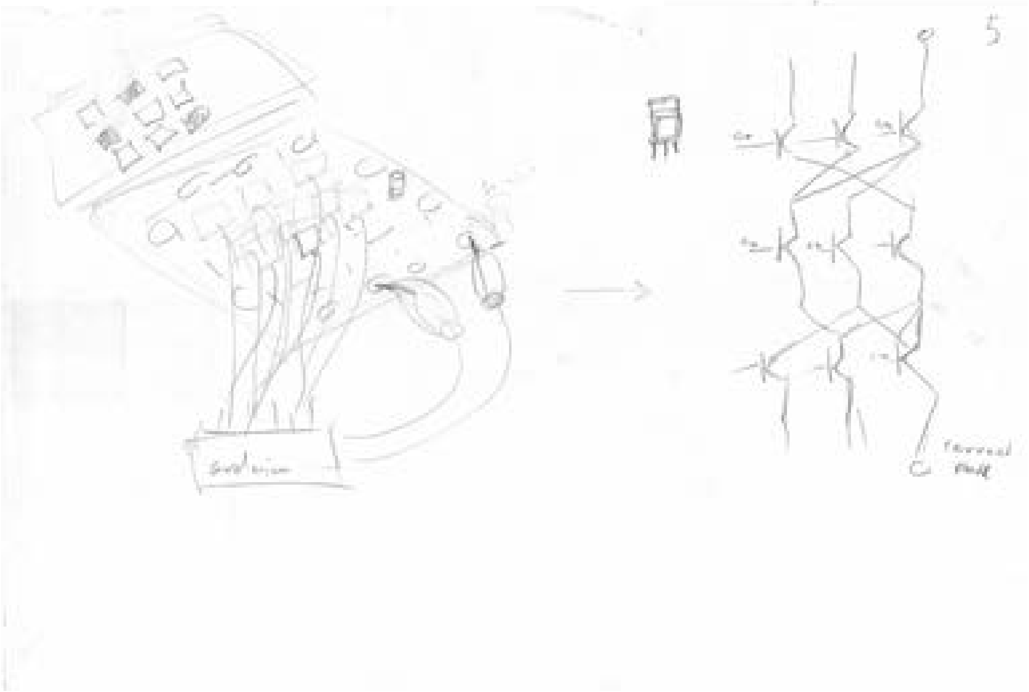


Figure 3: initial design for a demonstrator as a fun experience with something someone can do with electrical engineering

With this demonstrator, potential students get into contact with a large part of electrical engineering in a fun way. This is done via an interactive game where the participant has to solve a maze. This maze is made up of various wires, transistors, and other common electrical engineering components.

The board is made up of an array of transistors that are connected to: each other, a microcontroller, or a ring of conductive patches in a certain as-of-yet undecided way. It also has a screen with a circuit diagram. When the game starts the microcontroller turns a couple of transistors that are connected to it on or off. It also shows those transistors on the circuit diagram. This connects two patches.

The participant has to find the two connected patches and touch them with two conductive probes to complete the circuit. They do this by studying the circuit diagram and relating that to what they see on the actual circuit board.

4.3.4 Power engineering diorama

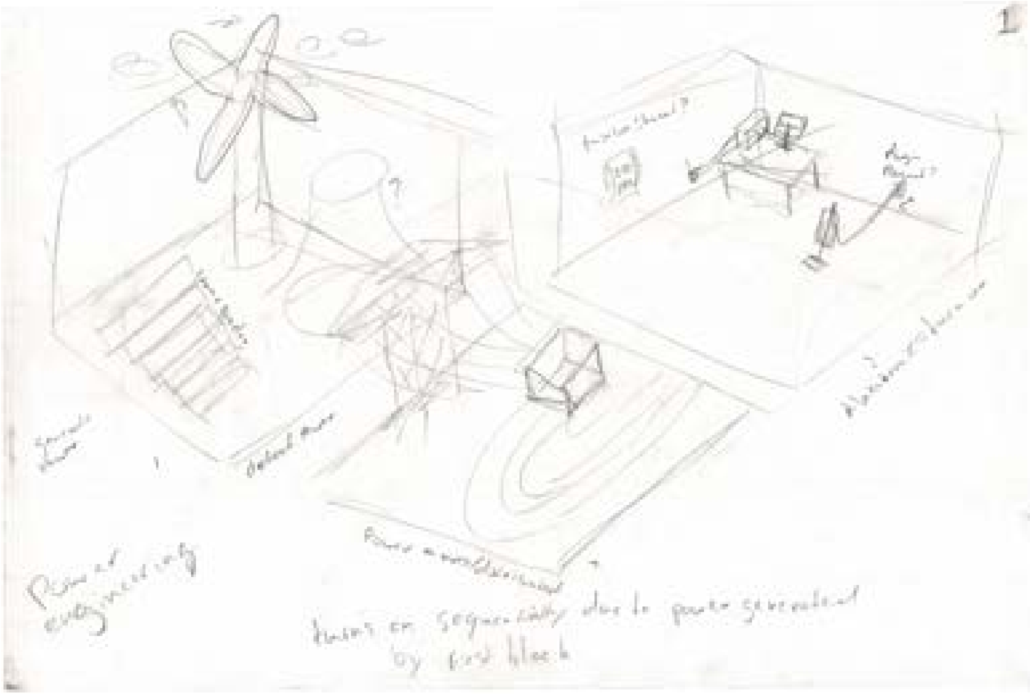


Figure 4: initial design for a demonstrator to show power engineering

The first idea is a 3 part small modular diorama made up of modular components that show several stages a power engineer can go work for. These stages are the following:
The first stage is the power generation stage. This stage will show multiple ways to generate the electricity we use today as well as some unconventional ways to do it. The ways we generate energy today can mean wind turbines or nuclear power plants, and unconventional ways can mean using piëzo-electric crystals to harvest energy from walking[28] or by using bio-voltaics[29].

Second is the grid system that distributes the generated power to the buildings that require it. This will show the impact of various types of infrastructure on the capacity and needed energy of the grid. This infrastructure can include houses with or without solar panels, various types of industry, and office complexes.

The third stage is the distribution inside a general household and the impact of different household appliances. It will also show the way this is dealt with inside a house. Connecting a lot of power-hungry appliances could for example virtually trip the breakers. Different appliances could also be compared by connecting them at different times and seeing how that changes the energy consumption of the household.

4.3.5 Sensor playground

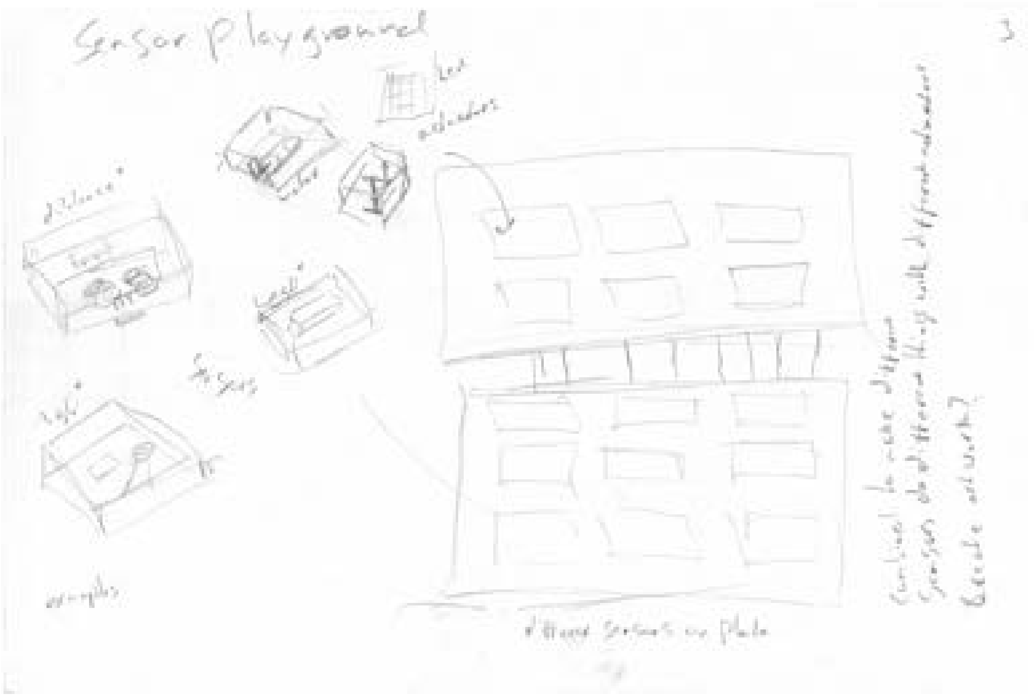


Figure 5: Initial design for a demonstrator to get people to experience building a simple circuit with little needed background knowledge

There are enough people who think Electrical Engineering is boring that a LinkedIn article was written calling that "the number 1 myth around EE."[30] The idea above is then designed to get people on the creative side of EE. It also adds a touch of Art to a STEM subject turning it into STEAM. This is beneficial when exciting and educating people about STEM subjects[26].

The device is a modular sensor playground. A participant can add sensors like a distance sensor or temperature sensor on one side and actuators like a linear actuator or an array of LEDs on the other side. Doing this connects the sensors to the actuators. When activating the sensors, the actuators activate and do something depending on what activator was put where and what sensor connects to it.
Changing the perceived distance in front of a distance sensor can change the color of the LED array for example. This can even be changed to have multiple sensors affect one actuator for more interesting control.

4.3.6 Analog control

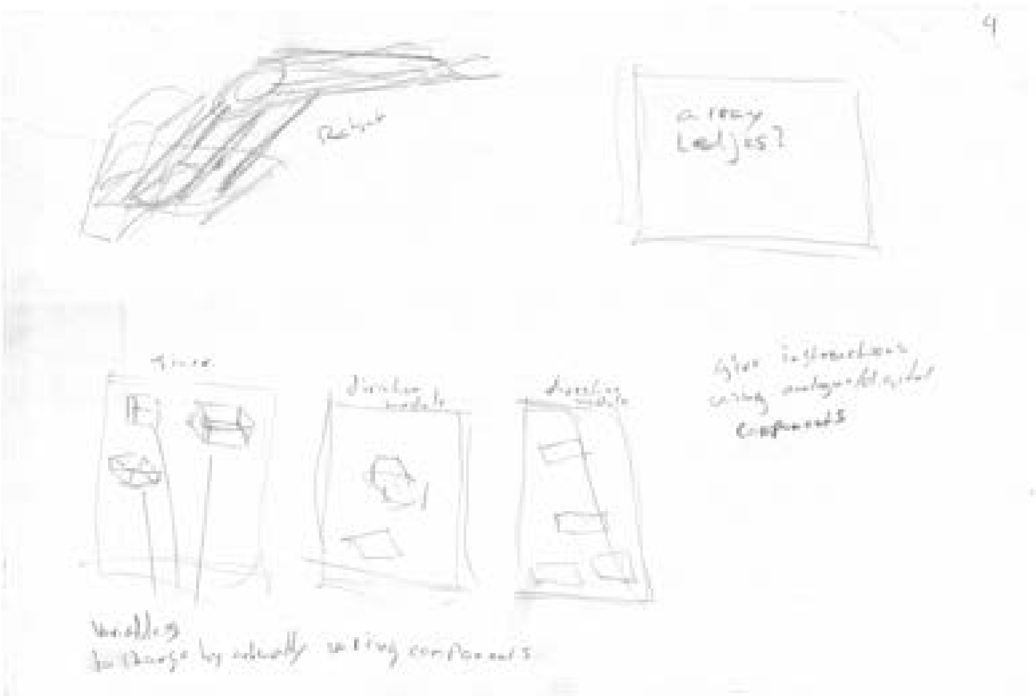


Figure 6: Initial design for a demonstrator to show the interesting world of analog components

This idea is similar to the sensor playground in both the modular aspect and the goal of getting potential students in contact with EE via an experimental and creative process. In this case the subfield of control engineering and analog electronics.

The idea is to have an array of modules containing a formula using analog electronics[31] that a participant can then put together in some way to control a little robot, LED square, or any other controllable device.

Essentially the goal of this device is to have people complete an interesting and creative exercise that promotes experimentation with directly visible results.

5 Specification

After the brainstorm explained under the headline: idea generation, a final idea had to be chosen. Both the requirements set and some additional considerations were used to make a final choice. These were then scored 2 to -2 based on the predicted ability to fulfill the requirements. This resulted in the table 1 below:

requirements	guess the appliance	wireless communication	transistor maze	power engineering diorama	sensor playground	analog control
small /portable	2	1	2	2	1	1
interactive	1	1	2	1	2	2
self-explanatory	1	-2	0	-1	2	2
representation	2	-1	2	2	0	2
repairability	2	1	-1	2	2	2
time requirements	-1	2	-2	2	-2	-2
educational	-1	0	1	2	1	2
enjoyment	2	0	2	2	2	2
final result	8	2	5	12	8	11

Table 1: The score of every idea based on the requirements from 2 to -2

Some requirements are not included in the results because those requirements were all the same. They did not impact the final result and were thus removed to make the table more clear.
The first 5 requirements are taken from the ideation phase. For more explanation of those requirements see the subsection requirements under Ideation. The last two requirements are based on the problem statement. The problem statement states that the demonstrator needs to be both educational and exciting.
For the scoring of time requirements, multiple considerations were made.

1. Time left to build the prototype. The initial projection of the time required to build the prototype was 4 weeks.

2. Ability to build the prototype. It would not be good to have to experiment with one aspect of the prototype for 3 weeks and still not succeed.

3. Amount of things that need to be done. The prototype should not be made of a million little parts that all take an hour to make since there is not enough time left to do all of that.

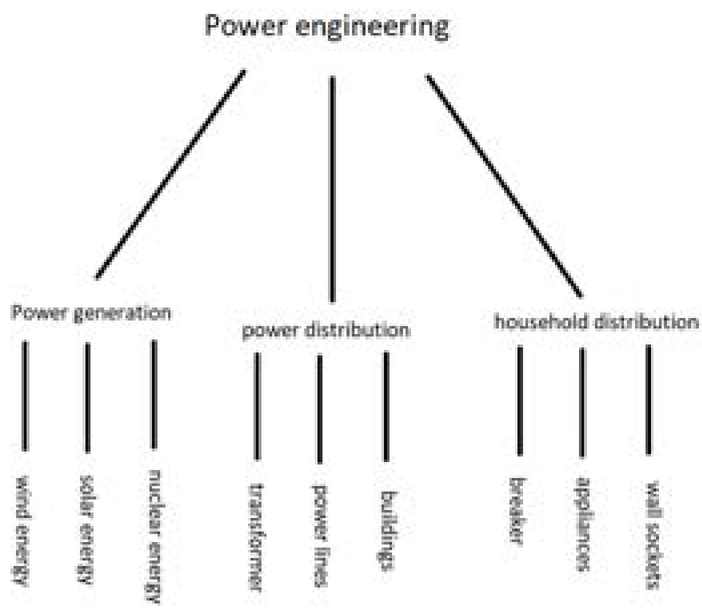


Figure 7: A simple tree graph showing what the subfields of power engineering are, with examples of various components of that field

The final chosen design is the power engineering diorama. The full design is made up of 3 separate platforms. Each of the platforms will display a section of the power engineering sub-field. The subfields and some keywords attached to them can be seen in figure 7 above. The final idea can be seen in figure 8 below.

A large part of the idea had to be left out due to various reasons. The home distribution platform was let out due to the huge leap between the power generation and electricity net platforms. To give an idea of the scale just for the Netherlands. The average production and consumption of the Netherlands is around 10000 million kWh per month.[32] The average household consumes around 290 kWh per month[33]. That is a difference of 999 999 710 kWh. This difference might make it very confusing so this platform was scrapped.

The other electricity distribution platform is left out due to time reasons. The four weeks left to build and test the platforms did not leave enough time to do all of them. The focus was thus put on the power generation stage.

The other platforms are still explained below. This allows future work to expand the device to take inspiration from the original idea.

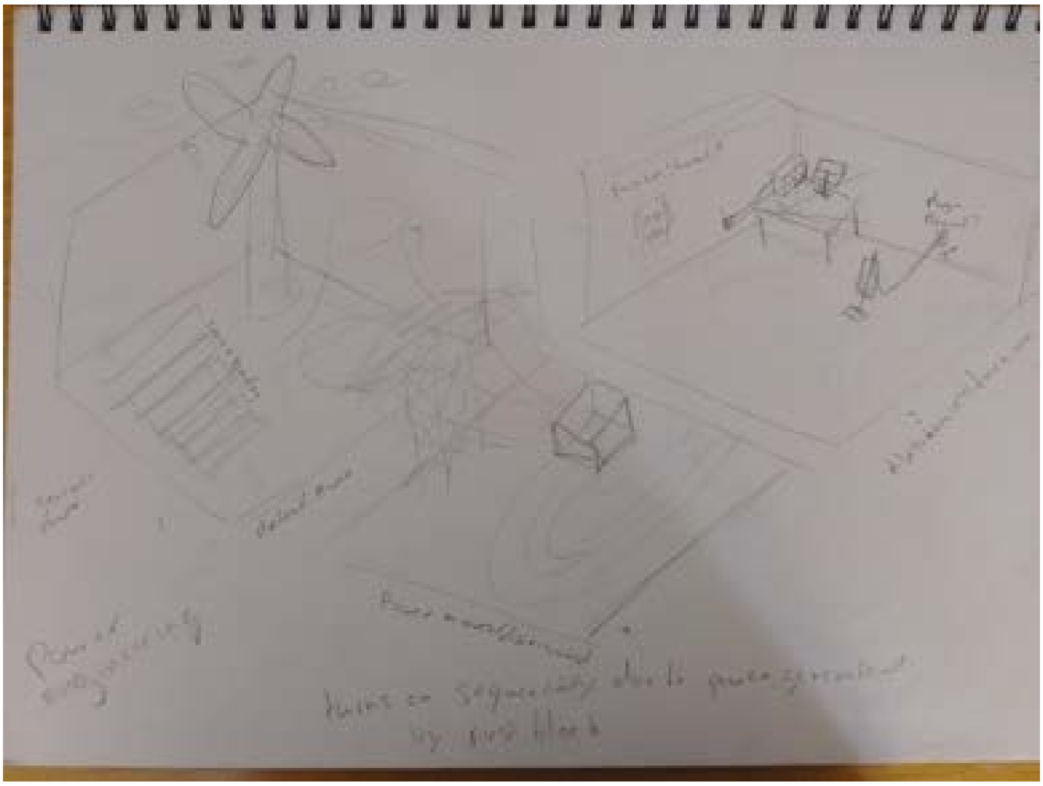


Figure 8: The final chosen idea, showing three separate platforms that have to do with power engineering

Starting with the generation of power. This platform, multiple designs are shown in figure 9, showcases different ways we get power.

This includes the well-known and often used ways[34] like:

- coal
- gas
- nuclear energy
- wind energy
- solar panels

It can also include more new, weird, and novel ways that are being researched and developed. [35] [36]

- piëzo-electric energy

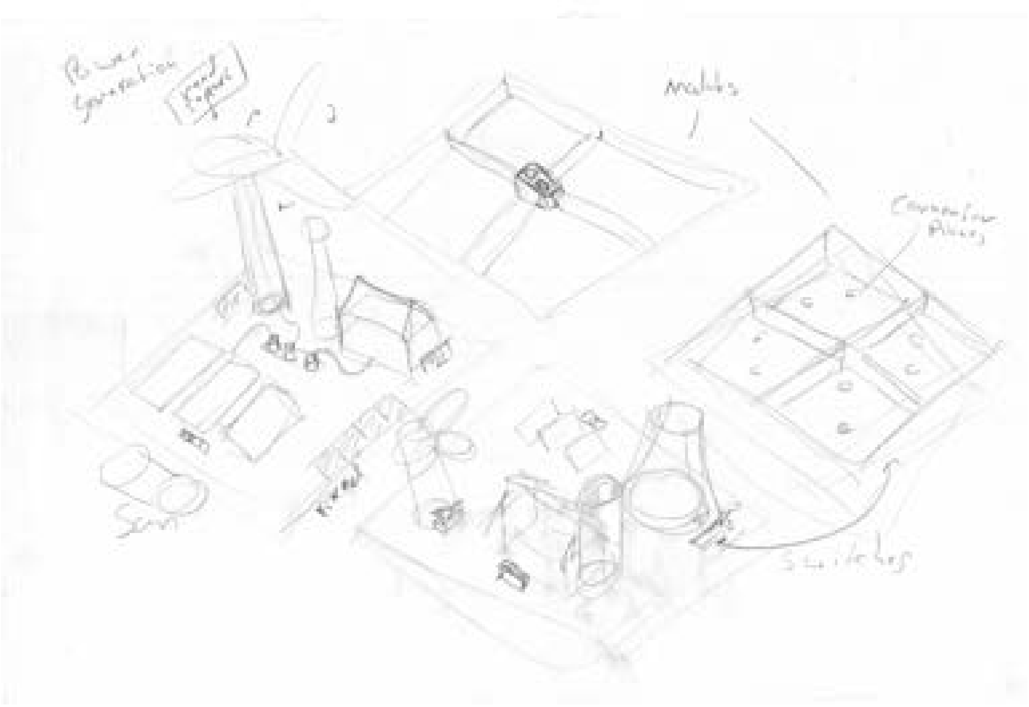


Figure 9: various designs for the power generation stage

- bio-photovoltaics
- rain impact
- humidity

Four different ways of generating power will be chosen. They will be represented as small interactive models. These models will have some form of interaction that simulates how these generators generate energy.
So for example, to show how a windmill generates power, a participant can spin the blades of the model. An array of LEDs will then turn on in relation to how hard the participant spun the blades. More LEDs turned on means more power being generated.

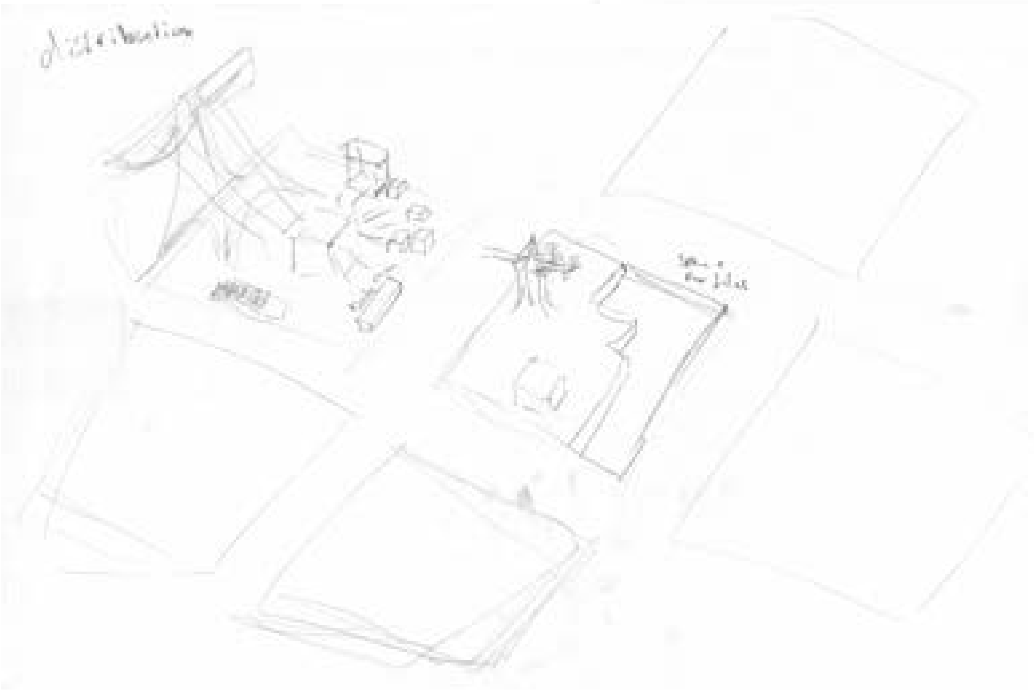


Figure 10: various designs for the power distribution stage

The second platform showcases the power net and how the electricity generated gets around the country. It can also show how different buildings impact the needed capacity and available power on the electricity network. It can do this by using various buildings, such as Data centers, office blocks, houses, or industrial complexes. These buildings all have their own energy needs. Some buildings, like houses with solar panels, can actually put energy back into the network.
Replacing buildings with others impacts the needed capacity of the electricity net. For example take this quote from tierpoint.com: "Data centers, in general, consume approximately 1,000 kWh per square meter. To put these numbers into perspective, this figure is equivalent to what the power consumption would be in 10 average American homes per square meter."[37]
A participant can play around with these buildings and experience what the effect is on the electricity net. Other scenarios can also be simulated. One of the problems that is very relevant at the moment is the overload of the electricity net due to a large amount of solar panels.
The energy produced by these solar panels is very concentrated around the spring and summer and only when the sun shines. When this energy is not

used, it will have to be put back on the net or the solar panels have to be turned off. Both of these cause problems that reduce the effectiveness of having solar panels on the roof of every house.[38]
For extra interactions, this platform can be connected via either cables or a wireless connection to the platform that generates power. This can mean that to keep the lights on in all the buildings on this platform, The participant has to generate enough power on the other platform. This can give a further understanding of the pros and cons of different types of power generation. It can also give the participant a better understanding of how the generation and consumption of electricity work together.

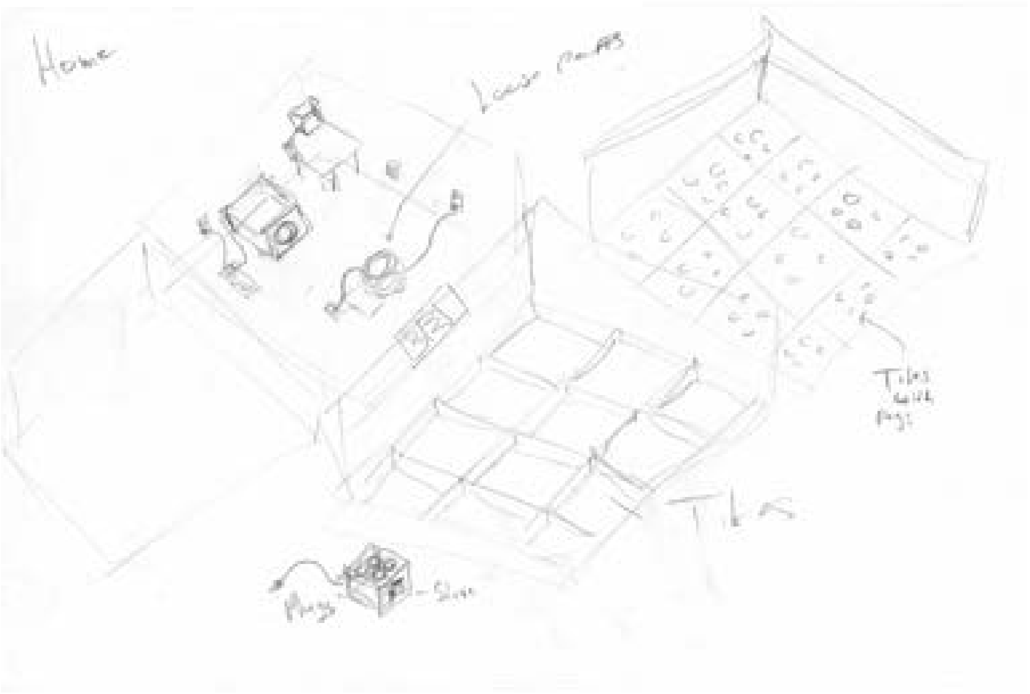


Figure 11: various designs for the household stage

The third and last plateau goes into the distribution of a general household, where the power is distributed into multiple different appliances. A participant can vary the type of appliance by plugging them in the installed plugs. Plugging in too many appliances or a couple of high-power appliances into the same group virtually flips the breaker and cuts off the power of every appliance. If there is not enough power to go around only some of the appliances will start working.

6 Realisation

Figure 12: Various sides of the fully assembled prototype

The final result is one plateau showing three different ways of generating power. The prototype is made up of the following parts:

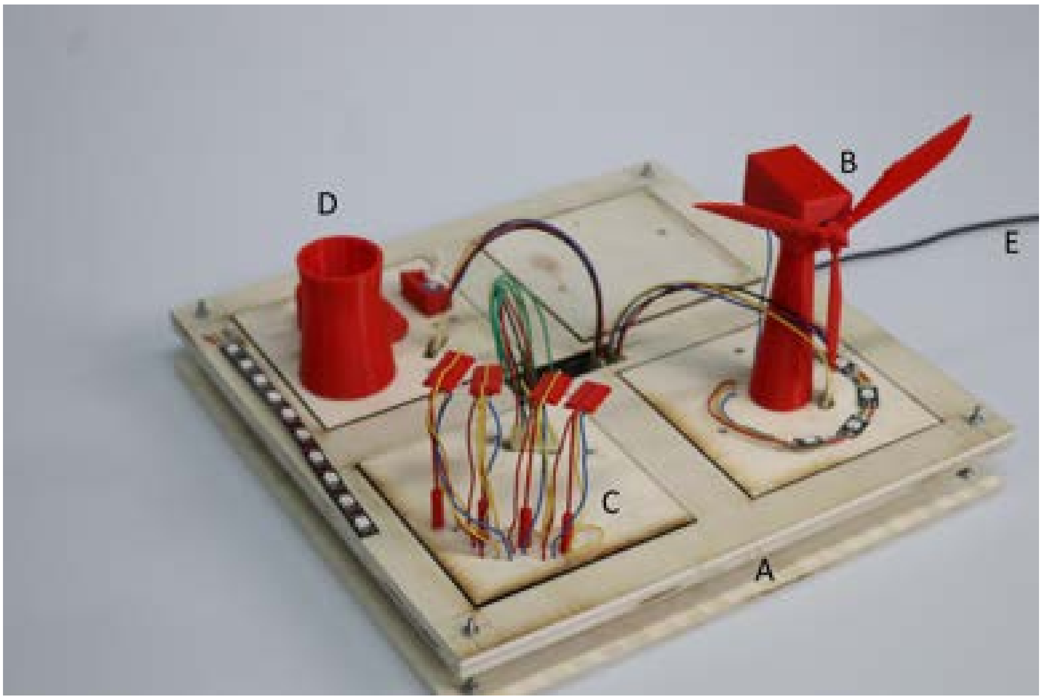


Figure 13: The fully assembled prototype with letters indicating what is what

1. The base plate. (A)
2. The micro-controller
3. A wind energy/windmill module (B)

4. A piëzo electric/stepping energy module (C)
5. A nuclear energy/model power plant module (D)
6. A power supply (E)
7. Code

6.1 The base plate

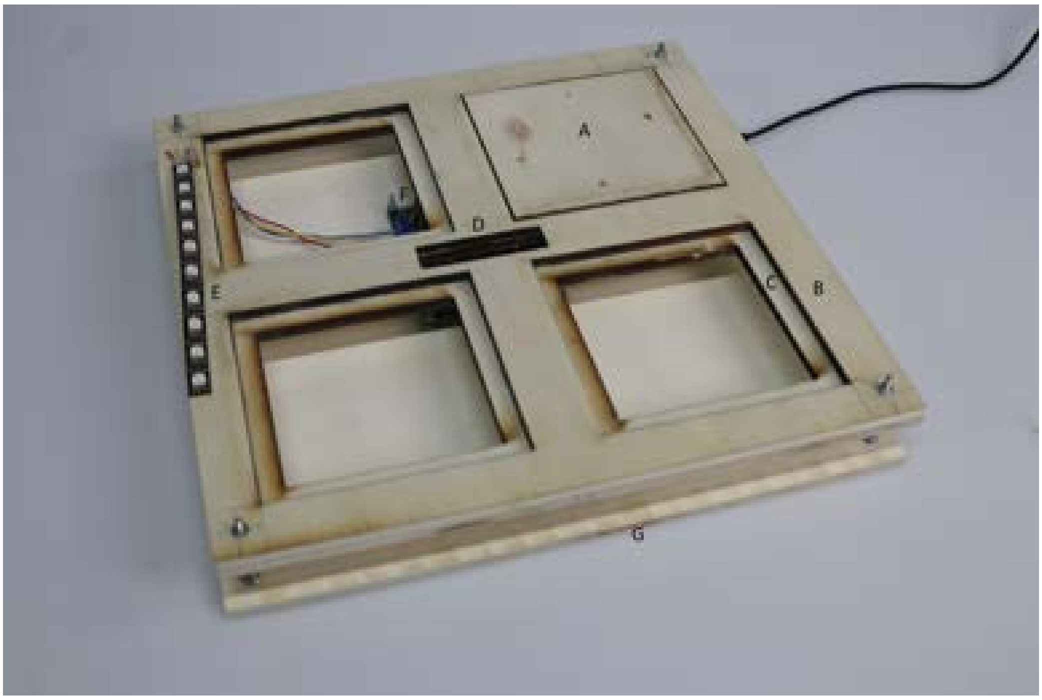


Figure 14: the platform with letters indicating what is what

A The base of a module. It fits snugly into the hole and rests on the wooden edge underneath.

B The first top board. The holes are 110 millimeters (11 cm) in both width and height.

C The second top board. The holes are 90 mm (9 cm) in both width and height. It makes sure there is something for the base of the modules to stand on.

D The middle hole where the cables connect to the microcontroller underneath.

E An additional LED strip that can be programmed for additional information. Currently, it is used for the nuclear energy module.

F A small part of the microcontroller. More about the microcontroller with better pictures under the microcontroller header.

G The bottom board. It holds the microcontroller and the screws used to space the boards apart.

The whole platform is made up of 3 plywood sheets. These sheets are 30 by 30 cm and laser-cut out of one 60 by 60 cm sheet of plywood. The plywood is 6 mm thick. Two of the 30 by 30 cm sheets have an assortment of holes cut out to allow the modules to slot in. The measurement and placement of these holes can be seen in figure 15.

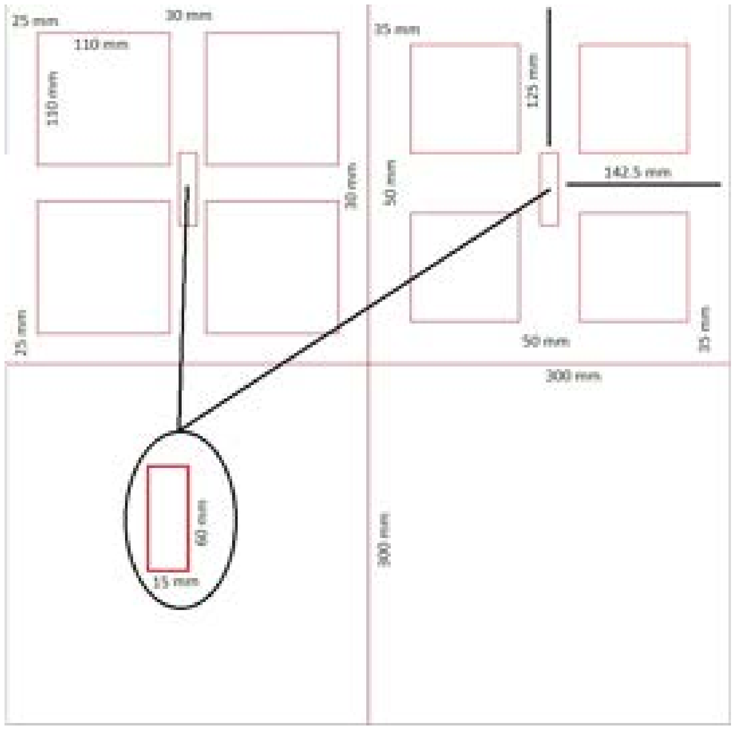


Figure 15: Lasercut file with the measurements of the platform

The two boards that make up the top of the platform (B and C in figure 14) are glued together. This increased the strength and makes it easier to attach the boards with the screws.

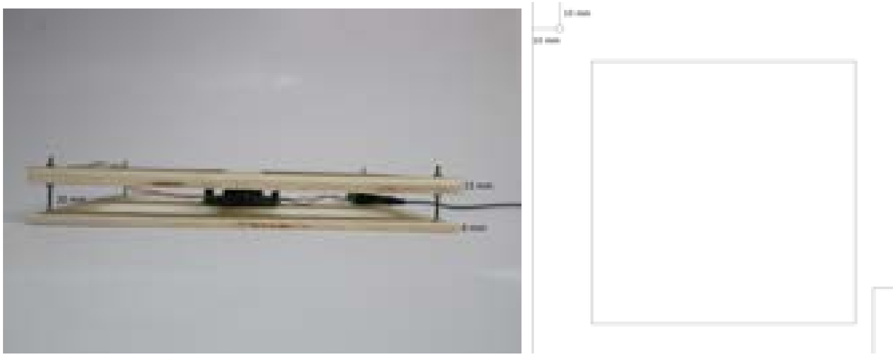


Figure 16: On the left, the side of the platform with the widths included. On the right, the distance of a bolt from one of the corners

The bottom board holds the microcontroller and the bolts that hold the top plate in place. The distance between the two boards is 2 cm. The boards are each 6 mm thick. With three boards that means that the total height of the platform is 38 mm.

The bolts that hold the boards together are 5 cm long, m3 bolts. They are spaced 1 cm from each edge in all four corners. See figure 16.

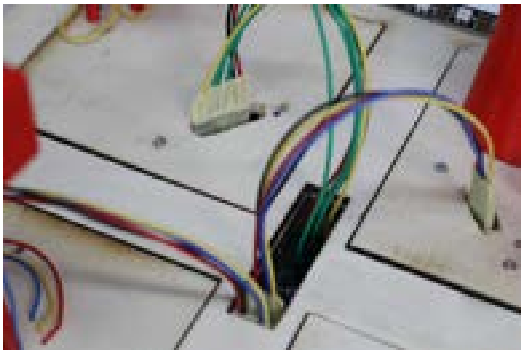


Figure 17: The middle hole that allows connections to be made to the microcontroller

A rectangular hole is cut in the middle of the board. This hole allows connections to be made from the modules to the microcontroller. The exact dimensions are depicted in figure 15

The full table of all the used materials in this prototype is in the appendix.

6.2 The microcontroller

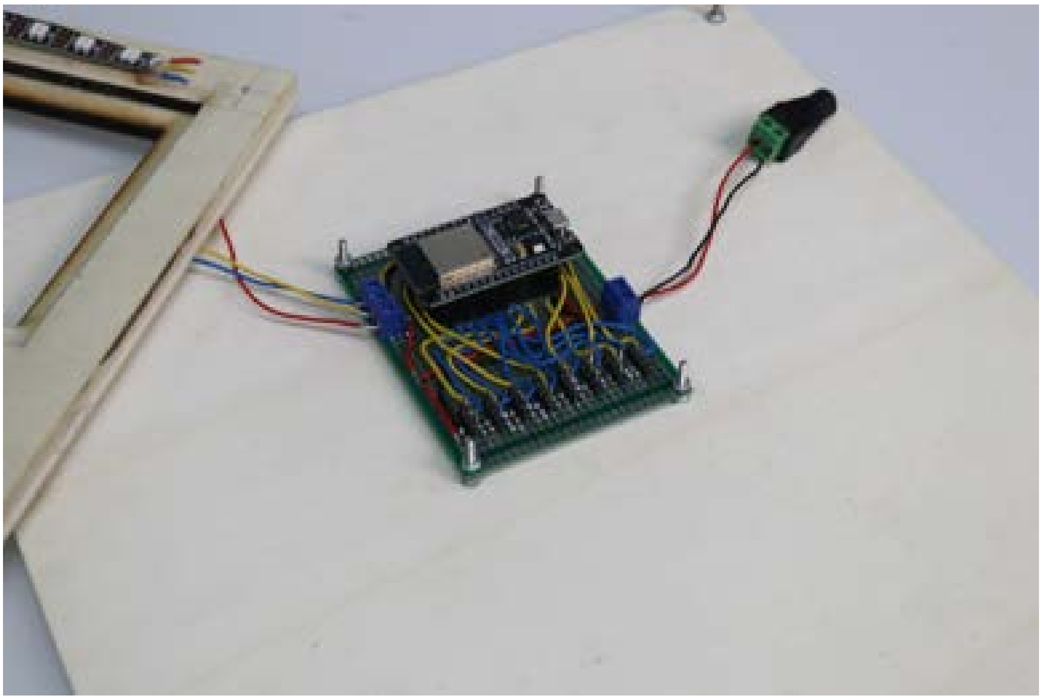


Figure 18: The microcontroller installed on the bottom of the platform

The microcontroller is the brain of the prototype and is used to plug in the modules. Doing this allows the microcontroller to receive signals from the modules and control them.
The microcontroller used is an ESP32 WROOM devkit v1. This is a development board with an ESP32 chip with an easy way to program and power it built in. This microcontroller was chosen due to the large amount of options for various interactions. See reference for full information[39]. Relevant to this project is the possibility of using wireless communication as well as the pin numbers and what their options are.
There are 15 safe-to-use pins that have no special behavior that can inhibit the ESP when used. They can be used for both input and output. There are an additional 4 Pins that are also safe to use but can only receive input. That gives a total of 19 Pins that can safely be used for this project. In the table below are the usable pins and the capabilities relevant to this project. Most of the pins have even more capabilities that might need to be used in the future, in that case, refer to the following reference: ESP32 Pinout Reference[39].

GPIO pin number	I/O	PWM	ADC1	ADC2*	input only
GPIO 4	✓	✓		✓	
GPIO 13	✓	✓		✓	
GPIO 14	✓	✓		✓	
GPIO 16	✓	✓			
GPIO 17	✓	✓			
GPIO 18	✓	✓			
GPIO 19	✓	✓			
GPIO 21	✓	✓			
GPIO 22	✓	✓			
GPIO 23	✓	✓			
GPIO 25	✓	✓		✓	
GPIO 26	✓	✓		✓	
GPIO 27	✓	✓		✓	
GPIO 32	✓	✓	✓		
GPIO 33	✓	✓	✓		
GPIO 34			✓		✓
GPIO 35			✓		✓
GPIO 36			✓		✓
GPIO 39			✓		✓

Table 2: Capabilities of every save pin of the ESP32

*There is a difference between ADC1 and ADC2. Although they serve the same purpose of converting analog signals to digital signals. The Analog-to-digital converter on the ADC2 pins does not work at the same time as the wireless communication. This means that if wireless communication is required they can not be used together. The current iteration of the project does not use wireless communication so currently it is not a problem.

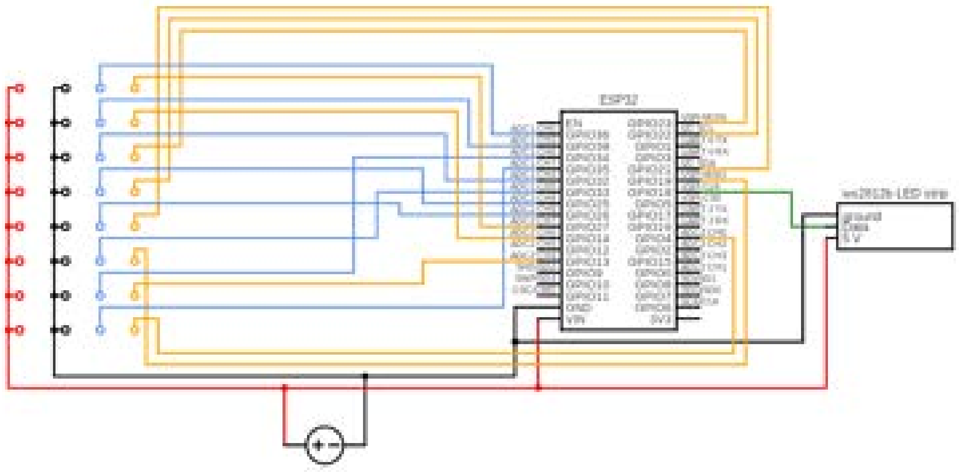


Figure 19: The circuit of the microcontroller board, the DC source outputs 5V

Figure 19 shows the used pins and the position of those pins on the connector rows on the left. The circuit board mirrors the actual position of the connector pins. From left to right the pin rows are 5V DC, Ground, Analog capable pins, general I/O, and PWM pins.

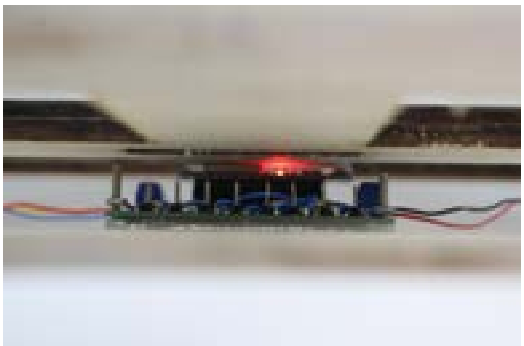


Figure 20: The microcontroller board when the platform is assembled

The full table of all the used materials in this prototype is in the appendix.

6.3 The modules

6.3.1 Wind turbine

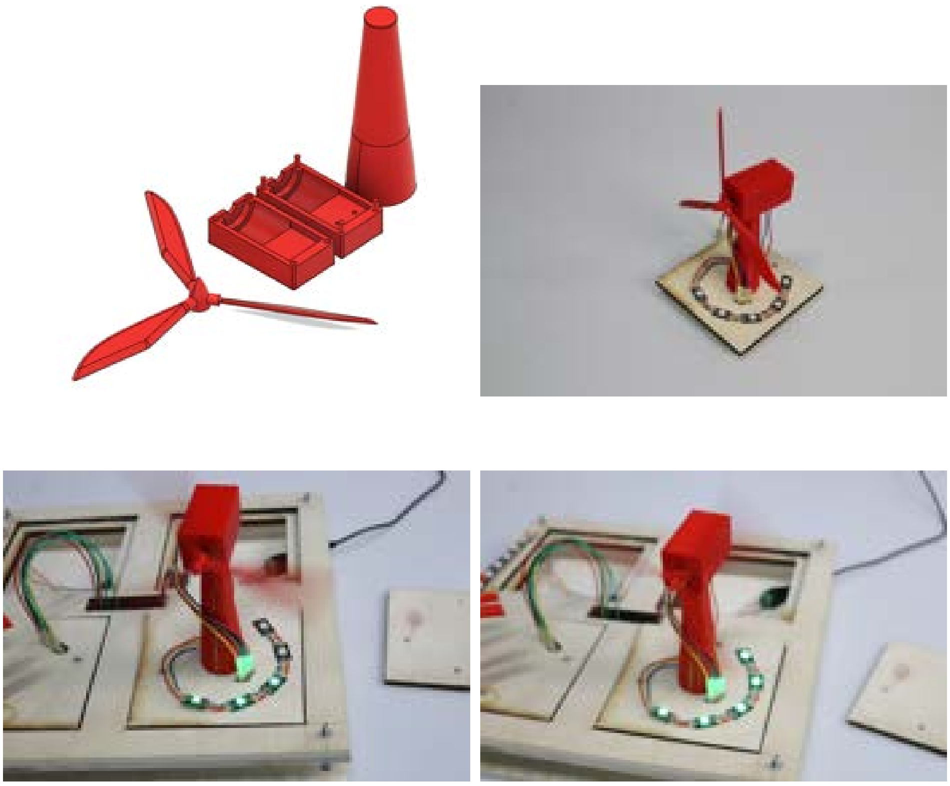


Figure 21: Various stages of the windmill, From top left to bottom right: the render of the 3d print, the windmill module, the windmill when turning, the windmill when turning as fast as possible

Pictured above 21 is the wind turbine module it uses a 3d printed design with a small DC motor embedded inside. When turning the blades the motor will output a small current which gets picked up by the analog pin of the microcontroller. The voltage of this current gets bigger or smaller depending on how hard you spin the motor.
This voltage translates into how many of the 5 LEDS are powered on. The largest measurable voltage is 3.3V which in code translates to a value of 4048. The motor can not reliably spin fast enough to make that happen, instead, the maximum value is capped at 1000. This inability to reliably get to 3.3V also means that the only time enough power is being generated to be picked up, is in the instant when hitting the blades to make them spin.

The measured value is thus multiplied by ten to make the LEDs turn off slower when not in use. This makes the change from 5 LEDs to 1 LED a lot more gradual. Otherwise, an onlooker would only see the LEDs turn on for a very brief moment. This way the people have more time to see how much power they have generated.
Using the value being measured, every LED turns on at steps of 200. If the measured and multiplied value is 320, the first 2 LEDs will turn on. If the value is 410, 3 LEDS will, and so on until the value is bigger than 1000 where all the LEDs turn on.

Figure 22: The 3d model used to 3d print the wind turbine

The wind turbine is 3d printed in 4 parts and then glued together. The motor fits in the two square blocks in the middle. The right of the two blocks is the bottom and the left slots in on top. The wires at the back of the motor can then be pulled through the holes at the back of the bottom block.
Not pictured here is a small indent at the bottom block. This indent is the guide for where the base and the bottom block have to be glued together. After putting the motor in the blocks and putting the three parts together, the blades of the wind turbine can be pushed on the shaft of the motor.

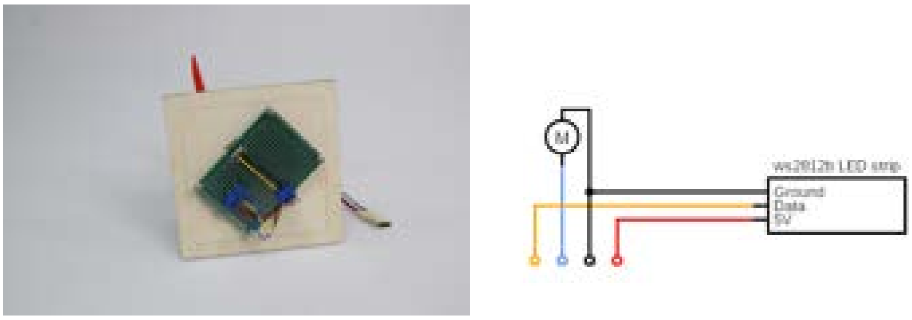


Figure 23: On the left, the circuit board when installed. On the right the circuit diagram

The circuit board for this module is very simple, as can be seen in figure 23. It consists of a DC motor connected to ground and the pin that needs to be connected to an analog-to-digital converter. It also has an LEDstrip that is connected to the 5V line, ground, and the pin that needs to be connected to a PWM pin.

component	width	length	height
wind-turbine	135 mm	68 mm	185 cm
base	110 mm	110 mm	6 mm
circuit board	40 mm	60 mm	1 mm
full module	135 mm	110 mm	220 mm

Table 3: Dimensions of the wind turbine module

The width is based on the maximum extension of the blades so the distance between the tips of two blades. Similarly, the height is also the maximum height with one blade standing right in the air. The full module dimensions are based on the maximum length in all directions including the circuit board.

The full table of all the used materials in this prototype is in the appendix.

6.3.2 Stepping energy

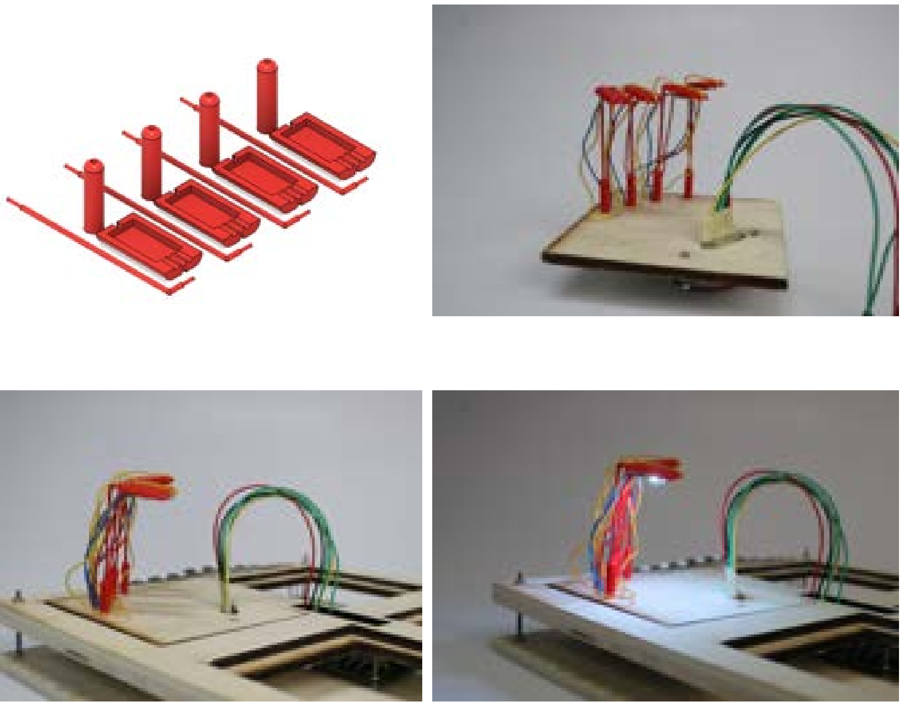


Figure 24: From top right to bottom left: the render of the 3d print, just the stepping energy module, the installed module, the installed module with the lights turned on

This module shows that energy can be generated from people walking which can then be used to power nearby (street)lights. This works using a crystal with a piezoelectric effect (see attached information sheet in the appendix for a simple explanation of the piezo-electric effect). Additionally see the reference: What is the Piezoelectric Effect?[40]
When people tap on the wood the microcontroller measures a voltage and turns the attached street lights on. Since this is a simulated environment the streetlights turn on after the microcontroller measures above a, in code, specified value. This value is random as it depended on the artifacts in the circuit board of the module when writing the code that could not be fixed in time.

Figure 25: The 3d model used to 3d print the street lamps

The street lights were printed out in 3 parts and then glued together. The L-shaped poles can be inserted in the hole of the cylinders. The LED holders can then be put over the other end of the pole with a small hole in the back. The back is the side with the three grooves.
The grooves are used to guide the wires, the front groove is used for the data wire that needs to connect to the other LEDs. The back three grooves are for the 5V, data, and ground wires. The LED needs to be put in the big hole in the middle. The only problem is that the LEDs on the used LED strip do not fit. So they are only placed inside partially with a lot of material on the side.
The idea for the wires as they are currently, see Figure 24, is that the wires go via the ground to the next street light. This is to mimic actual streetlights that are also not connected via wires in the air.

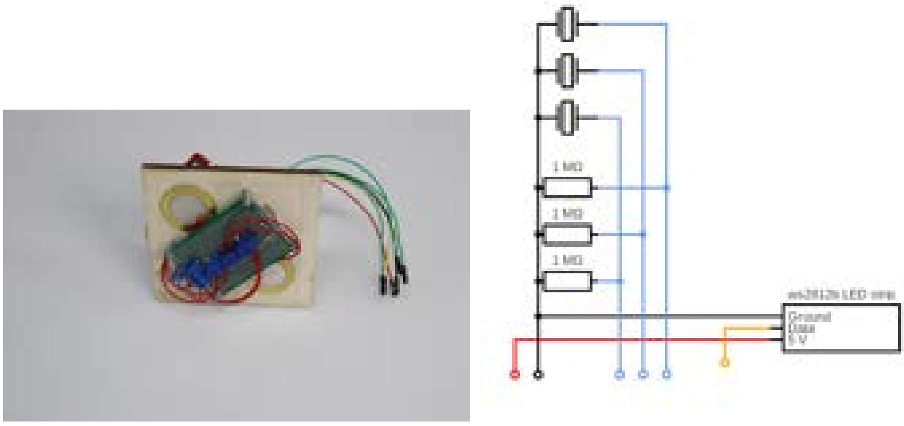


Figure 26: On the left the circuit board of when installed. On the right the circuit diagram

The circuit for this module is mainly made up of 3 piëzo-electric crystals. All crystals have their own output pin as can be seen in figure 26. These pins all need to be connected to an analog pin. They also have a 1 Mega ohm resistor across them to eliminate floating input. The other component attached to the circuit board is the LED strip that makes up the street lights. This LEDstrip is attached to the 5V, data, and ground pin. The data pin needs to be connected to a pin capable of outputting PWM signals.

component	width	length	height
street lights	13 mm	28.25 mm	90 mm
base	110 mm	110 mm	6 mm
circuit board	40 mm	60 mm	1 mm
full module	110 mm	110 mm	110 mm

Table 4: Dimensions of the stepping energy module

The full table of all the used materials in this prototype is in the appendix.

6.3.3 nuclear energy

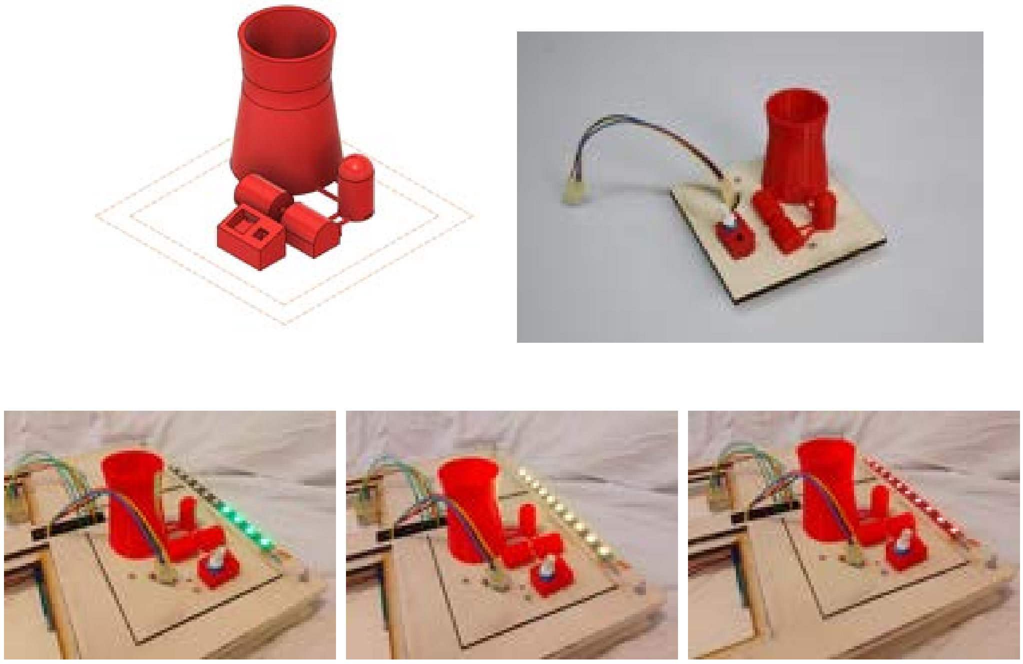


Figure 27: Various versions of the nuclear module. From top left to bottom right: the render of the module, the build module, the module on its lowest setting, the module going in the yellow, the module going in the red

The nuclear module is made up of a representational model of a nuclear power plant showing the most important buildings. These are the cooling tower, the building that holds the nuclear reactor, the steam engine, and the dynamo that converts the rotational energy from the steam engine into electricity. The scale between all these is not correct and is only meant to show the different buildings.
The interaction is made of a potentiometer. Turning the potentiometer turns the nuclear reactor on. The power that is being generated by the reactor is shown with an LED strip on the side of the platform. This LEDstrip has 10 LEDs and it is there to show that there is power being generated and how much. More LEDs will turn on if you turn the potentiometer further.
These LEDs are a representational value and not based on the actual power that a nuclear power plant generates. Just turning on the power plant already gives a certain amount of power and turning the potentiometer will result in higher and higher power output.
Turning the knob further however also results in the nuclear reactor heating

up faster and getting closer and closer to a meltdown, this is represented in the model by the color of the LEDs.
The LEDs start at green, this means that the heat is still at acceptable levels. Putting the potentiometer almost at the lowest point does not make it heat up at all but also gets you the least amount of energy.
Turning the knob all the way gives the most energy but also makes the reactor heat up much faster. The LEDs turn first to yellow to signify that the heat is closer to the danger zone and then go to red until they eventually flash on and off to signify imminent danger. The simulation does not go further than that and the LEDs just keep flashing on and off until the participant turns the knob to the off position. This will cool the reactor down and the power being generated decreases until all the LEDs are turned off.

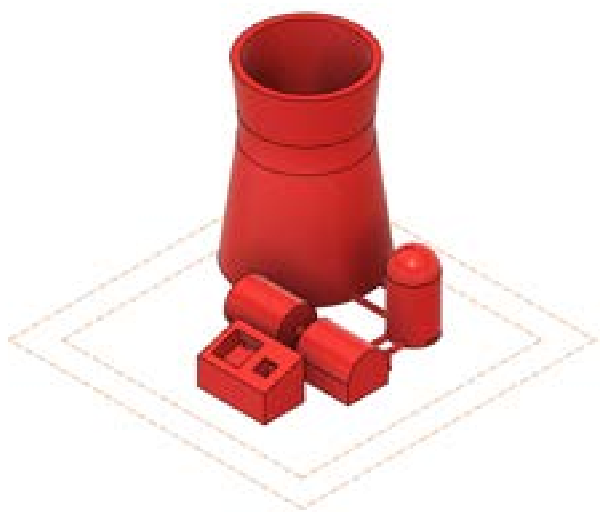


Figure 28: The 3d model used to 3d print the module

The 3d print is made up of 2 parts, the control panel and the rest of the buildings. The rest of the buildings are one part due to them being connected with pipes.
The control panel is hollow to allow for easy access to wires and to install an LED next to the potentiometer. The recess for the potentiometer is exactly the size of the base of the used potentiometer (full component list in the appendix). It has three holes inside to push the leads of the potentiometer through.

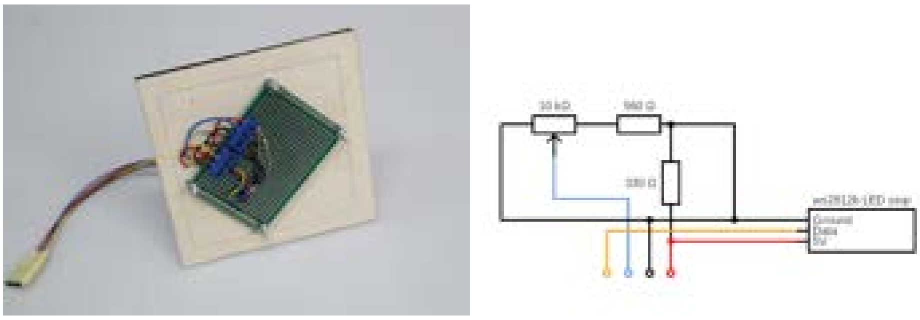


Figure 29: Caption

The circuit board for this module has two parts. The first part is the voltage divider connected to a 10 kOhm potentiometer. It reduces the voltage from the 5V line down to 3.2 Volts. This is done to protect the microcontroller since the pins can only take a maximum of 3.3 volts. Turning the potentiometer to the minimum position outputs a maximum of 3.2 volts to the ADC pin, instead of the maximum being 5V. The potentiometer needs to be connected to an ADC-capable pin.
The resistor values are 560 Ohm and 330 Ohm, in the configuration that they are in now as seen in figure 29. The resistor values give us the following equation: $\frac{560\Omega}{560\Omega+330\Omega} = \frac{560\Omega}{890\Omega} \approx 0,63$. Doing that with the voltage gives the following equation: $\frac{560\Omega}{560\Omega+330\Omega} * 5V \approx 3.146V$. Due to the values of the resistors being slightly off the actual output voltage is slightly different. Measuring the output voltage gave the 3.2 volts mentioned above.
The second part is a single LED attached to the 5V, ground, and data pin. This LED does not work in the final prototype, the LED strip attached directly to the microcontroller is used instead.

components	width	length	height
nuclear buildings	81 mm	65 mm	65 mm
nuclear control panel	25 mm	15 mm	15 mm
base	110 mm	110 mm	6 mm
circuit board	40 mm	60 mm	1 mm
full module	110	110 mm	90 mm

Table 5: dimensions of the nuclear energy module

The full table of all the used materials in this prototype is in the appendix.

6.4 power supply

The current solution for the power is to use an adapter with a DC connector for easy connecting. The adapter being used outputs 5v with a maximum of 2 Amps. This means that the demonstrator needs to be plugged into a wall socket. This can be hard to find sometimes and does mean that the space you can put the device in is limited.

this can be resolved by using a rechargeable battery, but then the problem becomes how long it can last one battery or how big the battery has to be to sustain the device for a predetermined amount of time. To predict that the calculation below is made.

The device has 19 working ws2812b LEDs, which have a maximum power draw of 60 mAmps[41] each when at full brightness and all colors are used. The maximum current draw will then be 19 * 60 mAmps = 1.140 Amps. In normal operation, this does not happen as most of the LEDs use only one color at a time. Multiplying the Current with the input voltage of 5v gives the following power draw of the LEDs: $1.140A * 5V = 5.7W$ The other main power draw is the microcontroller. Online was found that the power consumption of the ESP 32 in active mode is 78.32 mW.[42] Adding that to the figure above gives $5.778W$. Since this is a prediction, the number is rounded up to 6W in order to account for missed power consumption and wrong estimations.

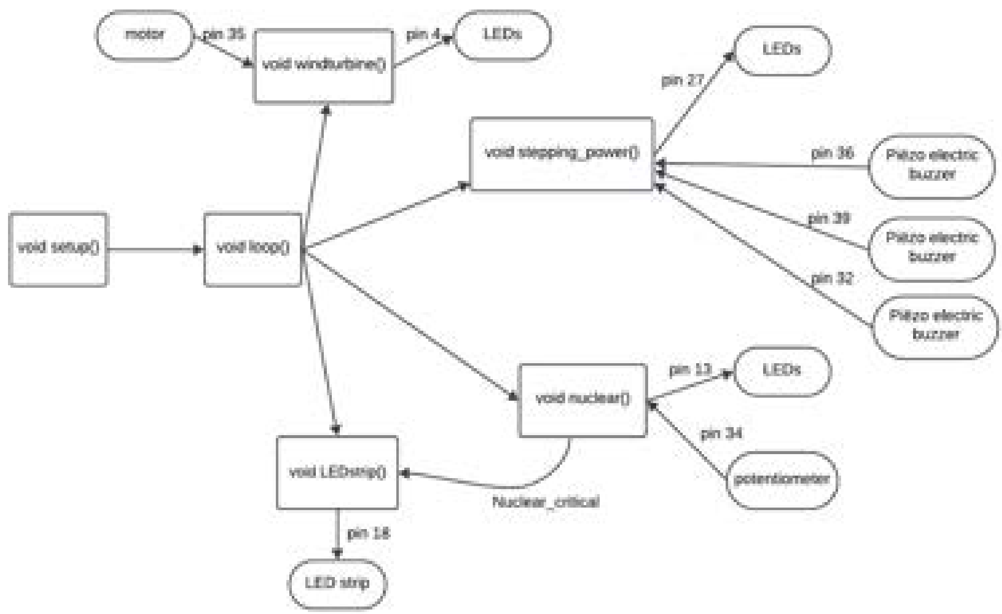


Figure 30: Flowchart showing the code for demonstrator

6.5 code

[ht] The code is mainly separated with every module having its own section in the code. The only exception is the LED strip that uses a variable from the nuclear energy module since they work as one module.

6.6 information sheet

To accompany the platform an information sheet was written. The information sheet is one a4 piece of paper with information about what the modules represent, how they work, and how EE is involved. The information sheet can be found in the appendix.

7 Evaluation

In order to evaluate the device it needs to be tested and evaluated by the stakeholders or approximation of the stakeholders. Below are the three forms of evaluation that were conducted. First, a user evaluation where the device is evaluated by outside observers. Then a supervisor evaluation where the device is evaluated from the lens of the people who need to work with the device. And lastly, an expert evaluation where the device is evaluated by researchers from the field of power engineering.

7.1 user evaluation

The user evaluation is used to evaluate how well the demonstrator fulfills the problem statement.

7.1.1 The questions

1. What was your first impression, before using the device?
   When used for the open days, this device is sitting in one place. First impressions are a good way to gauge how intriguing or interesting the device is.

2. How fun was it to interact with the device?
   To find out if the exciting portion of the problem statement is satisfactory, some way to measure excitement would be needed. The self-reported fun people had while interacting with the device was used.

3. Which module(s) was/were the most fun to interact with?
   In order to find out in what direction future modules could go, knowing which modules are the favorites is a good first step.

4. Did you learn anything new?
   The educational aspect also needs to be tested since that is part of the problem statement. If a majority of people answer yes then the demonstrator is educational.

5. What did you learn?
   It is also good to know what they learned to see what similar modules could be used to teach people.

6. Would this device have made you more likely to choose electrical engineering, why or why not?

The main purpose of the demonstrator is to attract people to the electrical engineering study. To test this, the participants were asked to call back to a time before they had to choose their study and answer the question above.

7. What could be done better?
   Everything can be improved but not every bad aspect of a design can be evaluated by the designer. The designer might have a blind spot for certain parts of a design or think they had a genius idea for something that ended up not working as intended in the eyes of a general audience.

8. The fourth spot is free, what could be put there?
   The general public has a wider knowledge base. This question might spark ideas for future improvements

9. any other remarks?
   In case there was anything that was not an answer to the questions above.

7.1.2 The procedure

The participants signed a consent form and were then led to the test setup. The setup consisted of the device with an information sheet next to it. This information sheet contained more information on the modules and their counterparts. The Information sheet can be found in the appendix.
The participants were asked to interact with the device and read the information sheet. After reading the information sheet and interacting with the device, they were led to a laptop. They were then asked to answer the questionnaire explained above.
While interacting with the device, any questions they had were answered and help was extended to those that had trouble interacting with the device. The nature of this help and the observations gained from observing the participants will be explained at the end of this chapter.
In total 5 people did the user evaluation. One fellow graduate student from creative technology and 4 graduate students from computer science that I got from a bachelor graduation study group. This does mean that they are at least 3 years removed from the point of having to choose a study.
The first participant had an older version of the test. They gave a lot of good feedback during the session. After that session, the code of the prototype was modified as it was the easiest modification to do at the time. They also were not given the information sheet and were thus unable to read it. Because of this Their answers were different from the rest and those differences will be

explained when applicable.

7.1.3 The results

What was your first impression, before using the device?

The overall impression was positive. Most answers included words like cool, interesting, and fun. The most interesting answer was: it looked very DIY. This answer can go both ways. It can be seen as a point of interest or it can be seen as a sign of unprofessional work.

How fun was it to interact with the device?

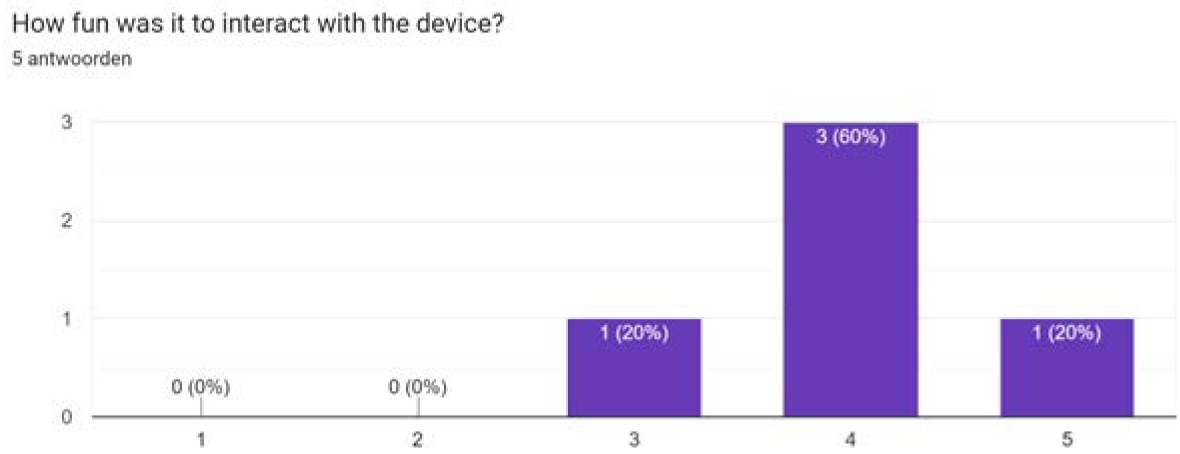


Figure 31: A graph showing how fun the participants of the user test found the device

As can be seen in the graph in figure 31, the answers were positive. With an average of 4/5, the device succeeds in being a fun interaction that leaves a positive impression on people.

Which module(s) was/were the most fun to interact with?

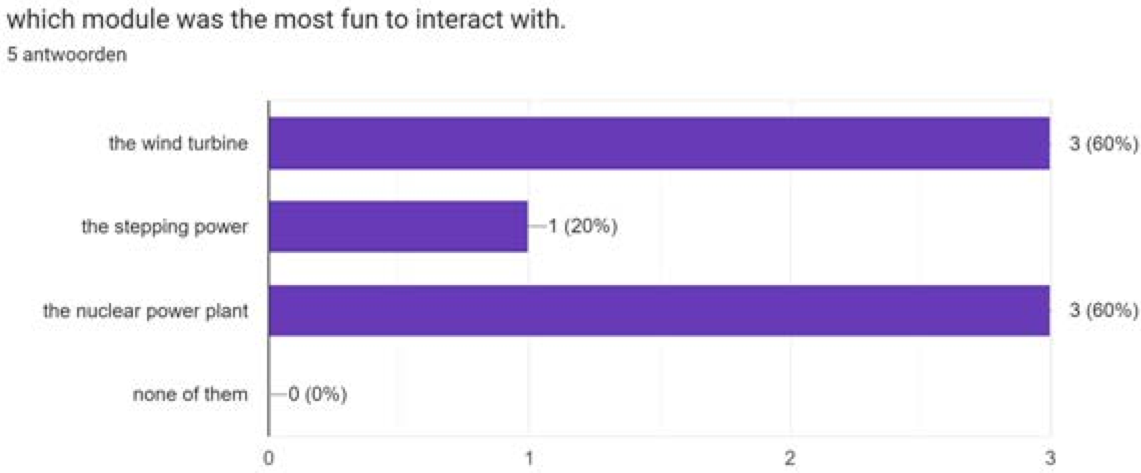


Figure 32: A graph showing what module(s) the participants of the user test thought was the best one

The answers resulted in a tie between the wind turbine module and the nuclear power plant module. The stepping power is the least popular with only one vote.

why was this module/were these modules the most fun?

The participants thought that the wind turbine was very easy to understand and very interactive but also fragile and easy to break. They found the nuclear power plant's LEDs to be fun due to the change of colors and their reaction to the potentiometer. The stepping power was not really commented upon. The participants who voted for it answered that they did not know that electricity could be generated by stepping.

Did you learn anything new?

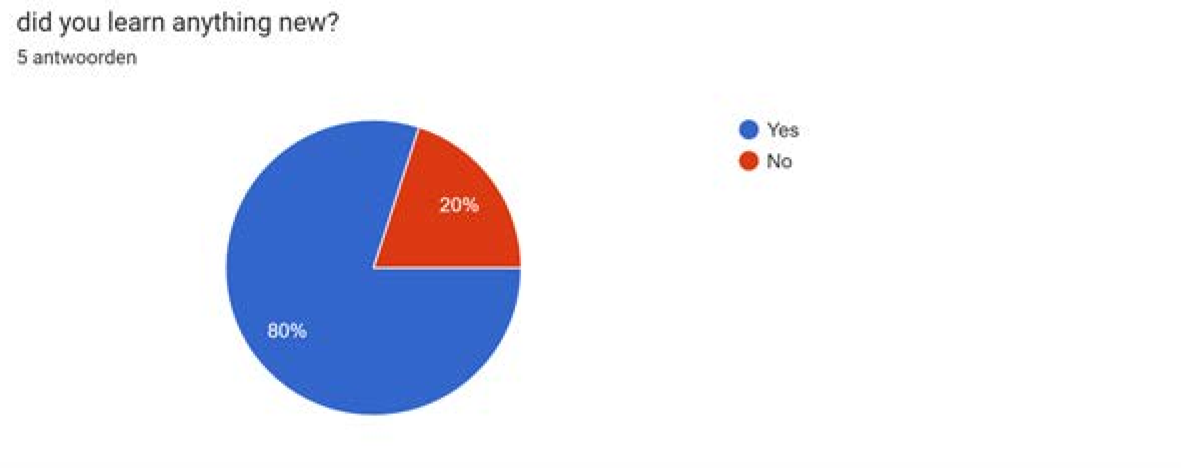


Figure 33: Pie chart showing the number of people who learned something during the user test

The demonstrator is educational, with 4 out of 5 saying that they learned something. However, there is one note to be made. The participant who said no, was the first participant. This means that they did not read the information sheet. Them saying no can thus mean two things:

1. The information sheet is the educational aspect of the whole demonstrator.
2. This participant already knew all the information that could have been gotten from just the device and answered no.

Based on the additional observation during the test. The most likely answer is the first one. With the device being the exciting aspect and the information sheet being the educational aspect.

What did you learn?

The participants who did learn something from the demonstrator all agreed on the thing they learned. They all learned that piezo-electric effects can be used to generate electricity from walking. One of the participants also added that they learned about the nuclear power plant.
Since almost all participants learned something, the demonstrator is educational.

would this device have made you more likely to choose electrical engineering, why or why not?

The answers for this are spread out. With two of the answers being a definite maybe, one being a yes, one being no, and one answer being inconclusive. This means that the answer to this question is inconclusive, and thus requires more research in order to get a conclusive final answer.

What could be done better?

The first participant commented on the nuclear module not making any sense, the programming for that module was changed after his feedback so the other participants had a better working nuclear module. Instead, the largest amount of answers found that the information around the demonstrator was lacking. Especially how the electrical engineering was involved when done for the generators that these modules showed.

The fourth spot is free, what could be put there?

The answers to this question were almost unanimous. Almost all participants suggested adding a solar panel to the empty spot on the device. The participants did suggest variations of the idea such as including a flashlight or having the future participants use their phone flashlight to get more energy. The one different answer suggested adding information about the wiring or giving an insider look at the workings of the device.

any other remarks? Out of the two answers to this question, only one was a usable answer as one of the answers just said no. The usable answer put forth that the demonstrator looks and feels very unfinished. This is a fair assessment as the device is not fully completed yet. For possible improvements see: discussion and future work.

7.1.4 observations

The biggest problem the participants had was the interactions with the device. Although they did understand what was happening after reading the information sheet. The actual operation was not intuitive enough. Most participants for example pressed on the piezo-electric/stepping energy module instead of tapping it as if it were steps and their fingers were feet. This could be improved by adding icons that showed what needed to be done.
Even if they did know what the interaction was supposed to be, it did not always work as intended. A lot of help was needed with the windmill for example. Just spinning it did not always do the trick, it has to be hit with a sharp tap on the blades to get a result.

After this was shown, the participants could get a response almost every time.

7.1.5 conclusions from the user evaluation

Overall based on the user evaluation, the demonstrator does fulfill the problem statement. The device is fun with the participants giving an average score of 4 out of 5. The demonstrator is educational with 80% answering that they learned something. The claim that it sways people to choose electrical engineering however is still inconclusive and will need to be researched further.

An important thing to mention is that using just the device as the demonstrator would not satisfy the problem statement. A poster is required in order to make it educational instead of just fun. The best solution is to have the device attract the people and have the poster be the component that educates them.
The last point that needs to be mentioned is that the device as it is now is not very intuitive. Most of the participants got stuck interacting with the demonstrator somewhere and had to be helped. This can be improved with better indications and more reliable modules.

7.2 handler evaluation

The device is not only used by the participants of an open day or school visit day but also by those who have to set up the device. In order to test how they might experience handling the device, multiple tests were carried out concerning the operation and transportation of the device.
These tests can be separated into three sections. First is the setup and operation of the device. Second is the transportation and storage of the device. And third is the repair-ability.

7.2.1 setup

In order to use the modules, they need to be connected to the microcontroller in the middle. This should be easy to do. To test this the modules were plugged in multiple times. These times were recorded and averaged. The average time can be seen in the table below.

module	plug into module	plug into microcontroller	plug into both
Nuclear module	4 sec	4 sec	10 sec
Wind-turbine module	4 sec	8 sec	14 sec
Stepping module	5 sec	2 Min 13 sec	2 Min 20 sec

Table 6: plug in times per module per method

The windmill and nuclear module are similar, the windmill module has a more inconvenient spot which makes it harder to plug in the microcontroller. The stepping module took the longest to plug into the microcontroller due to the cables being separated instead of taped together.

In order to set up and turn on the device at the chosen spot, the device needs to be connected to a wall socket using a cable with a DC plug. To test the time this takes the setup in figure 34 was used. Plugging in the device multiple times took an average of 15 seconds. Although this does depend on the distance between the plug and the device, the setup time should not take more than a minute.

Figure 34: The setup for testing how long it takes to plug the device in

7.2.2 transportation

In order to test the ease of transportation, the device was taken to various locations. The observations from these tests are recorded below.

Pros: The device is light with 900 grams. This is around the same weight as an 1100-page book. This makes it very easy to carry for long periods of time. This lightness also makes it possible to hold it in one hand to open doors and pick things up.

The device is also very easy to store, with its small 30 by 30 cm footprint there was no trouble putting the device down somewhere. It also easily fits on a shelf or in a closet.
Cons: Due to the top-heavy modules, it is recommended to hold it like a tray. However, this does make it harder to move around in a packed crowd. Although recessed in the platform, the modules do sit loose on top of the platform. This means that by turning the device to too large of an angle the modules will fall off. Especially the wind turbine module since it is very top-heavy.

7.2.3 repair

The device is very easy to repair. Whenever that was needed the broken module could quickly be taken off the platform and taken apart. The bolts that hold the circuit boards make it very easy to take the circuit board off. Additionally, any wires that need to connect to a component on the module are attached with screw contacts. These two facts mean that the circuit board can easily be separated from the rest of the module and repaired.

7.3 feedback from experts

A meeting was planned with two researchers who currently work at the university in the field of power electronics. Their overall impressions of the demonstrator were positive. They did have multiple points of improvement. Starting with the information on the poster. Although they could not vouch for every bit of information on there, since they did not have enough knowledge about nuclear power plants. They did give some points on the windmill. The information sheet posits that the dynamo of a wind turbine is similar to a DC motor. This is wrong as the output of a DC motor is DC whereas the output of a wind turbine is AC. They also suggested improvements to the information sheet as a whole. Adding more real-world examples for example or giving examples of current research to improve the electric generators. They also suggested adding more pictures that explain the effects discussed in the information sheet. For the device, they gave suggestions on what to put at the empty fourth spot. Just like the user evaluation, the first thing they proposed was to put a solar panel there. They added that it would be fitting as they are currently researched at the university. This module can thus be used as an example of what can be done after completing the study. The second suggestion was to go for a more related concept, namely energy storage. This is related to energy generation as it is seen as one of the possible solutions to the current energy problems.

8 Discussion

8.1 discussion

Although the demonstrator was also well received, it ended up being a first prototype and a proof of concept. As such there are a lot of things to change and improve. For example, there are still a lot of reliability issues. Modules only work when interacted in specific ways or not at all. They also were not as intuitive as hoped. The modules could be improved with some icons or other visual elements that would show participants how to interact with the modules. Something like a dial from one to ten, or from green to yellow around the potentiometer of the nuclear module. A full list of possible improvements is in the future work section below.
There were also external ideas that could have improved the prototype if they were made. These are not improvements to the device but additions that could bring more understanding or easier handling. For example, due to time constraints, the electricity net platform could not be built. This platform would have added more understanding of the relationship of power generation and distribution to the demonstrator. It would also have been easier to incorporate our current energy problems into it. This might have attracted people who want to solve current problems.

In retrospect, the question: Which module was the most fun to interact with? could have been asked in a better way. It could have been improved a lot by having the users rank the modules from 1 to 3 and then give 3 points to the favorite module, 2 points to the second favorite, and 1 point to the least favorite. This could have given more interesting results and might say more about how well each of the modules performed.
There were also not a lot of participants for the user evaluation, so at least one of the results was inconclusive. More evaluation needs to be done to resolve this. Another point is that the participants were all graduate students, these people have done their respective study for a long time and might find it hard to imagine a time when they had to choose their study.

8.2 suggestions for future work

This prototype is the first prototype, the proof of concept. As such there are a lot of improvements that can be made to increase the quality of the device. Additionally, a lot of feedback was gained during the evaluation sessions. There are two types of improvements:

1. Changes to the currently made device.

2. Additions to the demonstrator as a whole.

These are separated into two sections.

8.2.1 Changes to the current iteration

1. A better poster can be made. Currently, the poster is one A4 with lots of text. It would be better to have a big poster with more information and pictures. The extra information can be about how exactly electrical engineering is involved in the generating of power. The pictures can show current examples of the generation methods the modules represent or more infographics that show how everything works both on the device and in the real world.

2. The interactive elements can be improved. Right now the interactive modules do not work reliably. The wind turbine for example only works if a person hits it hard and the voltage the microcontroller picks up only lasts for less than half a second.

3. The look of the platform can be improved. Right now the platform has a lot of artifacts from the mistakes made during the design process. The wood can be painted to hide the burn marks from the laser-cutting process; There are still pencil marks for the bolt placement and the bolts are not always put in straight.

4. The platform or module bases can be re-cut out of clear Plexiglas or other see-through materials. This way the participant can better see behind-the-scenes work, such as the circuit boards. This ultimately makes it easier for people to see the electrical engineering that makes the demonstrator possible.

5. The models can be painted. Currently, everything is 3d printed in a solid red color. The models can instead be painted in the correct colors. So instead of all red, the windmill can be painted white, the street lights of the stepping module a metallic gray, and so on.

6. More visual elements can be added to help people to interact with the device. Like a drawing of a hand with a visual cartoon hitting star, to signify that people have to tap instead of press on the stepping module.

7. An additional module can be added. Currently, there are three modules while the board is made for four. The remaining space can be filled up with another type of power generation, like a solar panel as suggested by the user evaluation participants. Or as suggested by the experts it can be used to show energy storage solutions instead.

8. The circuits can be laid out neater. Currently, the circuits are very bunched up and all over the place. This reduces the visibility of the wires and makes it harder to follow one of them. If combined with the clear Plexiglas idea it can make it more exciting to look at instead of it being a jumbled mess of wires as it is now.

9. The boards can be turned into PCBs. This will require a better layout of the pins but would make the end product much nicer. Not to mention that it would make soldering and problem-shooting a lot easier.

10. The demonstrator can be made sturdier. The base is very sturdy but the 3d prints are hot-glued on. and although they can withstand regular usage any undesired hits can break the 3d prints. This can be done using stronger and more specialized glues or by screwing them in.

11. The models can be made less fragile. Currently, all of the modules are 3d printed, the PLA plastic used is not known for its strength. Although the 3d prints are strong enough for casual interaction, multiple participants of the user evaluation found the modules to be fragile. The modules can be made less fragile by using stronger 3d print materials. This is the easiest as the 3d print files can be kept the same.

12. The demonstrator can have more in-the-moment modularity. Currently, the modules need some setup to work. When other modules need to be used the code needs to be changed to accommodate that new module. Instead of that the modules could be changed dynamically. So while the demonstrator is turned on one of the modules can be exchanged for another one without needing to change the code.

8.2.2 additions to the demonstrator

1. The demonstrator can use a carrying case. Although easy to carry due to the low weight of the prototype, the 3d prints on top are not very sturdy and have to be handled with care so they do not get crushed. That is why it would be best to have a case made. This makes the demonstrator even easier to carry and reduces the chance of one of the modules breaking.

2. The electricity net counterpart can be made. The original idea included the power-net aspect of power engineering. This can still be added, it would add another layer and could show the interaction of the power generation stage with the power network. This interaction would give people a better understanding of how these components work together. For the full idea see the chapter: specification.

3. Something entirely different can be put on the platform. Currently, the demonstrator shows energy generation techniques but they are not fixed to the platform. This means that the modules can be swapped out for something completely different.

9 Conclusion

The goal of this graduation project was to find the components that make an interactive demonstrator that excites and educates potential students about the field of electrical engineering.

Starting with the background research, the 5 subfields of electrical engineering were identified. This was done to find out what students could do after doing the EE study. A museum namely the Universiteitsmuseum Utrecht was visited because they also teach science using demonstrators and it could give inspiration. The open days were visited as well, this was to orient the project and see what could be improved or added. Last but not least the literature research focused on types of, ways of engagement, and education with, demonstrators. This was to answer the question of how to educate people about in-tangible and theoretical concepts in an engaging way using demonstration.

During the background research phase, the stakeholders were identified. Identifying the stakeholders revealed two new requirements that were added to the list of requirements from the supervisors.
Using the list of requirements and the inspiration and knowledge from the background research, a list of ideas was developed. That list was evaluated and the best design for this project was chosen

The final design is a wooden platform that shows multiple ways of generating electricity. On the platform are 3 loose modules that each show a simulation of one way of generating electricity. The modules are: a wind turbine module, a nuclear reactor module, and a stepping power/piëzo electric energy module. Each module is interactive in some way. The wind turbine can be spun to turn on 5 LEDs at the bottom. The nuclear energy module has a control panel where you can adjust the amount of electricity being produced with the small price of having the nuclear reactor go to critical heat faster. The stepping power/piëzo electric energy module can be tapped to turn the streetlights attached to the module on.
Additionally, an information sheet was made that contained information about what the modules represent, how they work, and how EE is involved. This final design was evaluated using three methods. A user evaluation, an evaluation through the lens of the people who need to work with the device, and an evaluation by experts. The demonstrator was well received and the feedback from these evaluations was very useful. Based on the feedback, a list of future improvements was made. This list includes things like increasing

the strength of the modules, designing a poster to replace the information sheet, or adding a fourth module with solar energy.

So what are the components that make an interactive demonstrator that excites and educates potential students about the field of electrical engineering? This project found that using interactive modules is a very fun way to excite people with the wind turbine and the nuclear power plant being the favorite.
Additionally, it found that the device draws the students in and the information sheet/future poster educates the students. Lastly, to take to take the word components literally. The materials that make up the platform and the modules are also the components that make an interactive demonstrator exciting and educational.

A appendix

B questionnaire questions and answers

what was your first impression, before using the device?

- Looked very diy
- That it was some kind of science experiment about different types of sustainable energy
- That it looks cool
- looks like a fun project. was wondering how it works
- interesting looking prototype

How fun was it to interact with the device?

- 3
- 4
- 5
- 4
- 4

which module was the most fun to interact with.

- the wind turbine
- the wind turbine
- the nuclear power plant
- the wind turbine, the nuclear power plant
- the stepping power, the nuclear power plant

why?

- turning quicker to engage more LED's is intuitive and motivates to get them all to light up, which is fun. shame it is quite difficult to get them to light up, it feels flimsy

- Very easily understandable, though I was scared to break it
- The windturbine is fun to spin, but I liked that the nuclear power plant leds change their colors
- it showed nicely how it works and was interactive
- i did not know that electricity can be generated by stepping. the leds reaction to the knob is quite interesting

did you learn anything new?

- no
- yes
- yes
- yes
- yes

if you answered yes at the previous question, what did you learn?

- I did not know how stepping power created energy
- I learned about the option to create power with the piezoelectric effect.
- i learnt about the stepping power and the nuclear power plant
- i did not know that electricity can be generated by stepping

would this device have made you more likely to choose electrical engineering, why or why not?

- its certainly fun to see the diy aspect of the project, which shows that building stuff like this is possible at the UT, but this does not necessarily to EE
- Not my immediate thought, it made me think more about sustainable energy
- Sure, because this looks like a cool project to make
- no because i am already studying something els

- maybe a bit more but generally it would not have changed my study choice

what could be done better?

- Nuclear energy made no sense to me, and the windmill is really difficult to get working
- make more clear how electical engeneering makes this possible
- I think the reasoning behind the project could be explained a bit better. You showed multiple ways to generate energy. But why?
- a bit more or information of how those things work in real life
- implement a fourth module

the fourth spot is free, what could be put there?

- solar panels? with a flashlight or something
- information about the wires? an insider look at how it works?
- Solar panels that react on a light source
- solar panel that creates electricity when shining flash light on it from the phone
- solar pannel

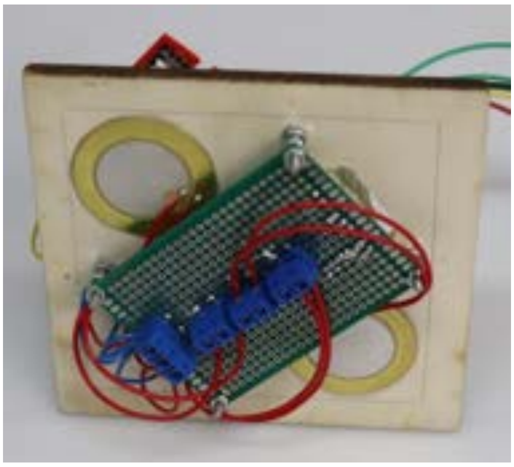
any other remarks?

- it looks and feels very unfinished
- no

C information sheet

Electrical engineering in power generation

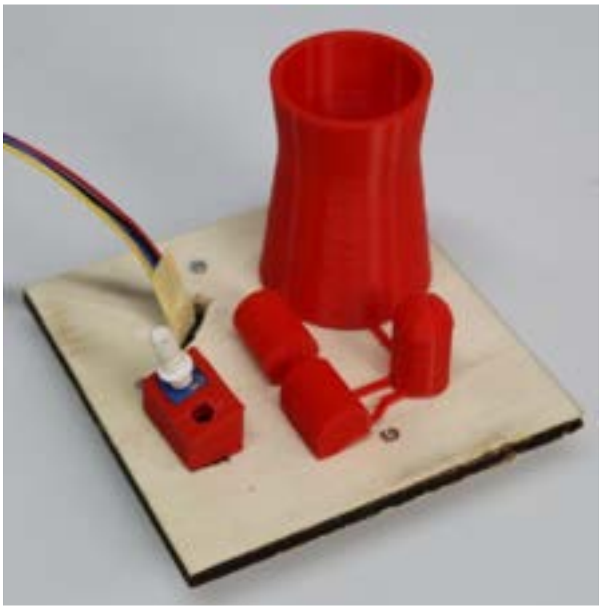
On the plateau you see various ways to generate electricity, from the now standard wind energy to the more weird and niche “stepping energy”.

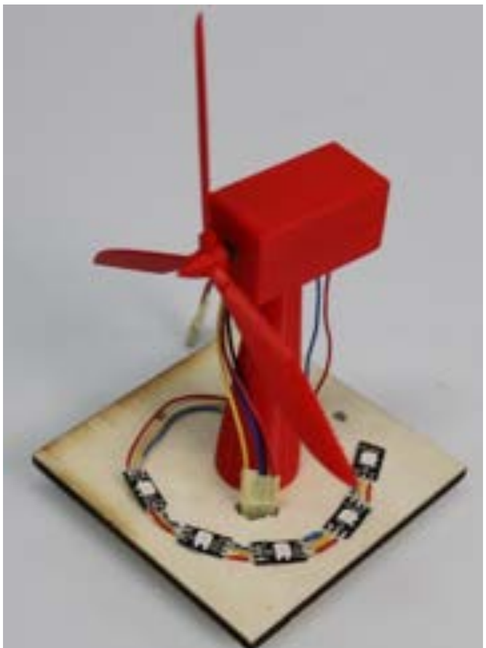


Underneath this module you pictured left you will see three circles next to each other, these are a certain sort of crystals that have what is called a piezoelectric effect. This means that when pressure , like pressing or stepping on it, is applied to these crystals it it generates a very small amount of electricity.

On a large scale this could be used to generate energy for things like street lighting in busy areas as well as detect if someone is walking there for added efficiency and reduced light pollution.

Electrical engineering is very involved in the safe operation of a nuclear powerplant. From the control panel to the sensors making sure that the plant operates smoothly and safely. The generator rotates due to steam generated by the heat of the nuclear fuel and interestingly the steam coming out of the cooling tower is not the water that was heated by nuclear power but water used to cool that water. In this model the working of a powerplant is simulated using a potentiometer and a warning light, turning the potentiometer to the right turns the power plant on and the more you turn it the more power is generated but the faster the nuclear rods reach critical mass, slow down or turn of to get it back to save levels.





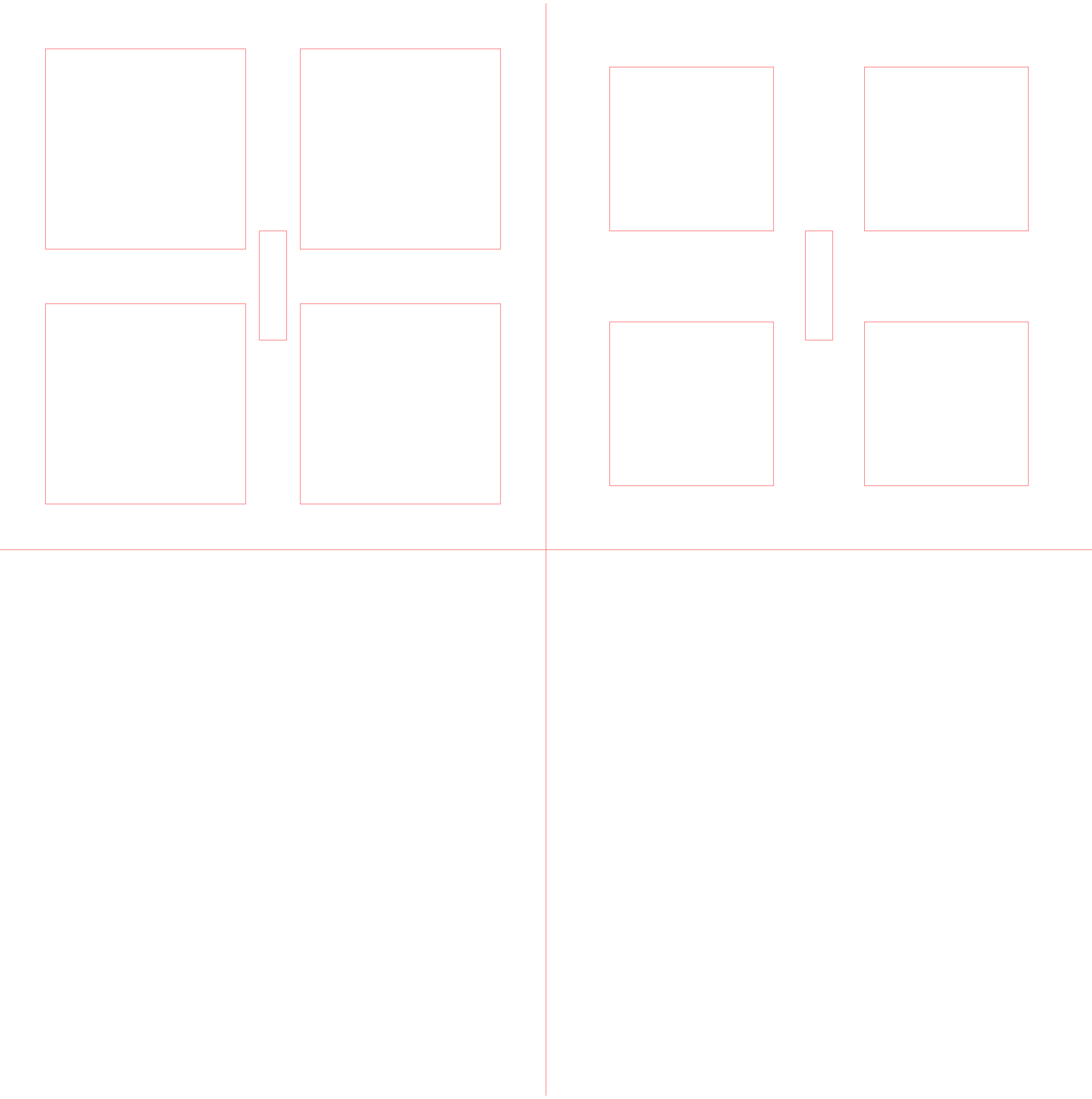
One of the biggest “new” clean way to generate electricity is using a wind turbine to capture energy from the wind. This is done using a giant wound coil of copper wires and magnets called a dynamo. The same principle is used in motors to use electricity to move and those work in reverse too. The model pictured left actually has a small motor that is used to generate electricity. This motor is the same type of motor used in things like electric toothbrushes and many power tools. Electrical engineers are involved on this by making more efficient designs for the generator to get even more power from the wind.

D Materials used + cost

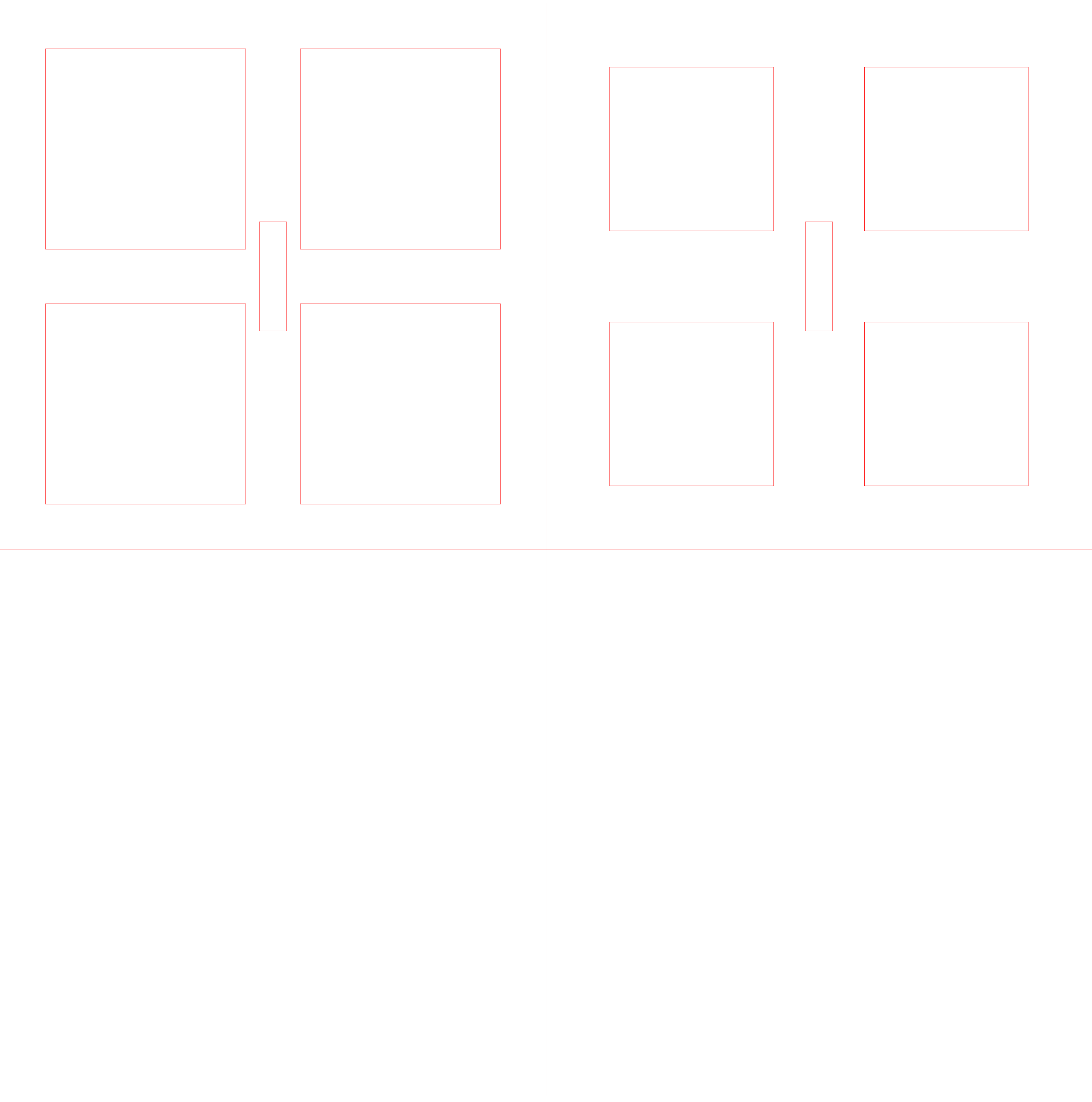
platform:	additional modifiers			amount	cost single item	cost total	
plywood sheet	60 cm width	60 cm length	6 mm thick	1	0	€ 0.00	
modules:							
Dc motor 3v-6v dc type 140				1	€ 1.08	€ 1.08	
resistor	1 Mohm			3	€ 0.10	€ 0.30	
resistor	330 Ohm			1	€ 0.10	€ 0.10	
resistor	560 Ohm			1	€ 0.10	€ 0.10	
Piezo Electronic Buzzer - Met draden gesoldeerd	35mm			3	€ 0.50	€ 1.50	
3 Pin Schroef Terminal Block Connector 5mm Afstand - Blauw				5	€ 0.70	€ 3.50	
2 Pin Schroef Terminal Block Connector 5mm Afstand - Blauw				4	€ 0.50	€ 2.00	
WorldSemi WS2812B Digitale 5050 RGB LED Strip - 60 LEDs 1m	original product not found, any WS2812B led strip works			1	€ 12.00	€ 4.00	(20 leds used)
Experimenteer-printplaat 7cm*9cm - Dubbelzijdig				1	€ 1.50	€ 1.50	
Experimenteer-printplaat 6cm*9cm - Dubbelzijdig				3	€ 0.70	€ 2.10	
potentiometer	unknown, from arduino kit, datasheet in link			1	€ 0.00	€ 0.00	
micro controller board:							
ESP32 Wi-Fi en Bluetooth Board - CP2102				1	€ 9.00	€ 9.00	
15 Pins header Female				2	€ 0.31	€ 0.62	
40 Pins header Male	not all headers used			1	€ 0.40	€ 0.40	
6 headers Male	no found product (used two 40 header male components)			1	€ 0.00	€ 0.00	
					total cost	€ 26.81	
*resistor values vary greatly € 0.10 per item assumed							
*plywood from designlab, can not remember cost							

Figure 35: Table of components + cost

E Used lasercut design



F Improved lasercut design



G code used for the demonstrator

```
#include <Arduino.h>
\library to control ledstrip
#include <Adafruit_NeoPixel.h>

int brightness = 0;
int ledWind = 0;
int ledStep = 0;
int ledNuclear = 0;
int timer = 0;
int NuclearTimer = 0;


\setting up the LED strips
#define LED 18 \the pin these LEDs are attached to
#define Count 10

Adafruit_NeoPixel outsideLED(Count, LED, NEO_GRB + NEO_KHZ800);
\Adafruit_NeoPixel name_of_variable{amount of leds, led_pin, no idea keep the
same}

#define Wind_input 35 \analog input pin
#define Wind_output 4 \LED strip pin
#define Wind_Num_LEDs 5
int Wind_Power = 0;
int Wind_Max = 0;

Adafruit_NeoPixel Wind_LED(Wind_Num_LEDs, Wind_output, NEO_GRB + NEO_KHZ800);

#define Nuclear_input 34 \analog input pin
#define Nuclear_output 13 \LED strip pin
#define Nuclear_Num_LEDs 1
int Nuclear_control = 0;
int Nuclear_critical = 0;

Adafruit_NeoPixel Nuclear_LED(Nuclear_Num_LEDs, Nuclear_output, NEO_GRB +
NEO_KHZ800);


#define Step_input_1 36 \analog input pin
#define Step_input_2 39 \analog input pin
#define Step_input_3 32 \analog input pin
#define Step_output 27 \LED strip pin
#define Step_Num_LEDs 4
int step_power_1 = 0;
int step_power_2 = 0;
int step_power_3 = 0;

int step_power_max = 0;
```

```
int max_step_power_1 = 0;
int max_step_power_2 = 0;
int max_step_power_3 = 0;

Adafruit_NeoPixel Step_LED(Step_Num_LEDs, Step_output, NEO_GRB + NEO_KHZ800);

void setup() {
Wind_LED.begin();
Step_LED.begin();
Nuclear_LED.begin();
outsideLED.begin();

outsideLED.clear();
Step_LED.clear();
Wind_LED.clear();
Nuclear_LED.clear();
Serial.begin(115200);
}

void loop() {
windturbine();
stepping_power();
nuclear();
LEDstrip();
}

\the part of the code that handles the wind module
void windturbine(){
\color of the leds 0 is off - 255 is full this color
int red = 0;
int green = 255;
int blue = 0;
brightness = 50; \how bright the leds are goes from 0 to 255

Wind_LED.clear();
Wind_Power = analogRead(Wind_input); \read the voltage from the motor
Serial.print("wind: ");
Serial.print(Wind_Power);

\multiply that value by 10, if it is higher thant the value that the last turn
gave replace it with that
if(Wind_Power*10 >= Wind_Max){
  Wind_Max = Wind_Power*10;
}
else{ Wind_Max -= 1;} \decrease the value to get a smooth decrease in leds

\every step of 200 above 10 results in another led being turned on
for(int led = 0; led < Wind_Num_LEDs; led++){
```

```
  if(Wind_Max > 10){
    Wind_LED.setPixelColor(0, Wind_LED.Color(brightness*red/255,
brightness*green/255, brightness*blue/255));
    ledWind = 1;
  }
  if(Wind_Max > 200){
    Wind_LED.setPixelColor(1, Wind_LED.Color(brightness*red/255,
brightness*green/255, brightness*blue/255));
    ledWind = 2;
  }
  if(Wind_Max > 400){
    Wind_LED.setPixelColor(2, Wind_LED.Color(brightness*red/255,
brightness*green/255, brightness*blue/255));
    ledWind = 3;
  }
  if(Wind_Max > 600){
    Wind_LED.setPixelColor(3, Wind_LED.Color(brightness*red/255,
brightness*green/255, brightness*blue/255));
    ledWind = 4;
  }
  if(Wind_Max > 800){
    Wind_LED.setPixelColor(4, Wind_LED.Color(brightness*red/255,
brightness*green/255, brightness*blue/255));
    ledWind = 5;
  }
  else{ledWind = 0;}
Wind_LED.show();
}

Serial.print(", Max Wind: ");
Serial.print(Wind_Max);
}

\the section that controls the piezo-electric / stepping module
void stepping_power(){
  \color of the leds 0 - 255
int red = 255;
int green = 255;
int blue = 255;
brightness = 255; \ brightness of the leds 0 - 255

Step_LED.clear();
\read the voltage from the piezo electric buzzers
step_power_1 = analogRead(Step_input_1);
step_power_2  = analogRead(Step_input_2);
step_power_3 = analogRead(Step_input_3);

\to make the lamps turn off after a little bit instead of immediately
```

```
\only one of the buzzers is working well
if(step_power_2 >= step_power_max){
   step_power_max = step_power_2;
}
else{step_power_max -= 2;}

\turn on leds after the value is larger than this value, chosen based on the
average input without any input
if(step_power_max > 250){
  for(int led = 0; led < Step_Num_LEDs; led++){
    Step_LED.setPixelColor(led, Step_LED.Color(brightness*red/255,
brightness*green/255, brightness*blue/255));
  }
  ledStep = 1;
    }
else{ledStep = 0;}

Step_LED.show();
Serial.print(", step power: ");
Serial.print(step_power_max);
}

void nuclear(){
\read value of the potentio meter
Nuclear_control = analogRead(Nuclear_input);

\add or subtract value from the amount of nuclear critical to determine the
color of the leds of the ledstrip
if(Nuclear_control > 0 && Nuclear_control < 1000){
  Nuclear_critical -= 1;
}
else if(Nuclear_control >= 1000 && Nuclear_control <= 2000){
  Nuclear_critical += 2;
}
else if(Nuclear_control >= 2000 && Nuclear_control <= 3000){
  Nuclear_critical += 4;
}
else if(Nuclear_control >= 3000 && Nuclear_control <= 4000){
  Nuclear_critical += 8;
}
else{Nuclear_critical -= 2;}

if(Nuclear_critical <= 0){
Nuclear_critical = 0;
}
else if(Nuclear_critical >= 6000){
Nuclear_critical = 6000;
}
```

```
\determine how many leds need to be turned on
if(Nuclear_control > 0){
  ledNuclear = int(Nuclear_control / 200) + 4;
}
if(Nuclear_control == 0 && timer < 1){\ turn of leds one at a time every 500
ticks.
  ledNuclear -= 1;
  timer = 500;
}
else{timer -= 1;}

Serial.print(", nuclear: ");
Serial.println(Nuclear_critical);
}


\controls the external led strip of the platform
void LEDstrip(){
\color of the leds 0 - 255
int red = 0;
int green = 255;
int blue = 0;
brightness = 50; \brightness of the ledstrip 0 - 255

outsideLED.clear();

\determines the color of the leds based on the nuclear_critical value
\incremented or decremented in the nuclear section of code
if(Nuclear_critical > 0){
red = map(Nuclear_critical, 0, 2000, 0, 255); \go from green to yellow
green = 255;
blue = 0;
}
if(Nuclear_critical > 2000){
red = 255;
green = map(Nuclear_critical, 2000, 4000, 255, 0); \go from yellow to red
blue = 0;
}
if(Nuclear_critical > 4000){
red = 255;
green = 0;
blue = 0;
}
if(Nuclear_critical > 5850 && NuclearTimer <= 100){ \turn leds on every 100
ticks
red = 255;
green = 0;
blue = 0;
```

```
NuclearTimer += 1;
}
else if(Nuclear_critical > 5850 && NuclearTimer <= 200){ \turn leds off every
100 ticks
red = 0;
green = 0;
blue = 0;
NuclearTimer += 1; \timing device
}
else{
  NuclearTimer = 0;
}


\turn on led strip
for(int led = 0; led < ledNuclear; led++){
    outsideLED.setPixelColor(led, outsideLED.Color(brightness*red/255,
brightness*green/255, brightness*blue/255));
}
  outsideLED.show();
}
```

References

[1] steve mould. (), [Online]. Available: https://www.youtube.com/@SteveMould (visited on 08/04/2024).

[2] steve mould. "The pythagorean siphon inside your washing machine." (), [Online]. Available: https://www.youtube.com/watch?v=Cg8KQfaT9xY&t=1s (visited on 08/04/2024).

[3] steve mould. "How to make a really simple motor." (), [Online]. Available: https://www.youtube.com/watch?v=0eOL7uVJnHw (visited on 08/04/2024).

[4] steve mould. "Mechanical circuits: Electronics without electricity." (), [Online]. Available: https://www.youtube.com/watch?v=QrkiJZKJfpY (visited on 08/04/2024).

[5] spintronics. (), [Online]. Available: https://upperstory.com/spintronics/ (visited on 08/04/2024).

[6] B. Haidet. (), [Online]. Available: https://www.youtube.com/@AlphaPhoenixChannel (visited on 08/04/2024).

[7] W. Asghar. "Best electrical engineering specializations." (), [Online]. Available: https://www.studyforfe.com/blog/electrical-engineering-specializations/ (visited on 18/04/2024).

[8] "What are different fields in electrical engineering?" (), [Online]. Available: https://www.quora.com/What-are-different-fields-in-electrical-engineering (visited on 18/04/2024).

[9] "Electrical engineering." (), [Online]. Available: https://en.wikipedia.org/wiki/Electrical_engineering (visited on 18/04/2024).

[10] "What do electrical engineers do?" (), [Online]. Available: https://www.nu.edu/blog/what-do-electrical-engineers-do (visited on 18/04/2024).

[11] "What is power engineering?" (), [Online]. Available: https://www.myelectriccareer.com/what-is-power-engineering (visited on 24/04/2024).

[12] "Control systems - introduction." (), [Online]. Available: https://www.tutorialspoint.com/control_systems/control_systems_introduction.htm (visited on 24/04/2024).

[13] "What is telecommunications?" (), [Online]. Available: https://www.mitel.com/articles/what-is-telecommunications (visited on 18/04/2024).

[14] “What is electronics engineering? (duties, skills and salary).” (), [Online]. Available: `https://www.indeed.com/career-advice/finding-a-job/what-is-electronics-engineering` (visited on 24/04/2024).

[15] “Microelectronics – definition, benefits, circuits, and faq.” (), [Online]. Available: `https://www.electronicsforu.com/technology-trends/learn-electronics/microelectronics-definition-benefits-circuit-faq` (visited on 18/04/2024).

[16] C. MacKay, R. Skow, M. Tymko *et al.*, “Central respiratory chemosensitivity and cerebrovascular co2 reactivity: A rebreathing demonstration illustrating integrative human physiology,” *advances in physiology education*, 2015.

[17] W. Loren, “A visual measurement of the speed of sound,” *North Carolina school of science and mathematics*, 1993.

[18] T.-G. Mimi, “”there’s so much more to it than what i initially thought”: Stepping into researchers’ shoes with a class activity in a first year psychology survey course,” *psychology learning & teaching*, 2015.

[19] B. McGuire, B. Carroll, A. Boynton, J. Mendez and G. Blake, “Ignition of thermite using the potassium chlorate “rocket” reaction: A systematic demonstration of reaction chemistry,” *journal of Chemical Education*, 2015.

[20] L. K. Chan, “Pulling my gut out—simple tools for engaging students in gross anatomy lectures,” *anatomical sciences education*, 2010.

[21] C. Vongsawad, M. Berardi, T. Neilsen, K. Gee, J. Whiting and J. Lawler, “Acoustics for the deaf: Can you see me now?” *The physics teacher*, 2016.

[22] S. Blackley, Y. Rahmawati, E. Ftriani, R. Sheffield and R. Koul, “Using a makerspace approach to engage indonesian primary students with stem,” *Issues in Educational Research*, 2018.

[23] S. Schmidt, D. Bohn, A. Rasmussen and E. Sutherland, “Using food science demonstrations to engage students of all ages in science, technology, engineering, and mathematics (stem),” *Food science education*, 2012.

[24] J. Overduin, V. Polyak, A. Rutah, T. Sebastian, J. Selway and D. Zille, “The hunt for red october ii: A magnetohydrodynamic boat demonstration for introductory physics,” *The Physics teacher*, 2017.

[25] M. Ahmed, Y. Anderson, T. Goins *et al.*, "Promoting stem-literacy by designing decision-driven interdisciplinary courses for non-science majors," *journal of STEM education*, 2020.

[26] P. Taylor, "Why is a steam curriculum perspective crucial to the 21st century?," 2016.

[27] A. Mader and W. Eggink, "A design process for creative technology," 2014.

[28] J. Fermoso. "Power generating floor in train stations light up holiday displays." (), [Online]. Available: https://www.wired.com/2008/12/power-generatin/ (visited on 15/07/2024).

[29] "Energy sources of the future: Seaweed and jellyfish." (), [Online]. Available: https://sofamel.com/en/b/news/news/p/las-fuentes-energeticas-del-futuro-algas-y-medusas-37-2 (visited on 15/07/2024).

[30] "You're considering a career in electrical engineering. what are the most common myths you should know about?" (), [Online]. Available: https://www.linkedin.com/advice/1/youre-considering-career-electrical-engineering-1twpe (visited on 15/07/2024).

[31] "Analog electronics definition, circuits, and applications." (), [Online]. Available: https://www.electronicsforu.com/technology-trends/learn-electronics/analog-electronics-basics (visited on 15/07/2024).

[32] "Elektriciteitsbalans; aanbod en verbruik." (), [Online]. Available: https://www.cbs.nl/nl-nl/cijfers/detail/84575NED (visited on 21/04/2024).

[33] "Gemiddeld energieverbruik per woningtype/aantal personen." (), [Online]. Available: https://besparingsland.nl/blog/gemiddeld-energieverbruik-nederland (visited on 21/04/2024).

[34] "Yearly electricity data." (), [Online]. Available: https://ember-climate.org/data-catalogue/yearly-electricity-data/ (visited on 18/07/2024).

[35] W. Sullivan. "This new device generates electricity from thin air." (), [Online]. Available: https://www.smithsonianmag.com/smart-news/this-new-device-generates-electricity-from-thin-air-180982263/ (visited on 18/07/2024).

[36] "The strangest ways to generate energy." (), [Online]. Available: https://www.cepsa.com/en/planet-energy/sustainable-innovation/ways-to-generate-energy (visited on 18/07/2024).

[37] "How data center energy efficiency promotes savings." (), [Online]. Available: https://www.tierpoint.com/blog/data-center-energy-efficiency/#:~:text=Server%20workloads%20and%20demand%20can,1%2C000%20kWh%20per%20square%20meter. (visited on 21/04/2024).

[38] "Stroomnet overbelasting oorzaken." (), [Online]. Available: https://www.essent.nl/kennisbank/zonnepanelen/hoe-werken-zonnepanelen/stroomnet-overbelast (visited on 18/07/2024).

[39] "Esp32 pinout reference." (), [Online]. Available: https://lastminuteengineers.com/esp32-pinout-reference/ (visited on 21/07/2024).

[40] "What is the piezoelectric effect?" (), [Online]. Available: https://www.nanomotion.com/nanomotion-technology/the-piezoelectric-effect/ (visited on 21/04/2024).

[41] "Ws2812b leds: Power consumption?" (), [Online]. Available: https://www.eevblog.com/forum/projects/ws2812b-leds-power-consumption/ (visited on 21/04/2024).

[42] "Current consumption measurement of modules." (), [Online]. Available: https://docs.espressif.com/projects/esp-idf/en/v5.2.2/esp32/api-guides/current-consumption-measurement-modules.html (visited on 21/04/2024).