Developing a Rapid Prototyping kit

For the Design of Creative Technology for Sports and Movement

Ysbrand Burgstede

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UNIVERSITY OF TWENTE.

Supervisors	Dees Postma & Richard Bults
Program	Creative Technology
University	University of Twente
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Abstract

We are living through a global health pandemic. According to the Dutch Central Bureau for Statistics 16% of Dutch adults are classified as obese in 2023, which is triple what it was 40 years ago [1]. To address this issue, the Human Media Interaction (HMI) research group from the University of Twente researches how technology can be used to encourage physical activity and teaches students of Creative Technology how to apply this knowledge to product development. This is done through the Research and Design of User Experience (ResDexUX) project. In this project, the students first come up with an idea for a system that can aid in sports and movement. Then they make a low-fidelity prototype of it to validate the idea. Afterwards, they have to construct a working prototype that involves technology. Despite the goal of the project being the user experience of the prototypes, the students are often found spending considerable time on the technical implementation of these high-fidelity working prototypes.

This graduation project investigates how a design system could aid Creative Technology students in making these high-fidelity prototypes. To achieve this goal multiple tools were developed to aid the students in selecting, implementing and integrating these technologies. To help the students choose technologies for their projects a website was developed featuring a filtering system, choice helper, and extensive documentation on the technologies. To help the students implement the technologies the documentation includes wiring instructions and code examples. Lastly, to help the students connect different technologies a novel tool was developed showing an interactive network graph of the technologies selected for the prototype, with the technologies needed to link them together automatically selected. This was done alongside Sven Rozendom[2] research on which technologies to support. Along with the creation of a physical box containing the selected technologies and small business cards to be able to reference the technologies quickly.

The usability of the toolkit as a whole was evaluated through user testing, including observations taken by the researchers along with interviews and the System Usability Score (SUS). Through this testing, the toolkit shows promising potential in aiding students in the technical implementation of their high-fidelity prototype.

Acknowledgement

First and foremost I would like to thank Sven Rozendom for collaborating on this project. I truly believe the achieved end result is more than we both thought was possible in 20 weeks, and we would not have come half as far on our own. In the beginning, having someone to brainstorm with has proven very valuable, and when splitting the project we have nicely complemented each other.

I want to thank Dees Postma, both in his role as supervisor, and also in his role as client for guiding us through this project. Without him, this would not have been possible. I also would like to thank Richard Bults, not only in his capacity as a critical observer but also for pushing us early on to scope this project and make our ideas more tangible.

Additionally, I would like to thank Ellis Dijkstra for helping me get structured in this Graduation Project and lending a sympathetic ear whenever needed.

Contents

List of Figures

List of Tables

1 Introduction

We are living through a global health pandemic. According to the Dutch Central Bureau for Statistics 16% of Dutch adults are classified as obese in 2023, which is triple what it was 40 years ago [1]. Kids are playing less and less outside and overall physical literacy is declining.

To help better this situation the Human Media Interaction group (HMI) of the University of Twente researches how we can use technology to get people to move more or with more proper techniques. One such example is the "Smart Sports Exercises" project that aims to develop new interactive ways to train for volleyball[3].

In addition to research, HMI also teaches students of the program Creative Technology how to design, realise and evaluate the interaction between people and technical systems. The course they give is called "Design and Research of User Experience". Here students learn how to design a low-fidelity prototype of an interactive system and how to test it with their intended user group to validate their ideas. A low-fidelity prototype is a low-cost, low-effort prototype which allows for quick iteration. This prototype does not have to feature any technology but should provide the intended user experience. When the students are satisfied with the interaction between the user and the low-fidelity prototype they make a fully working ICT-based prototype. The main focus of this project and prototype is the user experience.

The technical decisions made here are to make the user experience possible. For instance, with the smart throwing targets[4] that have been a product of this project, the added value to the athletes was not the exact wireless technology or LED strips used, but instead the overall experience that the athletes got to enjoy. Despite this, the technical details are where the average group in this project spends a relatively large amount of time. They need to make a technical design and research which sensors and actuators to use. Then they need to solve how to make these parts work together and by what method to distil the raw data provided by the sensors into the information they are interested in.

The challenge here lies in the fact that for the high-fidelity prototype, we are not interested in the individual piece of technology, but in the user experience it can provide. Ideally, you can take a functional requirement like "needs to be able to measure the heart rate of a field hockey player on the field" and have a guide on which technologies to put together to achieve this, and what strengths and trade-offs these technologies provide.

Due to the breadth of this Graduation Project, it was done in collaboration with Sven Rozendom [2]. The parts done in collaboration are the background research and the ideation phase. The Evaluation was also done in collaboration to evaluate the system as a whole.

1.1 Problem statement

To further empower Creative Technology students in creating creative solutions using technology in sports, and help them focus on the user experience, we want to provide them with a design system that aids them in designing the technical aspect of these high-fidelity prototypes tailored to sports.

Main research question

To help the students realise their high-fidelity prototypes the main research question needs to be answered:

- How can we support the technical design practices of students aiming to design interactive systems for sports using a design system?

Sub research questions

To effectively answer the main research question we will first need to answer the following sub-research questions:

- What (interactive) technologies are currently already used in sports research?
- What functions did the previous students want to achieve in their projects?
- What sensing, actuating and support systems should be supported by our toolkit?
- What information should the students be provided about these systems?
- What is the best way to present this information to the students?

2 Background Research

To give a solid basis for the rest of the research, it is important to provide a clear overview of the existing research, technologies and products within the design space for sports. This background research will be used as the foundation for the ideation phase of this paper. To give a framework for this, we will first describe the kinematics sports. This is an important field to quantify the technique of an athlete. Then, the important physiological factors for indicating an athlete's performance will be discussed, along with the relevant sensors for measuring these factors, both in and outside of the lab. At last, currently available solutions from which inspiration can be drawn will be discussed in the state of the art.

2.1 The kinematics of sports

To know how one plays a sport we must be able to define the movements one makes. This is the area of kinematics. This area focuses on describing the position, velocity, and acceleration of objects as they move through space and time. Within sports, the subjects of interest are not just any objects, but in particular the position of human bones. This data can be used to calculate forces on the human body and to create a representation of possible movements.

Optical motion sensing

Optical motion sensing is the process of capturing motion through cameras. These systems derive the position and angles of joints from their input. A subset of optical sensors called marker-based optical sensors are considered the golden standard in the field of motion analysis because of their accuracy in measuring kinematic parameters[5][6]. Optical sensor systems require static cameras to be placed around the subject of interest. With the right setup and calibration, their error rate can be submillimetre. Aurand et al.[7] even acquired an accuracy of 200 µm and under over an area of $135m^2$.

However, the use of optical sensors may not always be feasible, as the cameras need to have a clear line of sight. For instance, when Gandalla et Al.[8] were designing a tracking system to track swimmers underwater, this category of sensors was ruled out because the water distortion made the results inaccurate. Furthermore, the amount of cameras influences practicality and accuracy. When Aurand et al.[7] remeasured their accuracy with 21 cameras instead of their initial 42, their measured error dropped from under 200 µm over 97% of their area, to only 91%.

Optical motion sensors can be segregated into two categories: systems that use markers placed on the subject (marker-based), and systems that estimate the position of joints purely through the use of the incoming image (markerless). These techniques will be discussed in the paragraphs below.

Marker-based optical sensing

The common factor among marker-based sensing systems is exactly like the name implies: markers are put on predetermined points of interest in the human body. The position of these can then be interpreted and mapped to a human skeleton model. This is currently considered the golden standard in high-fidelity tracking[5][9]. However, these systems can be quite expensive, in the range of €8000-€150000[10]. Marker-based optical imaging systems used for sports place markers on top of the skin. According to Ceseracciu et al.[6] this is where the first limitation of these systems comes in. They note skin does not stay perfectly still relative to the underlying skeleton, which is defined as a "skin artefact". "skin artefact" is the error in joint position due to the movement of the sensor due to skin. Schroeder et al. further add that due to this measurement errors of a few millimetres and degrees are unavoidable.

A second limitation is that a marker must always be visible to at least two cameras to estimate its position [10]. Another aspect to consider in marker-based sensing is the markers' complexity. Chiari et al.[11] indicate there are two types of markers, passive and active. Active markers send out some sort of signal (most commonly infrared light) themselves which is picked up by the cameras. Passive markers are markers that do not emit a signal. Their research seems to suggest that the sample rate of active markers can be higher than that of passive markers. Van Schaik et al.[10] agrees with this, and adds that they can achieve a higher resolution and are less susceptible to errors from reflective surfaces. This is in stark contrast with actual tests from Schroeder et al., where the two tested active marker technologies came out with the lowest accuracy. These benefits seem to be implementation-specific.

Markerless optical sensing

Markerless optical sensing is measuring kinematics with only images of the subject. The angles and positions of the joints are estimated based on a computer vision algorithm. The computer takes the full-body image and runs it through a neural network which then tries to determine the angle and rotation of the limbs. This technology has already been proven able to achieve an accuracy of under 30mm in walking and jumping[12].

Accuracy and ability are two limitations of markerless motion sensing. In the research of Ceseracciu et al.[6], certain knee extension angles were found to be unreliable when measured with markerless technology. In addition, the earlier mentioned 30mm of accuracy is at least two factors of accuracy behind the golden standard of marker-based sensors.

Inertial-based motion tracking

Inertial-based motion tracking combines data from multiple sensors to estimate the position of the sensor in 3D space. These sensors commonly are an accelerometer, gyroscope, and magnetometer, which can measure acceleration, orientation and gravity [13]. Of these factors, you can derive the movements made from the starting position. These sensors combined are called Inertial Measurement Units or IMUs [14]. Van Schaik et al. adds that optionally a Magnetometer can be included to determine the sensor's orientation in space, resulting in an M-IMU. These systems can be acquired relatively cheaply, in the range of €50-€5000[10].

One of the advantages of inertial-based motion tracking is that the system can be self-contained. After initialization, the sensors can record their data on their own. There is no need for outside processing or observation. Research performed by Ianculescu et al. [14] has even shown that the processing required for this form of motion capture can be done in real time with a companion smartphone app. This means this type of sensor can be used outside of a controlled environment.

The accuracy of inertial measurement units drifts over time. According to Comilla et al.[15] this effect is caused by the natural drift of a gyroscope. The position of an IMU is derived from their movement over time. Due to this, errors also accumulate over time. Filippeschi et al.[16] has measured the average position error for an IMU-based system and found an average position error of 35mm.

Motion sensing for the purpose of high-fi-prototypes

The three types of motion sensing described above can quantify the position of objects and in particular human bones. For our purposes, all of them could be useful. Which one would be preferred is highly dependent on the circumstances. Keeping in mind that the user experience is the main focus of the Research and Design of User Experience Project, the setup time and the ability to be non-intrusive for a participant is important. Therefore markerless and IMU-based motion sensing makes the most sense.

2.2 The physiological aspect of sports

As humans, we continuously strive to push the boundaries of athletic performance. We aim to go harder, better, faster and stronger. An athlete's technique can be measured with the earlier described motion sensing. Another important factor then presents itself: for how long can the athlete sustain the effort? Joyner and Coyle[17] suggest that for endurance in sports, three aspects are important: an athlete's VO_{2_max} and lactate threshold. These measures are generally considered good parameters for tracking and estimating an athlete's performance. [17][18][19]

An athlete's VO_2max is the maximal oxygen uptake they can consume and use on sea level. It is measured by the maximum millilitres of oxygen consumed in 1 minute per body weight in kilograms. This is considered the gold standard for measuring a person's aerobic fitness level.[20][19][21] To measure an athlete VO_2max, one needs to measure the oxygen-rich air going into the athlete's lungs and the resulting less oxygen-rich air coming out of them. To do this, refined gas analysis equipment is necessary to assess oxygen consumption accurately, which is connected to the participant with an oxygen mask.[19] The athlete needs to do a test to exhaustion, which is called a maximal test. Noonan and Dean[22] state doing maximal testing can be dangerous for people with a wide range of (unknown) conditions, as the body gets strained to the fullest. Both the gas analysis system and the test till exhaustion make this an invasive method. Outside of the lab, Shandhi et al.[23] have proven with their research that instantaneous VO_2 can be deduced from a non-intrusive patch on an athletes sternum containing a seismocardiogram (SCG), an electrocardiogram (ECG) and an atmospheric pressure (AP) sensor. Cook et al. shows the same ability to measure this with a non-invasive and non-intrusive method measuring with a single lead ECG device combined with an accelerometer worn around the waste. This in combination with the submaximal tests described by Noonan and Dean [22] can give an estimation of a person's aerobic fitness level without being intrusive and invasive.

A sporter's lactate threshold is the point of deflection where the blood-lactate concentration rises exponentially[24]. McGehee et al.[24] state that this is a good indicator of performance for (long) distance runners. In their research in the lab, the lactate threshold is measured in a lab using a sample of blood from the athlete's finger every 4 minutes. This is an invasive and expensive process, as you also need the technical expertise to analyze the lactate in the blood. McGehee et al.[24] further researched methods to estimate the lactate threshold. They found the lactate threshold can be estimated outside of a lab with a simple heart-rate monitor or known distance of a running track, as there is a strong relationship between heart rate and the lactate threshold, and between running velocity and the lactate threshold using a 30-minute time trial method. This has runners running at a self-selected race pace at a 1% grade after a warm-up. The lactate threshold can be calculated by measuring the distance run and the average heart rate.

In conclusion, interesting physiological sensors to estimate and keep track of an athlete's performance are heart rate and running velocity for estimating an athlete's lactate threshold, which a heart rate sensor and accelerometers can measure. To estimate VO_2max, a seismocardiogram (SCG) with an electrocardiogram (ECG) and an atmospheric pressure sensor in combination with a predefined running are of interest.

2.3 State of the art

In this state-of-the-art, relevant technologies to a toolkit for sports and movement will be looked at. This will include relevant measuring technologies, data processors and support systems. Inspiration for a configurator tool will also be mentioned.

motion sensing

The state-of-the-art sensors for the earlier-mentioned optical-based motion tracking are currently the optiTrack systems [25]. Their cheapest option for a camera is their Prime^{x}13 camera which boasts 0.2 mm 3d accuracy and costs $2,499 per camera. When using the configurator tool on their website a system that has a capture volume of a 5x5x2 meter area with 16 cameras the total price is $37,205, which can be seen in Figure 1.

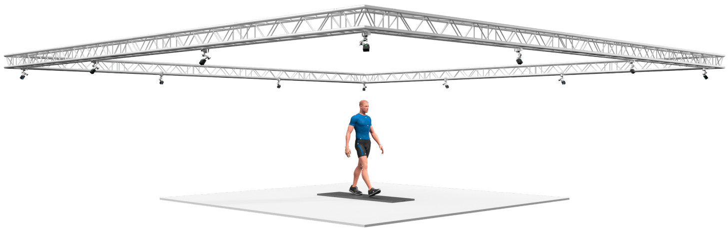


Figure 1: An optiTrack system. Multiple camera angles and physical markers are used to track movement.[25]

The state-of-the-art system for IMU-based motion tracking is the tracking suits made by Movella[26]. These suits measure the acceleration and rotation of each of their sensors and use their software to calculate this into kinematic data. Their full-body tracking suit costs $4590 and needs to store its data until a computer can process it. Their cheaper option is the Movella Dot which can be seen in Figure 2. This is a package of 5 individual sensors which can connect to a smartphone to provide real-time data. At the time of writing this costs €750.00 for the full package, and provides a Software Development Kit to write your own code against.

Figure 2: The Movella Dot package that uses IMUs to provide real-time data[27].

Supporting technologies

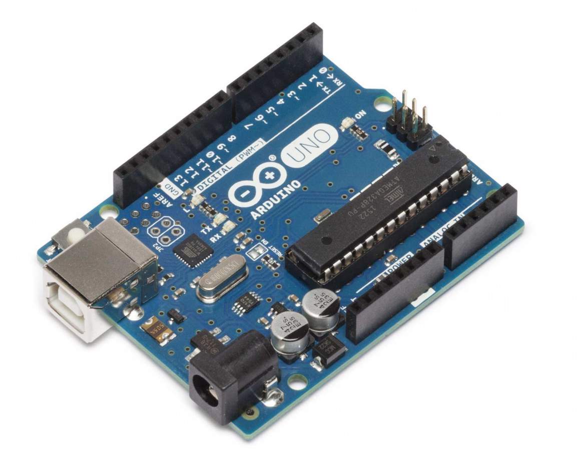
One of the problems that is aimed to be solved is making the use of sensors for students easier. To do this the supporting systems of the sensors and actuators also have to be considered. The sensors you can buy have to be interfaced with code to be able to make decisions based on their data. This has to happen both on a physical and software level.

To interface with a sensor a device is needed that can read the electrical signals the sensor is producing. This is where microprocessors come in with General Input and Output Pins (GPIO). In the study of Creative Technology (CreaTe), the students already learn to work with the Arduino family of microprocessors[28], more specifically with the Arduino Uno which can be seen in Figure 3a. This microprocessor can deal with input analogue and digital input signals of up to 5 Volts. It can also produce signals of up to 5 Volts to control other devices. It can be programmed using a subset of the C++ programming language.

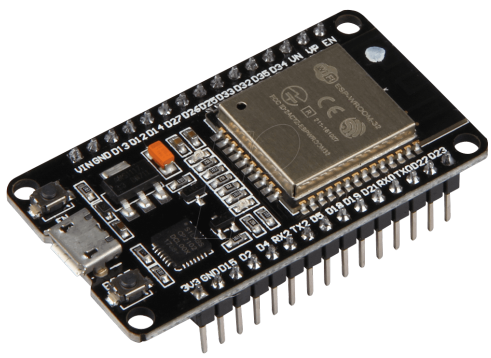
For the electrical interface to work there has to be a physical connection to the sensor. Wiring everything up to the correct pin takes time and is prone to errors. This is where the Arduino ecosystem has invented shields. Shields are complimentary printed circuit boards (PCB) which take care of the physical connections to an Arduino, by plugging into the headers on top of the Arduino. If extra circuitry is required, for instance, to step up or down the voltage of a sensor or amplify the signal, this can be included as well. This makes interfacing a sensor a click-together-like experience.

With the sensor connected to the board, software to interface with the sensor is still needed. This software can vary wildly per sensor and information protocol used. This is where libraries come in. These are pieces of complementary software that make interfacing with a sensor or protocol easier. For instance, it can take the raw pulses from a sensor, and convert it to the intended measurement.

The Arduino Uno does not come standard with wireless technologies, and its processing capabilities are not the fastest. The Arduino standard and design are open-source, and therefore different companies are able to make Arduino-compatible products. This is often done to extend the capabilities. One such example is the ESP-32 development board made by Espressif[29], which can be seen in Figure 3b. This board adds the ability to wirelessly connect over Bluetooth and WiFi, along with a faster processor.



(a) An Arduino Uno [28]



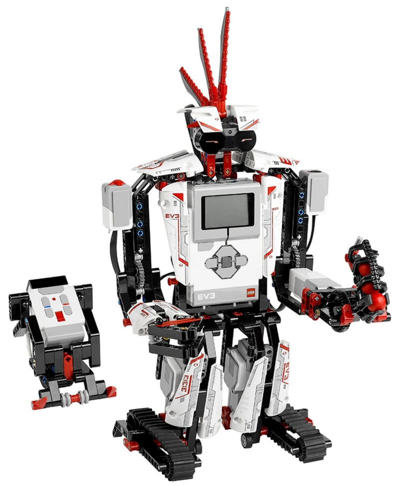
(b) An ESP32 development board [29]

Figure 3: Development boards

An interesting project to mention that already combines all the mentioned fields is the IMU packages made in-house by the University of Twente for the course "Biosignals & Medical Electronics" which is given in Module 8 of CreaTe. They have made relatively small ready-to-use sensor packages which include a Bluetooth-ready development board, an MP6050 IMU sensor which is capable of measuring 6 degrees of freedom and a battery with a charging circuit. The students can connect to this over the Bluetooth protocol and use the Python library that is specifically made for this package[30]. The package gives you the raw XYZ data and XYZ data of the gyroscope. This makes it so the students can easily access this data without having to think about the technical implementation of the sensor and the supporting technologies.

When designing a design system, the level of abstraction it provides should be considered. In the earlier described Arduino shields, the electrical logic to convert the signals from the sensor to something an Arduino can read is abstracted from the designer. With a library, the conversion from the signals is abstracted. These abstractions are trade-offs between ease of use for the designer and control over the sensor. An example of a system where almost everything is abstracted is the Lego Mindstorms system (Figure 4). Lego has designed a central "brain" (Figure 4a) where all supported sensors and actuators are plugged in via the same physical connector. They also provide a visual programming environment where you can link measurements to actions, for instance, if the distance sensor is closer to an object than 5cm, drive the motor. This allows you to build your own complex systems like robots (Figure 4b). They abstract away everything from the sensor-specific code to the electrical implementation. This has the benefit that it is trivial to assemble a system, with the drawbacks being that only sensors they make are supported and finer control than they provide is not achievable.

(a) The Lego Mindstorms system[31]



(b) A robot made with Mindstorms [31]

Figure 4: The Lego Mindstorms system

A middle ground of this level of abstraction is the sensors produced by a company like Adafruit. These sensors are more sensor packages and provide all the supporting circuitry on the package. With each sensor, they provide the documentation and Arduino code necessary to get started. One such example is their 9 degrees of freedom BNO085 motion sensor[32] which combines all of the sensors you need for an IMU with a processor and firmware to give you the acceleration and gravity factor together with the absolute rotation straight out of the package. It combines the data of the three types of sensors together so the user does not need to know the physics behind it. They also provide getting-started guides and extensive documentation to get you up and running quickly. This would be a good direction to take this project as this leaves most of the control with the designer but abstracts away the hard sensor-specific part.

Recommendation systems

When building a high-fidelity prototype implementing and getting the data out of the sensor is only one step of getting your prototype to work. The first step of that process is knowing which sensor, technology and supporting systems to use. Earlier in the background research three types of motion sensing were already described. With motion sensing alone the right type of system can be highly dependent on the environment and circumstances the high-fidelity prototype needs to function in. With an array of ideal easy-to-use sensors the designer still needs to be guided to the right one for the prototype. This is where a recommendation system comes in. Such systems already exist for other domains, like the consumer technology market. This market has the same challenges as our problem, as the end-user knows what they want to achieve with the product, and the technical details dictate what the product can achieve, but the user is not necessarily interested in the technical details. As an example, the general population cares about how quick their cellular is when using the web but does not care about which specific type of antenna is in there or even which type of cellular they are using.

The first approach to such a recommendation system in this domain is the website tweakers.net [33]. Here you can filter on technical aspects of a phone, like which processor and how much system memory it has. When you have found two or more you want to choose between they can be added to the comparison, which takes you to the comparison page. This page can be seen in the Figure 5. It simply lists all the technical specifications of the two phones next to each other in one big list. This would be helpful when one knows exactly what to look for in a phone, or to make the final decision between your two last remaining choices.

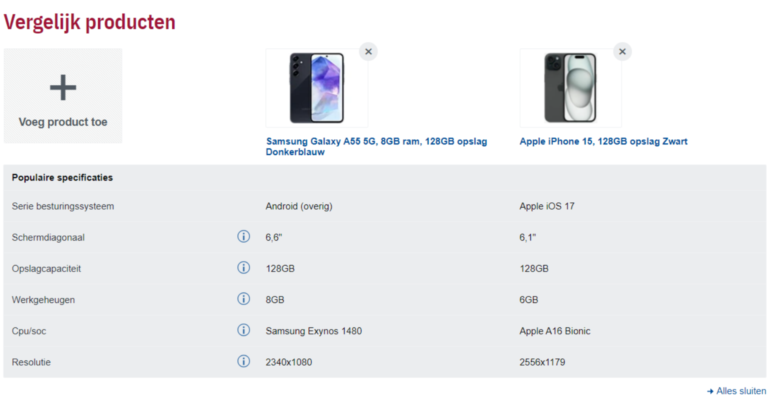


Figure 5: The comparison tool on the Tweakers website. [33]

Another approach is the choice helper of the Consumentenbond[34] as seen in

Figure 6. This choice tool asks the consumer functional questions about the device they would want to purchase, like if they are going to use it to take photos, if yes how often and how professional and how they expect to unlock their phone. This system then filters the technical abilities of the phones to be within the expected parameters and even recommends the option it thinks suits best.

Figure 6: One of the questions on the Consumentenbond website [34]

The style of the comparison tool of the Consumentenbond would be more appropriate for this project because if the designer knew all the technical details of the sensor in advance this research would not be needed.

3 Methods and Techniques

The method used to design the toolkit will follow the Creative Technology design method described by Mader and Eggink[35] and visualised in Figure 7. This process has four main phases: Ideation, Specification, Realization, and Evaluation. Do note that these phases are not linear but cyclical. When a later phase reveals shortcomings one iterates upon earlier stages to try to negate the discovered problem. In the subsections hereafter the four phases will be discussed. The detailed version of each phase can be read in their respective chapters. The Ideation and specification phases have been performed twice. In the first round, the design space of the entire toolkit was discovered. Hereafter the split was made in this Graduation Project between the physical toolkit, which became the responsibility of Sven[2], and the envisioned support website, which is further worked out in this graduation project.

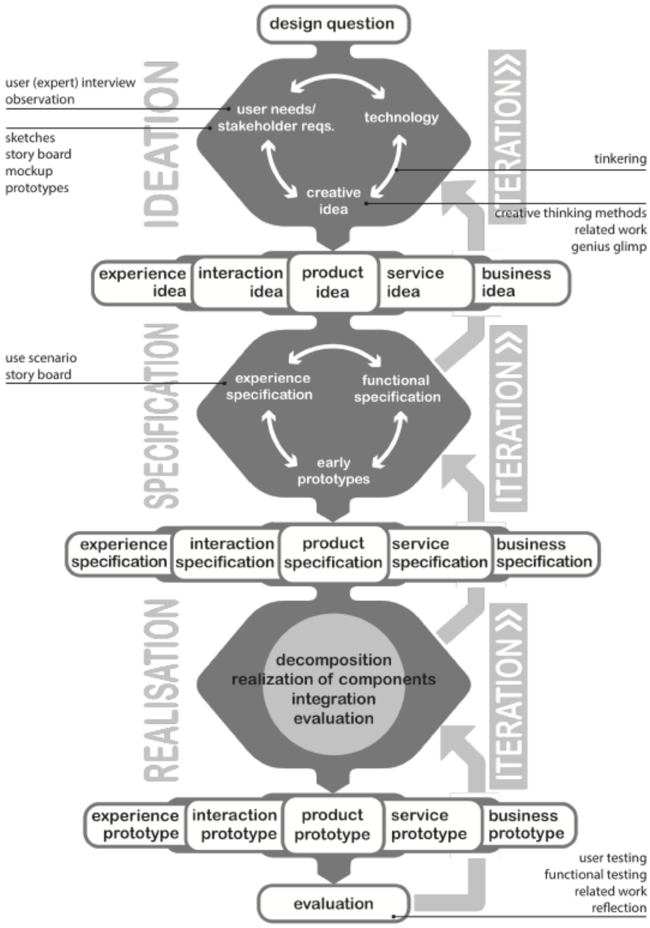


Figure 7: The Creative Technology Design Process.

3.1 Ideation Phase

The Ideation phase is where the original design question is transformed into an elaborated product idea. This is done through a back-and-forth between problem definition, acquisition of relevant information and related work. Here a multitude of different ideation techniques can be applied to generate creative ideas. For this project, we started the ideation phase from the needs of the client. This was done because the design question was user (client) initiated. The scope of the project was set with a thematic analysis performed on project reports of past projects done in Module 6 of Creative Technology. The end goal of this phase is to have a more clear idea of the final product, together with the requirements it needs to have. Multiple ideas were thought of and discussed with the client. These ideas cover the physical form of the toolkit but also what the contents should be. The requirements in this phase have been formulated according to the MoSCoW method [36]. This means that the requirements have been split up into four categories: Must have, Should have, Could have and Will not have (MoSCoW).

3.2 Specification Phase

The Ideation phase flows over into the Specification phase. Here the design space is discovered using multiple prototypes which are evaluated to form a short feedback loop. For this project, multiple small prototypes were made to discover different aspects of the design space for the toolkit. With a small prototype of a building block the abstraction level of a building block in the kit was determined. Furthermore, with cards and information sheets, the amount of information the kit should provide per item was explored. The end of this phase resulted in a product specification for the toolkit. Further specification for the website has been done using Unified Modeling Language (UML) diagrams. Finally, a medium-fidelity prototype was made and tested to further define the specification.

3.3 Realization Phase

With the product specification, the realisation phase can be started. This phase works towards an actual product, realising and integrating the necessary components. In this phase, the actual toolkit was made. The realised toolkit consists of two parts, the physical toolkit and the online support platform. The physical toolkit and information are constructed by Sven Rozendom [2] and the support platform in the form of a website is constructed by the author of this paper. The realisation of the support website follows the earlier mentioned UML diagrams.

3.4 Evaluation Phase

After realising an actual product, the Evaluation phase starts. Here, final user testing was done to evaluate the product concerning the earlier determined requirements. This testing was done with the whole toolkit, meaning the physical toolkit in combination with the support website. After doing the test the users were subject to an interview and the filling out of a System Usability Score (SUS). Reflection on the design process was also performed in this phase, as found in the Discussion.

4 Ideation

In this section, the original design question will be transformed into an idea for a final product. To start the ideation phase we need the stakeholder requirements and the user needs. These will first be identified through a stakeholder analysis, interviews and a thematic analysis. Afterwards, product ideas will be generated to help the users achieve their goals.

4.1 Stakeholder analysis

To develop a product that will be effective for our stakeholders, they first need to be identified. This can be done by the question thought of by Mendelow [37]: "Who are the persons, organizations, and institutions which could influence the ability of the organization to realize its goals?". The first step in the identification process was interviewing our clients. The identified stakeholders can be found in the subsequent sections below. Their needs and interests will be stated, and how they can influence this project. This will later be used to construct Mendelow's power interest matrix to get an insight into their control over the project.

Client

Our client is Dees Postma. He is a professor at the Human Media Interaction (HMI) group at the University of Twente. He also gives the Research and Design of User Experience (ResDexUX) project which the toolkit will primarily be designed for. The client has given us the assignment to build a physical toolkit comprised of functional building blocks with which the students are enabled to prototype quicker.

Functional building blocks are building blocks that provide a particular function to the student. The student should be given information about the building blocks so they can pick them based on their needs for their project. To take the example from the introduction: a student might have the requirement "needs to be able to measure the heart rate of a field hockey player on the field". This design system should allow the student to find the right technologies to use without knowing the intricate details of the technology, but choosing based upon what the technology can provide in functionality for them.

Students of Creative Technology

The second group of stakeholders identified in this project are the Creative Technology students who are following the Research and Design of User Experience project. They will primarily be the designers using the toolkit. They expect this project to aid them in choosing the right sensors and actuators and then making these easier to implement. They need the project to be helpful, easy to understand and the extra documentation to be on their level. They also need the toolkit to have the building blocks to support their application. This group can later be extended to all designers of interactive sports systems. Their influence over this project is that the product will be tested with them and their feedback will guide the further development.

Research and Design of User Experience teachers

The third group of stakeholders are the teachers of the Research and Design of User Experience project. The teachers must support the students through the project and help them use the toolkit. They expect the toolkit to help the students achieve their intended high-fidelity prototype while still achieving the course's intended learning outcomes. The effectiveness of the toolkit can have an impact on the quality of their teaching.

Supervisors

This project is done as a Graduation Project for the study of Creative Technology at the University of Twente. This Graduation Project has to adhere to the rules set by the program. It will be graded by the supervisor and critical observer. Therefore, they have a lot of influence over this project.

Lab managers

The third group of stakeholders are the lab managers of the university. These are the group of stakeholders who will have the job of maintaining the toolkit. When the provided documentation or sensors become outdated, they need to be able to update the toolkit. They expect the documentation to be clear, consistent and amendable. When they need to add new sensors the method of adding a sensor or actuator to the toolkit should also be documented.

The end-users of the high-fidelity prototypes

The fourth stakeholder group is the end-users of the designed interactive sports products. They need the toolkit to help improve these products by helping the designers spend more time on the user experience.

Collaborator

Sven Rozendom is the other researcher in this project. His interests are in the successful completion of the project for his graduation. Our work both contributes to the end goal of one unified toolkit that can be used in the Research and Design of User Experience project. Therefore he has significant power in this project.

Power-interest matrix

To get an insight into how these stakeholders influence this project they have been put into a power-interest matrix. This matrix comes from the research of Mendelow[37] and aims to rank each of the stakeholders on two axes: their power over the project, and their interest in the outcome of the project. Power here is defined as their ability to influence the project. Interest is defined as how interested that stakeholder is in the project succeeding. The goal of this matrix is to get an overview of the role our stakeholders should play in this project. The filled out power-interest matrix can be found in Figure 8.

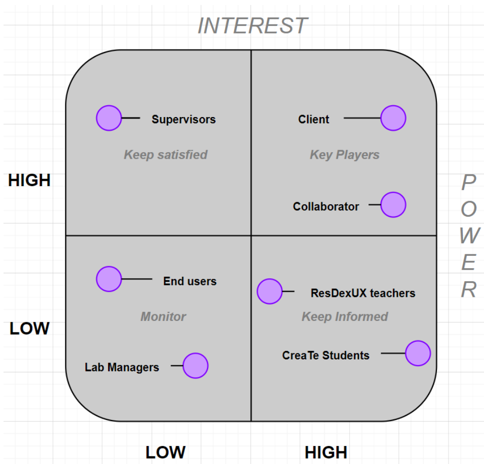


Figure 8: The power-interest matrix with stakeholders.

In this matrix, four quadrants can be found. The most important one is in the top right. These are the key players in our project, having a high interest and a high influence. This quadrant is occupied by our client and my collaborator. This means these two should be managed closely and be included in all the important decisions.

Moving one quadrant down to the left the 'Keep Satisfied' quadrant can be found. These are the stakeholders with high power but a lower interest in the outcome of the project. These stakeholders should be kept in the loop. In this project, these consist of the supervisors and the Research and Design of User Experience teachers.

The third quadrant in the bottom right consists of the stakeholders who should be kept informed about the project. These are the stakeholders with a high interest but low power over the direct outcome. In this project, these are the Research and Design of User Experience teachers and the CreaTe students, as they both have something to gain from the product.

The last quadrant consists of the stakeholders with a low interest and low power. These stakeholders should be monitored, but are not a high priority in a project. The Lab managers and end-users of the projects that the students create fall under this quadrant. These groups do not directly benefit from the envisioned toolkit. The lab managers do interact directly with the product but since they do not directly benefit from the product their interest will be low.

4.2 Interviews

To identify the needs of our other stakeholders expert interviews were conducted. The information letter of the interviews can be found in Appendix E.1. These interviews were semi-structured interviews, which means that some questions were prepared in advance, but the researchers can deviate from these during the interview.

Interview Assistant Professor Interaction Design

The first interview was conducted with an assistant professor from the research group Interaction Design. This interview was done because this professor works with Creative Technology and Interaction Technology students in project settings where they must make high and low-fidelity prototypes. The transcript of the interview can be found in Appendix E.3. The goal of the interview was to see where the students currently struggle when designing these prototypes. When asked what students struggle with when making a high-fidelity prototype they answered: "How can we find the sensors, which sensors should be used, and how do we implement it, and how actually the sensors will work for the purpose of it?" (Appendix E.3; timestamp 00:02:20). From their further answers, we have concluded that the students struggle with three separate steps in going from a high-fidelity to a low-fidelity prototype: selecting the right components, implementing the components and making them work together. These three steps could all be aided with our toolkit.

Another important aspect that came to light during the interview was the different technical abilities of the students. They mentioned some students are comfortable with the physical building of a prototype, while others take it as a struggle. A starting point would be helpful, especially for this last group of students. This starting point could help the students feel more confident, as long as it is easy to use. Because of this difference in skill levels, the toolkit should be useful for students of differing technical abilities.

Interview Professor Biomedical Sensor and Systems

The second interview was conducted with a professor from the research group Biomedical Sensors and Systems. The goal of this interview was to understand the decision factors between different sensors, how that data can be presented to students and how to guide students in implementing the sensors. The transcription of this interview can be found in Appendix E.4.

This interview again underlined the importance of tailoring the kit to the different technical skill levels of the students who will be using it. From their answers, it was concluded that having a student implement a full IMU set up in 10 weeks is not possible. Therefore this project should aim to provide students with enough information about each building block to implement it in the given time frame.

Moreover, the teacher mentioned that there is no decision tree for which sensor to use with which project. This is another aspect our toolkit could help with.

4.3 Thematic analysis

To identify the user needs a thematic analysis of past projects of the Research and Design of User Experience project was done. A thematic analysis is a way to analyze qualitative data by identifying the common themes among them[38]. For this project, an inductive thematic analysis was done. The goal of this thematic analysis is to identify which technologies past students have used and have wanted to use. This is to generate an idea of the technologies to support that support the broadest amount of projects. Because the analyzed 55 papers were already in report form transcription was not necessary. Thematic analysis is usually done in six steps, but due to time constraints, the steps of familiarization and coding were combined.

The first step performed is scan-reading and coding. To do this, the abstract, introduction, high-fidelity prototype, conclusion and discussion chapters are scanned. This way the scope of the project is identified. They were also coded with this pass. This is the process where you assign a label to a topic or sentence of interest within the text. The second step is to come up with themes. Themes are groups of codes which are similar. It is important to keep in mind the type of data you want to collect from the analysis and the research question when choosing the themes. In the third step, the themes are evaluated against the reports. If a theme is not relevant for the research question it can be discarded, split or merged with another theme. The fourth step is to define and name the themes. It is important to exactly define what we mean by each theme and to give it a succinct name. The last step is to make a write-up of the results. This can be found in Appendix D.

In the thematic analysis, three main themes can be identified: button games, wearables and interactive motion capture systems. The reaction game theme contains systems which use inputs spread out over an area, which the user should press based on certain signals. In most cases the inputs are buttons and the signals are provided by LED strips. The second theme of wearables covers a bigger collection of systems. The goals and technologies this theme encompasses vary wildly, but the common factor is the desire to make small systems that can be worn on a person. The common technology here used for feedback is haptic feedback. The third theme of interactive motion capture systems consists of systems that use motion tracking, usually through computer vision, to provide feedback to the user. The feedback given by these systems is most commonly done through a screen or virtual reality.

Concluding from the thematic analysis, three main themes of systems were identified: reaction games, wearables and interactive motion capture systems. The final toolkit should at least support creating these three types of systems. The components needed to support are not only components that can connect to an Arduino. In the rapports, we found students also used systems like Unity and computer vision in their projects, which run on their laptops. Therefore our toolkit could also include a way to integrate these programs into the designs.

4.4 Preliminary requirements

With the stakeholder analysis, we can identify preliminary requirements to give scope to our ideation phase. They will be split into functional and non-functional requirements. Functional requirements explain what the product needs to do in a way we can measure, while non-functional requirements tell us how the product should tackle the problem. Non-functional requirements pose limits on the implementation of the functional requirements in terms of the quality of the product [39]. For the preliminary requirements, only the stakeholders that are going to interact with our prototype are considered.

Client and teacher requirements

Hence our client is part of the group of teachers for the Research and Design of User Experience project, the requirements from these groups will be stated together.

Functional Requirements

1	+ The toolkit must contain functional building blocks
2	+ The toolkit must provide documentation about the functional building blocks
3	+ The toolkit should provide students with functional information about the building blocks
4	+ The toolkit could aid the students in connecting the components

Non-Functional Requirements

1	+ The toolkit should help the students prototype more quickly
2	+ The toolkit should be useful for students of varying technical levels.

Student requirements

Functional Requirements

1	+ The toolkit must provide documentation on how to use each functional building block
2	+ The toolkit must aid students with choosing the right building blocks for their project
3	+ The toolkit should support components that connect to an Arduino
4	+ The toolkit should support software running on a laptop

Non-Functional Requirements

1	+ Implementation of a functional building block should be straightforward
2	+ Implementation of a functional building block should not take longer than a day
3	+ The toolkit should support the use case of as many projects as possible, within the scope of the Research and Design of User Experience project
4	+ The toolkit shall be easy to use

Maintainer requirements

Functional Requirements

1	+ The documentation within the toolkit must all be in the same format
2	+ The information provided per building block should be consistent

Non-Functional Requirements

1	+ The toolkit should be amendable

4.5 Ideation

From the research up to this point, three problems students the toolkit can help students with were identified: selection of the right components, the implementation of these components and connecting the chosen components. In this section, the ideation for these problems is discussed along with the ideation for the physical manifestation of the toolkit.

Selection of components

The first problem of selecting the right components for your project has been divided into two parts. The first part of the problem is filtering the items available in the toolkit based on functional criteria. The second part of this problem is having the right information about the components to choose between them. A mind map was made to generate solutions to these problems, as seen in Figure 9.

Figure 9: The mind map for the recommendation system

Filtering the items in the toolkit based on functional criteria

To filter the items in the toolkit based on functional criteria additional tools are needed besides a physical box with components. The first idea for a tool to help with this was a filtering component. With this filtering component, a student would be able to select the properties the building block should possess, and then see an overview of all the items that match those properties. From the Background research, content-based filtering was selected as the best option for the type of filtering. Additionally, a choice helper as seen in Figure 6 of the State of the Art could be useful. This would allow the toolkit to ask about the functional requirements in question form, and then filter the items on the corresponding attributes. The idea of having an interactive chatbox powered by a natural language model with which the students could state their requirements in natural language was also briefly discussed but decided against due to the limited time available.

Connecting the chosen components

The last problem our toolkit could aid is the connection between the building blocks. This can be made easier in multiple ways. The first idea was to make the building blocks plug-and-play. This would be done by providing them with the same connector and building a central controller where they could all connect. The students would then only need to interact with the main controller via, for instance, a visual interface. This would behave like the Lego Mindstorms system mentioned in the state of the art (Figure 4). This would mean that for every building block an adaptor needs to be written. Additionally, if the toolkit does not support the specific use case the student needs, it renders the entire toolkit unusable. This is due to the closed-off nature of this solution.

The second idea is to give the students the guidance and documentation needed on a per-component level. For example, you want to control the colour of an LED if someone raises their hand. You detect this by a computer vision script running in Python on your laptop. To get the data from Python to Arduino a serial communication protocol that sends the data via the USB cable needs to be implemented. This requires a bit of software in Python, on the Arduino and the physical connection. During the ideation for this, Sven[2] showed the component graph he had made to figure out which types of systems to support. This can be seen in Figure 10.

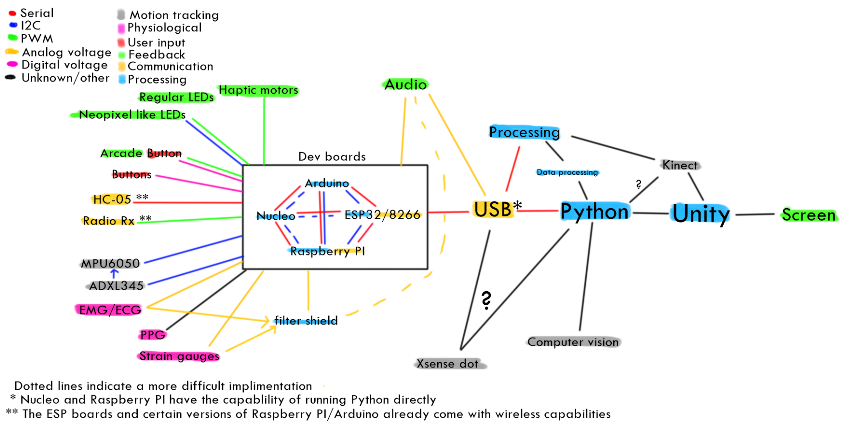


Figure 10: The component connection graph as made by Sven[2]

This inspired the idea to make this graph for all items in the toolkit. This graph would have an addition, where the paths between the items would contain extra items that explain how to connect the items together. These blocks have been coined 'middleware'. And this idea will be referenced from now on as the item graph.

To ensure all items in the toolkit can be put together a common node is needed. For the plug-and-play building blocks, this would quite easily be the central controller. With the building blocks on an item level, this becomes a bit harder. Most of the components seen in the Thematic Analysis connect to an Arduino. However, the students have also used Computer vision and Unity as input and outputs for their systems. To support these types of systems as well the Arduino can not be the central node. The first idea for this central node was that all components should have a path to a PC. The problem with this is that a PC is not a specific enough requirement. With this requirement, an Arduino can output its data to a terminal using the serial protocol, and computer vision can be run in Python. This still leaves the students on their own to figure out how to get the data from the terminal to Python.

This problem can be solved by making the requirement more specific. All building blocks should be able to (indirectly) communicate with Python. Python was chosen because it is a general-purpose programming language that is already being taught within the program of Creative Technology. It also has Application Programming Interface (API)s for a wide variety of programs. It also has libraries to directly control an Arduino or communicate with its serial protocol. When all building blocks have a path to Python, this can be used as the central place to orchestrate the behaviour of the prototype.

Implementing the components

To let students implement the components it was clear that documentation was needed. As seen in Figure 9 under the heading 'information provided', multiple ideas on what kind of information to provide were generated. Due to the limited time for this Graduation Project, it was decided that the idea of generating "How to"-videos would not be feasible within the given time frame. The rest of the ideas generated are all able to be put into the form of writing. Therefore it was decided that a document would be made on a per-building block basis on how to implement it. What this document should exactly contain was prototyped in the specification, and can be found in subsection 5.2.

4.6 The physical form of the toolkit

The client specified the need for a physical box with building blocks he could hand to the groups of the project. This still leaves room for ideation on the physical manifestation of the box and additional tools. Additional tools that can be incorporated are documentation, the decision helper and an item graph. There were three versions of the toolkit ideated: self-contained, online, and hybrid. From the ideation, the preliminary requirement to support students with different technical abilities was also thought of. It was decided to make two scenarios per idea: one for a more technically advanced user and one for a less advanced user. The difference between these is that while the toolkit would aim to reduce the prototyping time for both, the less advanced user would need more guidance in choosing the components and connecting them. This is in contrast to the more advanced users who would already architect the system themselves.

Self contained

The first idea for the overall appearance of the toolkit was a fully self-contained box. This toolkit would have physical representations of the additional tools. For the documentation, this could become a booklet, for the filtering tool a decision tree and for the item graph a printout. However, this would mean the documentation booklet would become quite large, as the example documentation for one item on average already spanned 1.5 pages. This would also mean an item graph would be the full overview as seen in Figure 10, which can become overwhelming and unclear with more items.

The user scenario for the less advanced user of the self-contained toolkit would be to use the decision tree to choose the components, and then look up the documentation in the booklet for that component and how to implement it. Afterwards, they could use the item graph to see how they could interface the items together, and look up the middleware blocks in the documentation booklet again. The more advanced users could choose which tools would be useful for them. For instance, if they already know which items to use and how to connect them they could look up the documentation for a reminder of how to implement the item exactly.

Online

The next idea was to have only the items in the physical box, and have all of the documentation and additional tools in a program. A support website would make the most sense. This website would have a filtering system, like an online web shop to filter the items to the user's needs. It could also incorporate the choice helper on the same page. For each of the items, it would have a separate documentation page. Having the item graph in a website would also allow the graph to be dynamic. The graph could only show the items the user selects for their system instead of for all systems, and dynamically add the middleware blocks their system needs. This would reduce the complexity of the graph and would be less overwhelming.

The user scenario for the less advanced user is to use the filtering or choice helper to find the correct items. These items could then be selected and added to the item graph. The item graph would only show the components required, with the corresponding middleware blocks.

The user scenario for the more advanced user is to look at the box to see what items are available and architect their system. Then they find the items they have chosen on the website using filters or scrolling through the list of items. Then click on that item to see the documentation. Then they find that item in the box and implement it. This user scenario is not ideal for the advanced user as they have to use the website and find the items there themselves.

Hybrid

The final idea and the chosen implementation is a hybrid system. The additional helpers and the documentation are implemented into a website. This comes with all the benefits of the online version. To improve the user story for advanced users, quick reference cards are added in the physical box with the components. These quick reference cards would contain direct links to the documentation for that item, letting them skip the step of finding the item on the website. This also has the advantage that the less advanced users would be given an extra point of information when choosing.

4.7 Project division

With the physical form of the toolkit ideated, it was decided that the toolkit would be divided into two separate parts: the physical box and documentation, and the support website. The support website would become the responsibility of the author of this paper, and the physical box and documentation the responsibility of Sven. From this point forward, Sven has decided which building blocks to make and has written the documentation on those. This means all the content that is seen on a documentation page of a building block has been written by Sven.

5 Specification

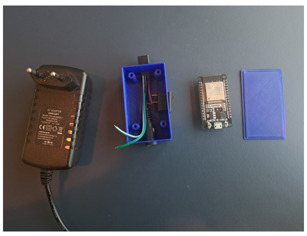
To get the current working idea into an executable concept more prototyping was needed. From the ideation, it became clear that we needed to prototype a building block to get to know what a building block should encompass. Further, it was needed to specify what information should be given to the students on a per building-block basis and what information should be provided on a physical card. Finally, a medium-fidelity prototype of the whole kit was made and evaluated.

5.1 Prototyping a building block

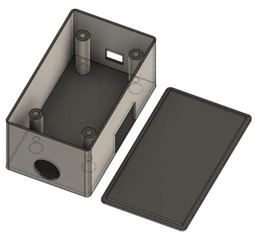
The client wants a toolkit comprised of functional building blocks. These blocks should be self-contained and give functionality to the user. On the one hand, black box controllers could be made, where the students plug in a sensor, and it ’magically’ works. This would abstract away the logic of power, microcontroller and physical connections. The other end of this spectrum is to give students the individual components, so the microcontroller, power supply, and wires separately, and give them guidance on how to implement these themselves. To further specify what one of these self-contained blocks should encompass a prototype was made (Figure 11).

For this prototype, both ends of the spectrum of abstraction were explored. First, a black-box LED-strip controller was made, where the students would only need to follow the instructions on how to upload a program and connect wirelessly. This prototype abstracts all individual components away from the user. The individual components of the prototype can be seen in Figure 11a. The prototype consists of four parts: the power supply, the physical interface between the microcontroller and the LED strip and the microcontroller itself. To get it to work nicely a case was designed and 3D-printed to hold all the components, as can be seen in Figure 11b. With some example code the student would not need to know anything about the technical implementation but pick up the box (as seen in Figure 11c), plug in an LED strip and have it work. The other end of the spectrum would be supplying the individual components as seen in Figure 11a. This means making the building blocks on the component level, with extra documentation needed on how to connect the components.

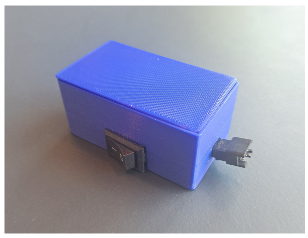
When evaluating this prototype with our client the decision was made to make the building blocks of the toolkit the size of the individual parts. This is done for two reasons. The first reason is that the toolkit can not contain infinite parts. While we have not received a budget for a toolkit, it still has to be provided to all the groups in the Research and Design of User Experience project. Having the building blocks and the documentation on the level of the individual parts allows for components like microcontrollers and power supply to be reused between multiple use cases. The second reason is that the client feels like it is important that the students understand how the system is put together on a component level.



(a) The exploded view from the complete building block controlling an LED strip



(b) The 3D model of the box



(c) A side of the LED controller with the power button and the LED connector.

Figure 11: The prototype of a fully encapsulated building block for controlling an LED strip

5.2 Prototyping the documentation

To see what would be needed in the documentation for a building block, a prototype for the documentation of a WS2812B LED strip was made. The full documentation page can be seen in Appendix C. The goal of this prototype was to make a template for a document that a student could take and get the building block working without any external documentation. This documentation contains the following paragraphs:

- **What does it do?** A summary of the function of the building block.
- **Control** A high-level overview of how to control the building block.
- **Physical setup** A description of which microcontroller pin to connect to the item, and which voltage the item expects.
- **Arduino/ESP** A description of controlling the item with an Arduino.
- **Raspberry pi** A detailed step-by-step guide of how to get the building block working with a Raspberry pi.
- **Controlling more than 10 pixels** For the WS2812B LEDs this heading is necessary to explain how to power the strip with external power.

The finalized documentation template

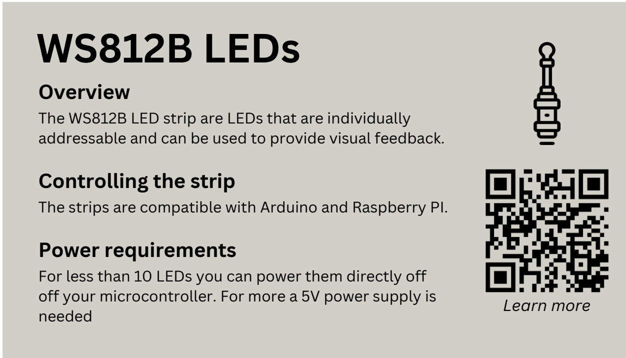
The prototype as seen in Appendix C was made in parallel with Sven's version of the documentation. Afterwards, the two prototypes were laid next to each other and discussed with our client. The general template that was decided upon for the specification is the following:

- **Description** A summary of the function of the building block.
- **Pros** A list of the advantages of using this building block.
- **Cons** A list of the disadvantages of using this building block.
- **Hardware considerations** Considerations to be taken into account when connecting the building block.
- **Software considerations** Information on the software needed to get data to or from this building block.
- **Wiring** A required wiring diagram to connect the item to an Arduino with additional instructions.
- **Example code** An example code snippet with which the students get the basics of the building block working. For actuators, this means getting basic control, and for sensors, it was decided that this example code should print raw output to the console.

5.3 Prototyping a quick reference card

When a physical block is constructed a student should have a quick reference to what part they are looking at. For this purpose, the idea of a quick reference card was developed. To develop what information should be on these cards another prototype was developed. This can be seen in Figure 12. With this prototype, it was determined that there should be four types of information on the card: name, picture, short description, QR code to the documentation, category and further context on the item that would be needed to make a quick decision.

(a) The front side of an item card showing the name, image and an icon showing that it is an actuator or a sensor.



(b) The back side of an item card gives a short description, control and power considerations, and a QR code that points to a more elaborate explanation page.

Figure 12: The first design of an overview card of an item in the toolkit

5.4 Conclusion of the prototypes

From the prototypes, additional requirements were found for the toolkit. These will be stated here.
From the prototype of the first building block, it was figured out that the toolkit should provide tools on a component level. Therefore the following preliminary requirement was changed:

1	– The toolkit must contain functional building blocks

1	+ The toolkit must contain building blocks on a component level
2	+ The components in the kit must have a(n indirect) way of getting their data to or from Python

From the prototype of the documentation, the following requirement was altered:

1	– The documentation within the toolkit must all be in the same format

1	+ The toolkit documentation should follow the finalised template as discussed in subsection 5.2

From the prototype of a quick reference card, the following requirements were formed:

1	+ The quick reference for an item should contain the name, picture, short description, QR code to the documentation, category and further context of each item

5.5 Final toolkit requirements

To give an overview of the finalised requirements of the toolkit, they are stated again here. They are divided into Functional Requirements and Non-Functional Requirements requirements. Within this division, they are grouped by Must have, Should have, Could have and Will not have.

Functional Requirements

1	+ The toolkit *must* contain building blocks on a component level
2	+ The toolkit *must* provide documentation about the functional building blocks
3	+ The toolkit *must* aid students with choosing the right building blocks for their project
4	+ The documentation within the toolkit *must* all be in the same format
5	+ The components in the kit must have a(n indirect) way of getting their data to or from Python
6	+ The toolkit documentation *should* follow the finalised template as discussed in subsection 5.2
7	+ The quick reference card for an item should contain the name, picture, short description, QR code to the documentation, category and further context of each item
8	+ The toolkit *should* provide students with functional information about the building blocks
9	+ The toolkit *should* support components that connect to an Arduino
10	+ The information provided per building block *should* be consistent
11	+ The toolkit *could* support software running on a laptop
12	+ The toolkit *could* aid the students in connecting the components

Non-Functional Requirements

1	+ The toolkit shall be easy to use
2	+ Implementation of a functional building block shall not take longer than a day
3	+ The toolkit should be amendable
4	+ The toolkit should help the students prototype more quickly
5	+ The toolkit *should* support the use case of as many projects as possible, within the scope of the Research and Design of User Experience project
6	+ Implementation of a functional building block should be straightforward
7	+ The toolkit should be useful for students of varying technical levels

5.6 Specification of the website

For the specification of the website, a medium-fidelity prototype was made. This prototype uses the same technologies as the final prototype, which can be read about in the realisation (section 6). The medium fidelity prototype includes the filtering tool, the item graph, the documentation and the physical toolkit with quick reference cards. Afterwards, the medium fidelity prototype was evaluated with our target group.

Functionality of the website

The first prototype includes a filtering component as seen in Figure 14a. With this filtering component, the user can filter the items based on attributes. An example of one of these attributes is the boards compatible with an item. An item is for instance compatible with an Arduino or with a PC. Here, PC and Arduino would be the attributes. These attributes fall under the AttributeType of Compatible boards and are grouped in the filter under Compatible boards. This relationship can be seen in the class diagram following the Unified Modeling Language (UML) in Figure 13. A class diagram describes the structure of a system by showing the classes and their attributes, and the relations between them[36].

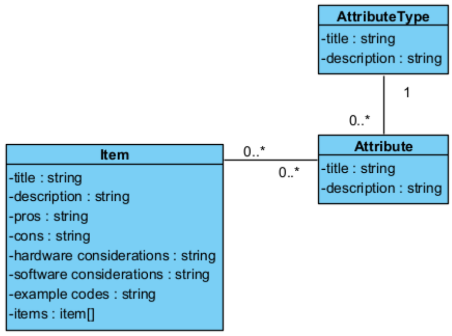
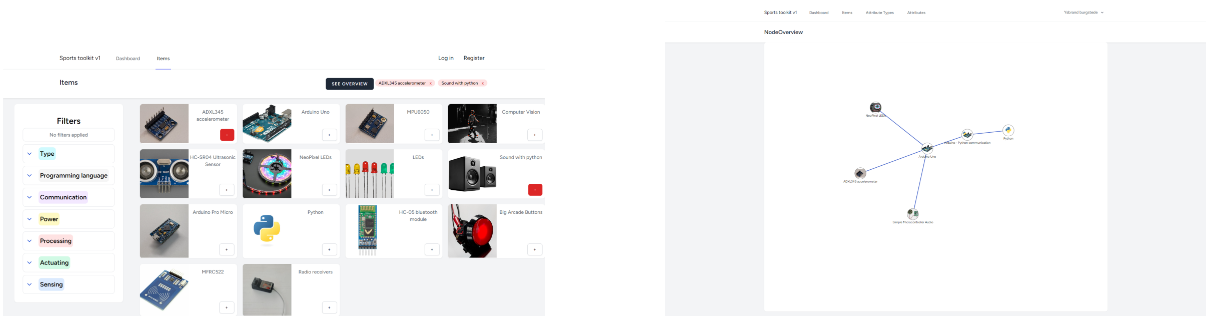


Figure 13: The class diagram made for the website

When a user has filtered the items and found the items they want to use, they can click on the + and add the items to their selection. This can be seen in the top bar as the pills with the item names. If they have all the items they want in their system the 'SEE ITEM GRAPH' button can be clicked and they will see the graph with their items as seen in Figure 14b. These items can be clicked and will lead them to the documentation as seen in Figure 16a.



(a) The main screen of the website.

(b) The Graph view with the ADXL 345 Accelerometer, simple sound with Python and Neopixel LEDs selected.

Figure 14: The two main pages of the first prototype of the website

Use case diagram

A UML use case diagram was created to identify which actors should perform specific actions on the website. This can be seen in Figure 15. A use case diagram is a behavioural diagram that shows the actions the actors expect to be able to do[40]. The two actors interacting with the website are the students and the maintainers. The students have to be able to see the items and filter them. To do this they need to be able to see the items, attributes and attribute types. The maintainers need to be able to edit all of these. However, the students should not be allowed to edit them. That is why it was chosen to let the manage actions extend the login action. This means that only users who are logged in will be able to manage them. The first prototype of the website was constructed according to this use case diagram.

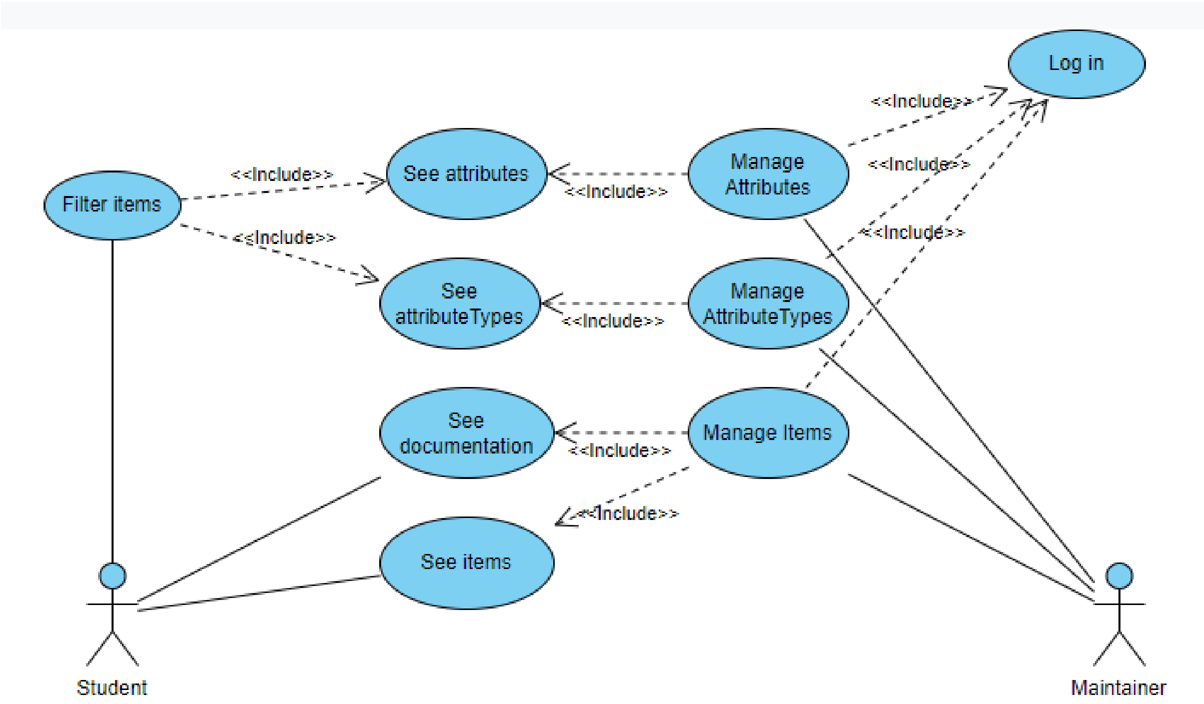
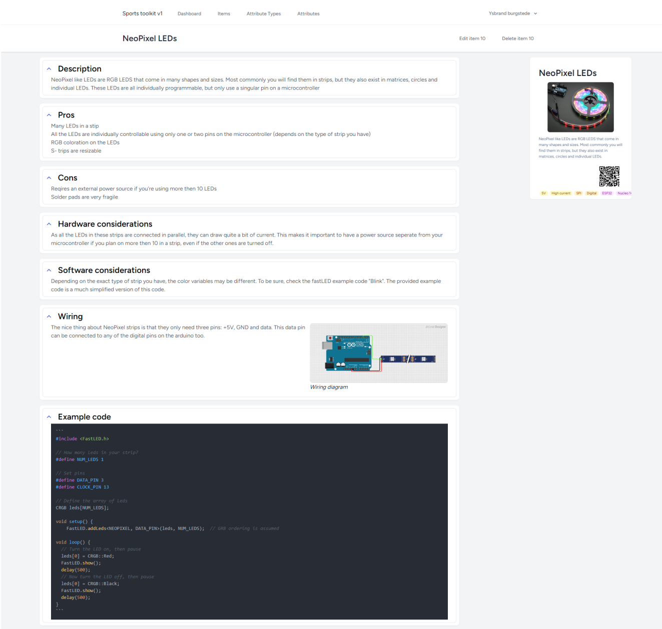


Figure 15: The use case diagram made for the website

5.7 Evaluation of the medium-fidelity prototype

In the medium-fidelity prototype, the first version of the physical kit made by Sven[2] was used along with the first working version of the website. The screenshots of all pages of the first working version of the website can be seen in Appendix B.1. A photo of the physical toolkit can be found in Figure 16b.



(a) The information page available per item that provides more detailed information. In this case, the information page for Neo pixel LEDs is shown

(b) The physical toolkit used for the specification with item cards as made by Sven

Figure 16: Elements of the toolkit as used in the evaluation for the specification

The goal of this evaluation was to judge the usability of the system from the student's perspective. To achieve this, it was decided to give the participants a design prompt and let them make a project with the kit.

The participants were gathered by sending a message in the general WhatsApp groups of second and third-year students of Creative Technology. These groups were chosen because these students have already completed the Research and Design of User Experience project, and know what the project entails. Through this, four students were found. To gauge the added value of the extra tools, two participants were given only the physical kit and quick reference cards with documentation, while the other two also got access to the filter tool and item graph.

Procedure

The evaluation has been done according to the following procedure:

1. Let the participant sign the consent form as found in Appendix F.1.
2. Explain the design task to the participant.
3. Present the toolkit and give a brief overview.
4. Let the participant work on the task (approximately 45 minutes) and take observational notes. When the participant gets stuck, give them short pointers on how to use the tool or guide them to the right documentation.
5. Perform a semi-structured interview (approximately 10 minutes).
6. Ask the participant to fill out the System Usability Score sheet as found in Appendix subsection F.3.

Design prompt

The design prompt chosen for this evaluation is *"Design a system that senses when someone is waving their hand and let the system give suitable feedback"*. In the semi-structured interview, the participants were asked to explain their train of thought for choosing these components for their system, along with whether it was clear how to make these components work together. They were also asked about the individual tools they had used and if they were clear and thought to be useful. The observational notes kept track of which components the user picked, how they selected these components and when a participant showed signs of confusion or frustration with the kit and with which system.

Evaluation results

The System Usability Scores given by the participants can be found in Table 1. The average SUS score of the participants was 85. According to research performed by Bangor et al.[41], this puts our product in the adjective rating of excellent. The difference in SUS scores between the users who used the additional tools versus the toolkit only is statistically insignificant, but when shown the item graph on its own afterwards all participants thought it would be a welcome addition.

User	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	**Final Score**
1	5	2	4	2	4	1	3	2	4	2	77.5
2	4	3	5	1	4	1	5	2	4	1	85
3	4	1	4	1	4	1	5	1	4	1	90
4	5	1	4	2	4	1	5	1	4	2	87.5
										Average	85

Table 1: The SUS scores from the specification

From the observational notes, one participant got stuck on the item graph. This is because the item graph shows all items and their defined paths to Python. This participant made a system that only used a sensor and actuator that connected to an Arduino, but the graph still shows the connection to Python. This was perceived to be confusing. Therefore the system should always show the shortest path between components, and not the individual paths to Python. All users also added the micro-controller they wanted to use to their system, while the graph does that automatically for you. This could be solved by only showing actuators and sensors on the main page, instead of all items.

From the two users with the digital tools the envisioned user scenario as mentioned in the ideation played out. They first used the filters to select the right components and used the documentation for the implementation of these components. Finally, they used the item graph for the connections.

From the interviews, a few points of improvement were common. The participants stated that the documentation could be more clear in places. Multiple also mentioned that a manual for the kit would be nice, with some basic reminders on common Arduino use cases. From the observational notes, this can be also underlined, as all four participants struggled with programming the Arduino. Another point of improvement was that the names of the filters were not always clear and that a short explanation of the items on the main page of the website would be a nice addition.

At this point, Sven had the first experience with adding items and documentation to the website and had additional requirements. He wanted the option to put images anywhere in the documentation and not only in the wiring diagram. Additionally, the need for multiple example code blocks was encountered.

6 Realisation

In this chapter, the overall overview of the systems used to construct the support website is shown. The website can be categorized into three separate parts: the overview/filter page, the page with the item graph and the overview page per component. First, the overall system design will be explained, and afterwards, the separate parts will be explained more in-depth. All code for the website can be found on GitHub [42]. Afterwards, to give an overview of the full toolkit, the physical kit and item cards made by Sven Rozendom[2] are shortly discussed.

6.1 The overall system

To serve a website, you need a server, a database and a front-end. In this project, it was chosen to make the end product a fully working website, and not a mock-up. Therefore, it was needed to decide which technologies to use for these three parts. In the following sections, the choice for all three will be further explained. The Unified Modeling Language (UML) use case diagram for the specification was updated to now also include the choice helper. The updated version can be found in Figure 17.

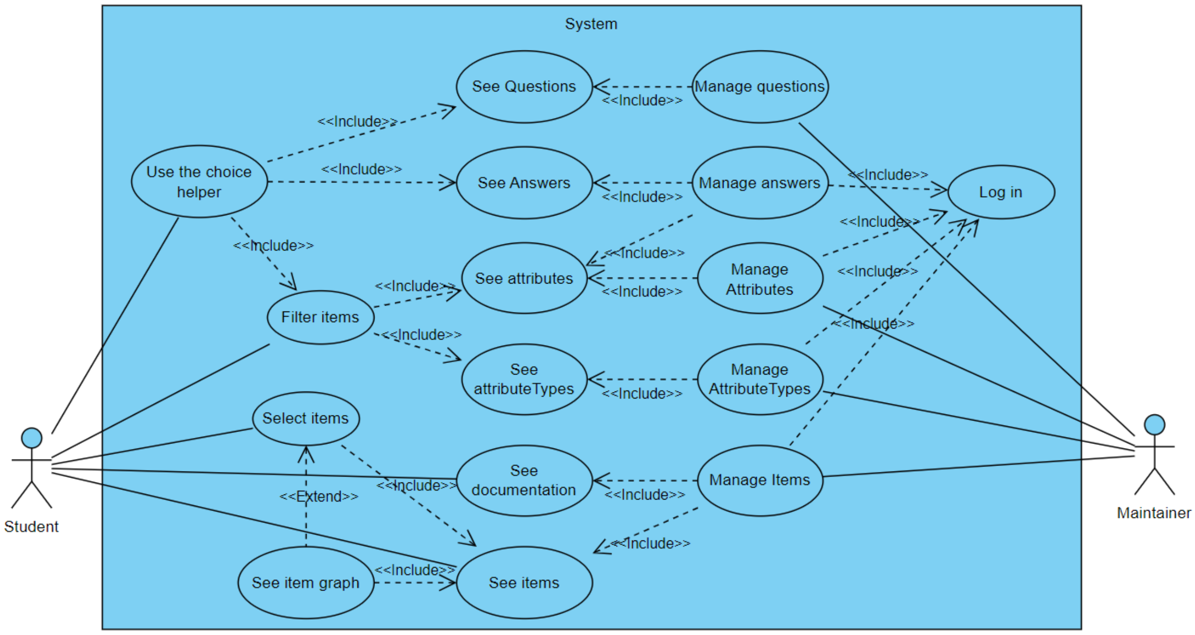


Figure 17: The final UML use case diagram of the system

Front end

The envisioned working of the item selection and the graph page require the front end of the website to be dynamic. This means that when you click the plus button to add an item to your selection, you want the list of selected items to update with that item. The required functionality is feasible with standard JavaScript. However, managing the complexity of some of these components would become difficult rather quickly. Therefore it was chosen to use a modern JavaScript framework called Vue.js [43]. Modern JavaScript frameworks make it easier to let the interface react to state changes. Instead of having to select the correct HTML and update it yourself, you can update a variable and the framework does that work for you. This in combination with the wide breadth of pre-made components available for this framework, made the project feel feasible to finish within the time constraints. To style the website, a CSS framework called Tailwind[44] was used.

Back-end

The back end is the code that runs on a server and decides which page the user needs, then gathers the right data and shows that page. For the realisation of this project, a simple hosting plan with 8GB of storage, 2GB of RAM and 2 CPU cores was used. To keep the deployment basic it was chosen to use a back-end running PHP Hypertext Preprocessor (PHP). This is because nearly all hosting providers support PHP. Also, the researcher was already familiar with one of the more well-known PHP frameworks called Laravel [45]. Laravel is a framework that follows the MVC architecture. MVC stands for Model, View and Controller. The Model is a PHP class that models your data and lets you interact with it, the View is the front-end layer that shows your data, and lastly, the Controller is a PHP script that orchestrates how to load the Models and which View to show. Laravel is known as a batteries-included framework. This means it already has options for authentication and authorization, database management and file storage built in. This in combination with the earlier mentioned familiarity made it the perfect candidate for the rapid development of the website. The Models of the website were implemented using the updated UML class diagram as seen in Figure 18.

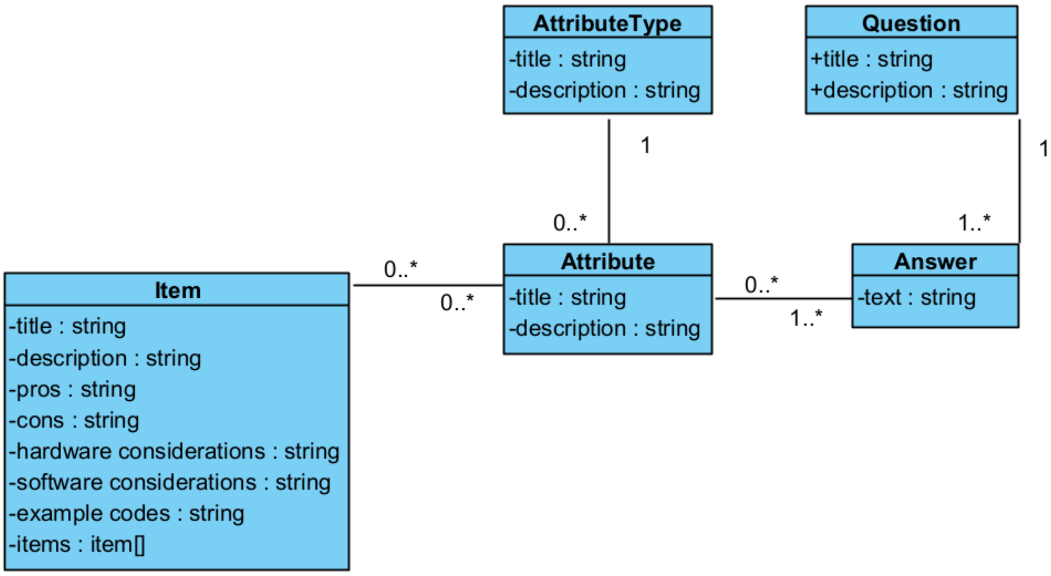


Figure 18: The UML class diagram for the final system

Database

With the inner workings of the updating and showing of the website figured out, we still need a database to store our data in. The hosting provider used gives a free MySQL database with every hosting package. This made it an easy choice to use for this project. Laravel provides an adapter for MySQL to its database management tools. This makes it so you never have to write SQL, but instead entirely deal with the earlier-mentioned Models via an Object-relational mapping. The database still needs to know which data will be stored. To plan and visualise this a database schema was constructed. This can be seen in Figure 19. The tables with the name of model_model are pivot tables. In Laravel a Many to Many relationship (in the UML spec 0..* - 0..*) is done via a pivot table. When a new association between the models is made a record is inserted into the pivot table containing the IDs of both of the models it needs to associate with each other.

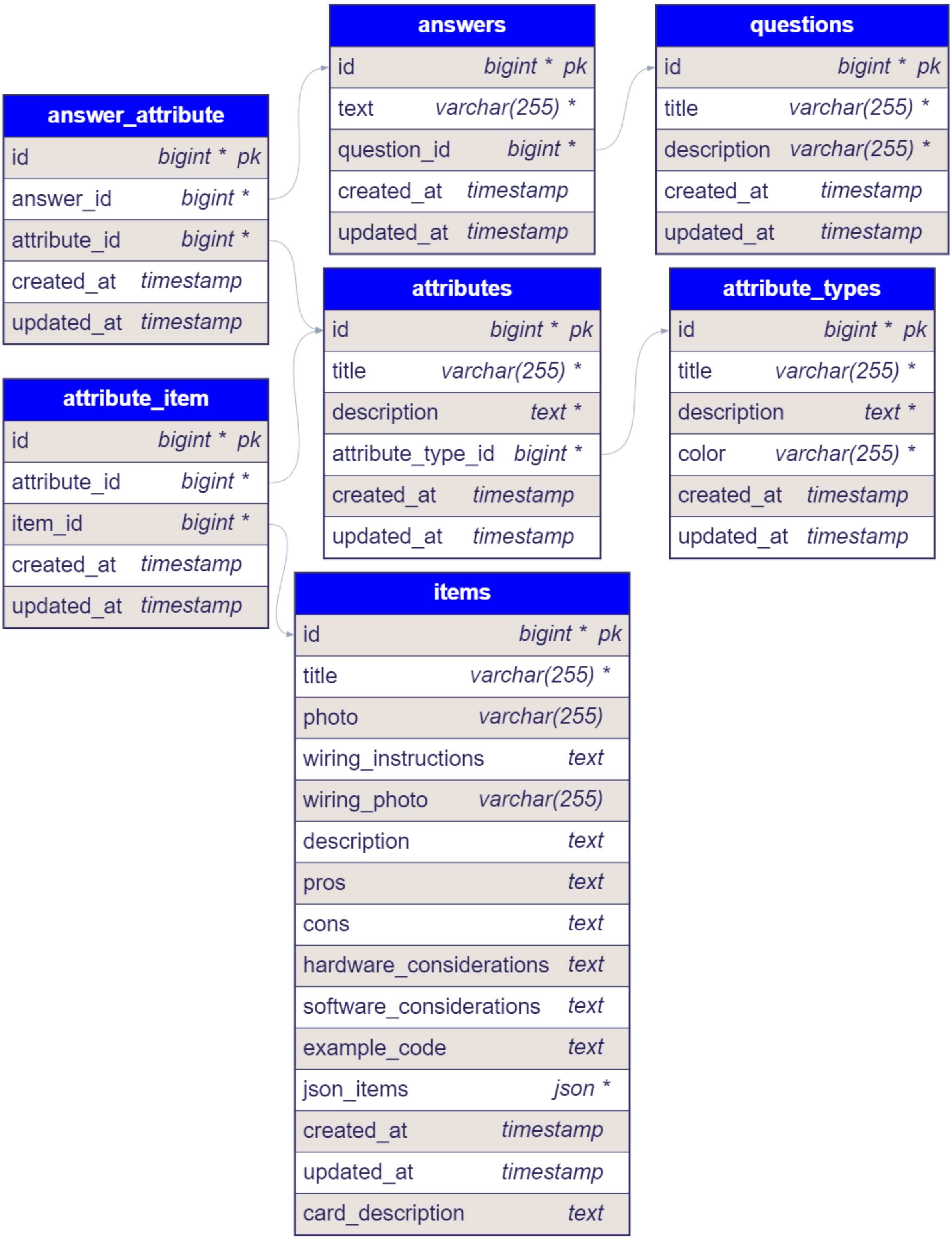


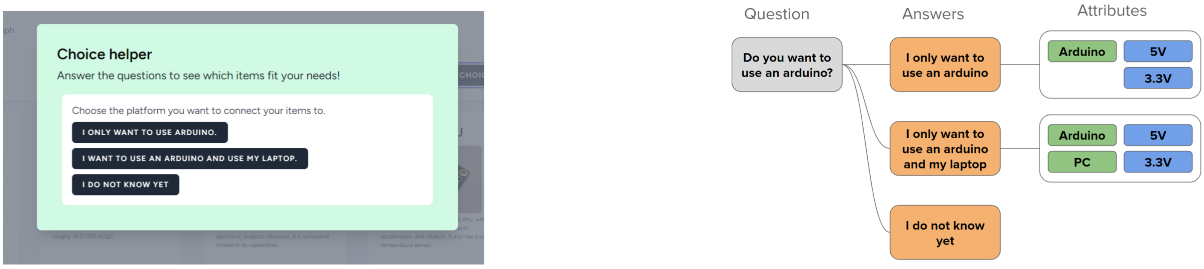
Figure 19: The database schema for the final system

6.2 The main page

The main page of the website shows an overview of the items. It can be seen in Figure 23. This is the page where you can filter the items with the filter components with the filter component on the left, add the items to your selection with the + icon and access the explainer and the choice helper. The items are shown according to the specification of the quick reference cards.

Choice helper

The choice helper is a popup with functional questions about your prototype. In the example in Figure 20a, the question is if the user wants to stick to only an Arduino. With each answer to this question attributes are associated, as shown in Figure 20b. These attributes will be set in the filter tool when that option is chosen. This question does not only set the attributeType of compatible controllers but also power requirements. Another example of a question is what type of sensing the prototype needs to do: health information, movement from an object or a person or touch.



(a) A question from the choice helper (b) The associations of the choice helper

Figure 20: The choice helper

Filtering

To show how the website filters items, a UML sequence diagram was constructed. This can be seen in Figure 21. A sequence diagram is used to show the flow of messages between the frontend, backend and database.

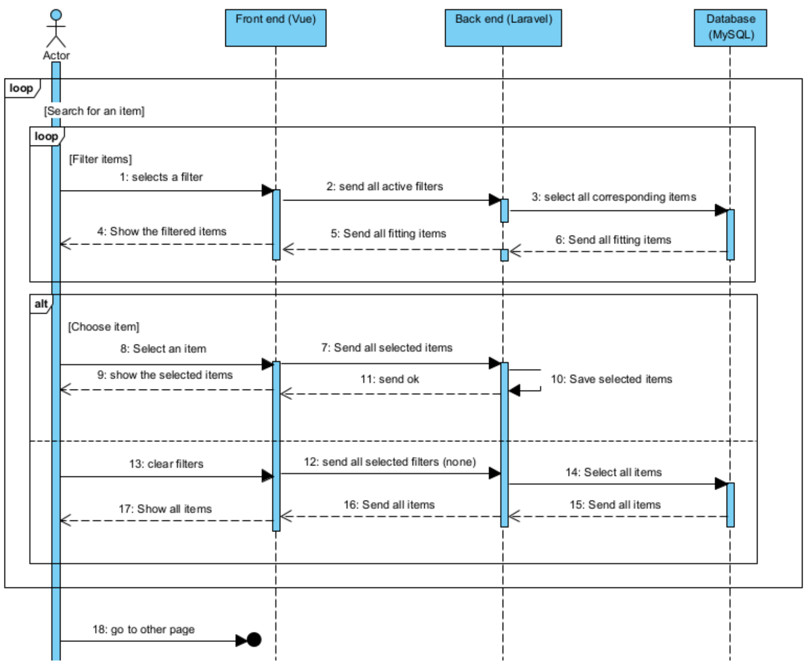


Figure 21: The UML sequence diagram for filtering and selecting items

The filters work per item category. The website fetches all of the items that have all attributes that are selected in that category. It then combines that with all the results for the next category. With the Query Builder Laravel provides this can be done in only a few lines of code, as can be seen in Figure 22.

```
$filters = $request->input('filters');
    foreach ($filters ?? [] as $attributeCategoryId => $attributeIds) {
        $builder->whereHas('attributes', static function ($query)
            use ($attributeCategoryId, $attributeIds): void {
                $query->where('attribute_type_id', $attributeCategoryId)
                ->whereIn('attributes.id', $attributeIds);
        });
    }
```

Figure 22: The code snippet that gets the filters per attributeType and then gets all items that have those attributes

When the user has found the items they are looking for and made their choice by the information given by the first information given on the item cards on the home page, they can add the item to their system with the + icon. This then gets added to their session, so when they go the the item graph the selection gets remembered. This can also be seen in the bottom of the sequence diagram in Figure 21.

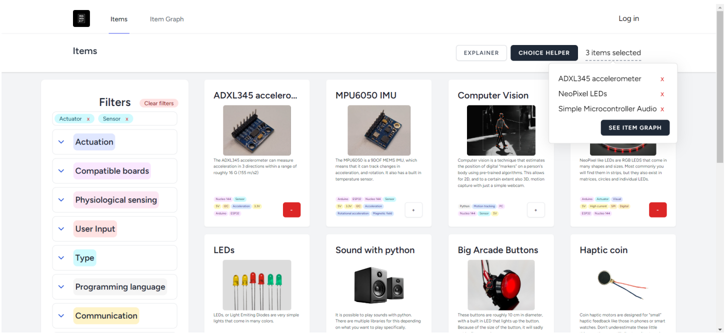


Figure 23: The homepage

The explainer pop up

Upon loading the main page for the first time the user is greeted with a popup with a short explainer of the overall system. This explainer can be seen in Figure 24. From here, the user can dismiss the popup or open the choice helper.

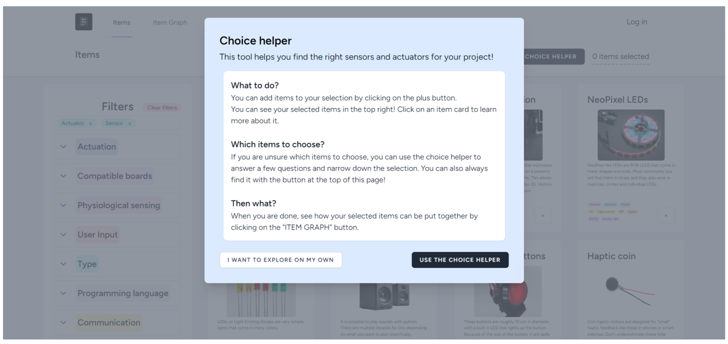
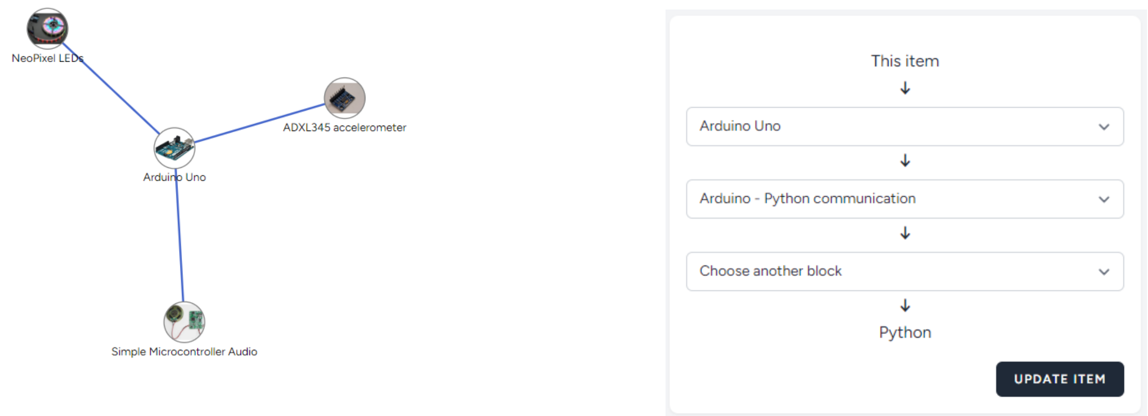


Figure 24: The explainer pop up on the website

6.3 The item graph

The item graph is the page where the user goes after selecting the sensors and actuators for their prototype. For example, when the user selects computer vision and the LED strip, steps need to be taken to let the computer vision running in Python on your laptop talk to the LED strip connected to an Arduino. To be able to achieve this, the website has been provided a path to Python for every item, using other items as stepping stones. For instance, in Figure 25b the path edit component for the LED strip can be seen. The maintainer defines that this item connects to an Arduino. From Arduino to Python some sort of communication is needed. This requires the second block, Arduino-Python communication, to arrive at the common node of Python.



(a) An example graph

(b) The edit component for the item graph

Figure 25: The item graph with edit component

For this page, all selected items are loaded as nodes in the graph along with all items defined in their path. A node in the graph is a circle with the name and the image of an item as seen in Figure 25a. This data gets sent from the back-end to the front-end. All these items get drawn as nodes with the Vue component v-network-graph[46]. The front end takes all the paths to Python as defined by the selected items and deduplicates and draws them. A path can be seen as a blue line in Figure 25a. For all of the systems that require Python, this produces the desired results, but for systems that can function with only an Arduino, this overcomplicates them. How this is solved is explained in the section hereafter. How the page looks with all items selected that are currently in the system can be seen in Figure 26.

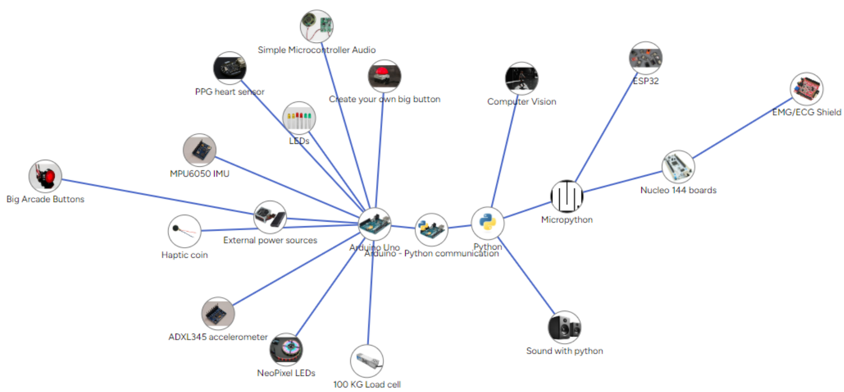
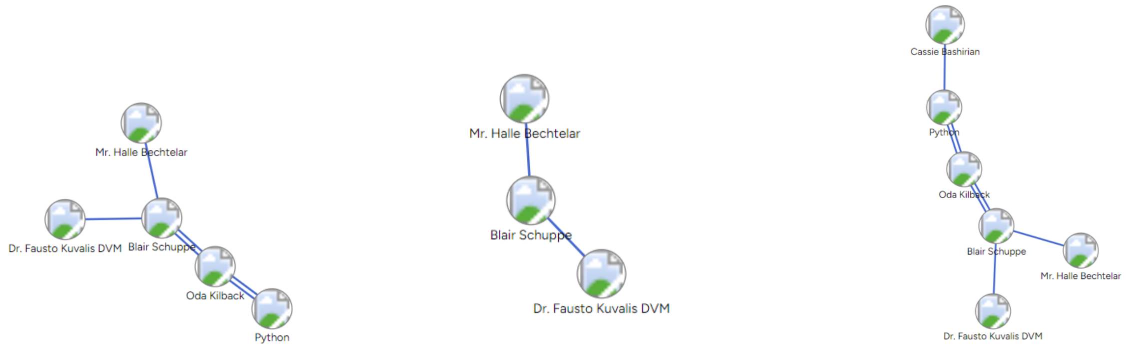


Figure 26: The item graph with all items selected

The graph problem

As mentioned in the section before, all paths from an item lead to Python. When all of these items get loaded the items defined in their path get loaded and displayed as well. To illustrate this, deduplication of the paths has been turned off in Figure 27a. This example graph has been made with two test items, called Dr Fausto and Mr Hale. You can see that both paths go from the item to Python, as defined in the edit component shown earlier. However, these test items directly connect to the item called Blair Schuppe, but the graph still shows the steps necessary to go from Blair Schuppe to Python. From the specification evaluation, we have specified that the graph should always show the shortest path between the selected items, and therefore the items of Oda Kilback and Python should not be shown.



(a) The graph from Mr Hale to Dr Fausto still shows the steps needed to go to Python.

(b) The final graph only shows the shortest path from Mr. Halle to Dr. Fausto

(c) The final graph includes both Mr. Halle and Dr. Fauci, but also Cassie, facilitating the need to show the intermediate steps.

Figure 27: The Graph Problem where always showing the path to Python is too much information.

This has been solved by not only deduplicating the paths in the front end but also removing nodes that have as many paths going to them as there are selected items. In the example graph of Figure 27a, the path from Blair Schuppe to Oda Kilback, and the path from Oda Kilback to Python exist twice, which is the same amount as there are selected items in the system. Therefore we know that we can remove these nodes and paths from the graph. This produces the correct graph as seen in Figure 27b.

This approach still holds up when there is an item in the graph that requires the blocks of the communication and Python to be there. An example of this can be seen in Figure 27a (note: this graph is rendered upside down from the other two). The item of Cassie Bashirian is added to the system, which does not directly connect to Blair Schuppe. Therefore the count of selected items is now three. The paths we previously deleted from the graph from Blair Schuppe to Oda Kilback, and the path from Oda Kilback to Python still exist twice. Therefore these paths do not get deleted by the graph anymore.

6.4 The documentation page

The documentation is implemented as specified by the prototype of the documentation (subsection 5.2). The page has a foldable header for each of the required sections. The text is rendered in markdown. Markdown is a lightweight markup language that allows additional styling to be added by the use of special characters within the text[47]. In the markdown, the maintainer can define a code block that gets automatically highlighted with the Javascript library called highlight.js[48]. Additionally, this allows for extra images to be put anywhere within a text block. This was a request from Sven after the medium-fidelity prototype. In the example as seen in Figure 28, the image of the USB cable is inserted in this way. The markdown also allows for additional features, like bullet lists often used in the pros and cons. The page also shows the same quick reference card as on the main page next to the documentation.

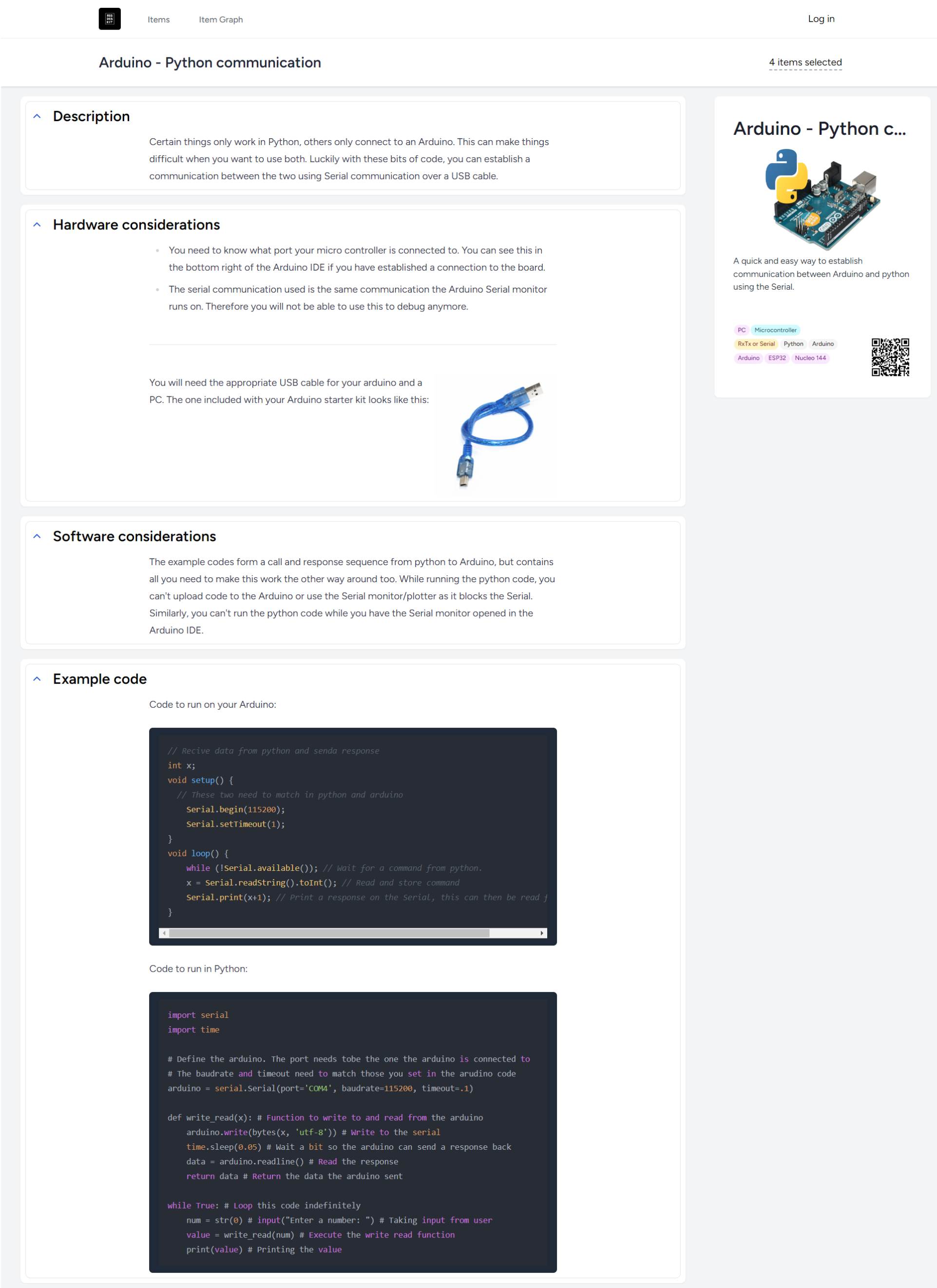


Figure 28: The documentation page for Arduino-Python communication

6.5 The maintainer pages

For all the Models mentioned in the UML class diagram (Figure 18), the maintainers should be able to make them, and edit their attributes. To not give the students access to these tools, they have been placed behind a login page, as specified by the include«login» use case of the case diagram in Figure 17.

For all the models two pages have been made: an overview and an edit page. On the overview page, the maintainers can see all of the existing entries of the models and click on a button to edit them or create a new one. These can all be seen in Appendix B.1. The edit and creation pages of a Model are the same. The edit page just prepopulates the input fields with the already-defined attributes of the model. Most edit pages of a Model directly translate the Model attributes to HTML input attributes. For instance, the title of an item directly corresponds to a text field. There is one special page, and that is the edit page of an item as seen in Figure 29.

The edit page of an item has four special inputs: live markdown input fields, the attribute filter, the path editor and the extra image upload component. The live markdown input fields are a special type of text input. These allow the maintainer to not only input text into this field but also extra special characters to format the text. The options for this can be seen on the top of the input field, for instance making the text **bold** or adding an extra image or a code block. The attribute filter is the same filter component as used on the homepage, only now it does not filter the items but just remembers which attributes have been selected from the drop downs. The edit path component was already discussed with the item graph, but this is a drop-down with all the possible items in the system. Every time you specify one a new input box is dynamically made, allowing for custom path lengths. And lastly the extra image upload component. This component allows for the uploading of extra images next to the required two. You will get an overview of the images associated with this item, and can then use the links generated in the markdown fields as image links to insert them there into the text where they are needed.

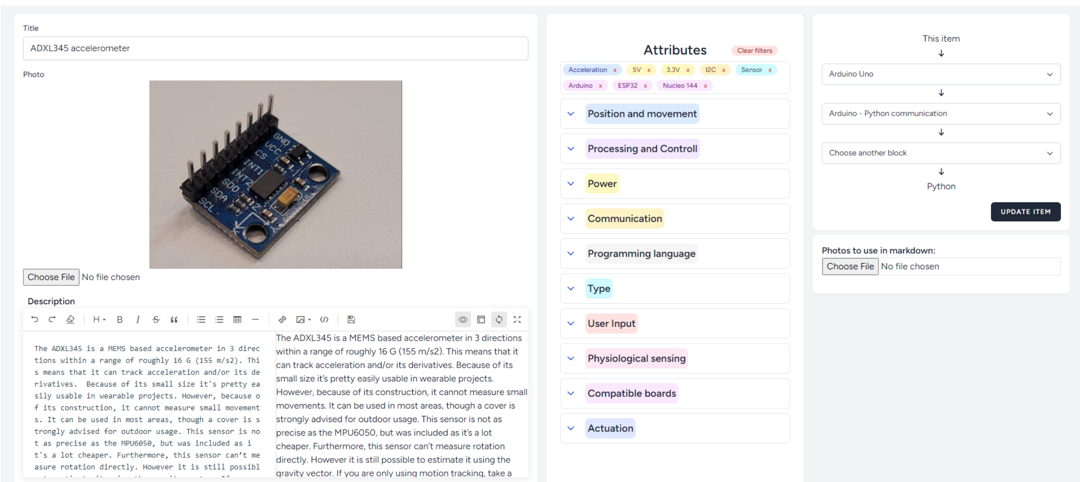
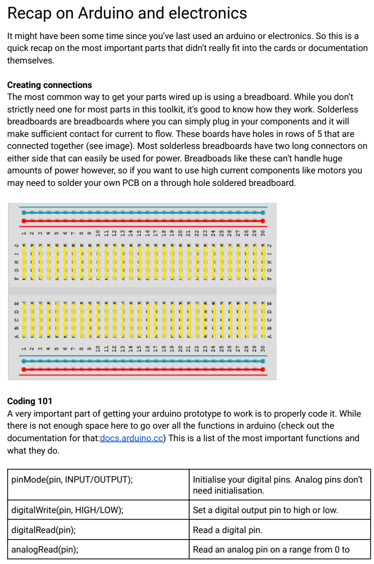


Figure 29: The edit page of an item

6.6 The physical toolkit

The physical toolkit as made by Sven consists of a custom laser-cut physical box as seen in Figure 32a, a physical manual explaining the toolkit and some Arduino basics, along with the physical version of the quick reference cards.

A page of the physical manual for the toolkit can be seen in Figure 30. The addition of a manual was suggested by multiple participants in the evaluation of the medium-fidelity prototype. The manual consists of an explanation of the whole toolkit. Additionally, the manual contains a recap on the basics of using an Arduino and breadboard, as in the evaluation it was noticed that the participants had to look this up.


Recap on Arduino and electronics

It might have been some time since you've last used an arduino or electronics. So this is a quick recap on the most important parts that didn't really fit into the cards or documentation themselves.

Creating connections
The most common way to get your parts wired up is using a breadboard. While you don't strictly need one for most parts in this toolkit, it's good to know how they work. Solderless breadboards are breadboards where you can simply plug in your components and it will make sufficient contact for current to flow. These boards have holes in rows of 5 that are connected together (see image). Most solderless breadboards have two long connectors on either side that can easily be used for power. Breadboads like these can't handle huge amounts of power however, so if you want to use high current components like motors you may need to solder your own PCB on a through hole soldered breadboard.

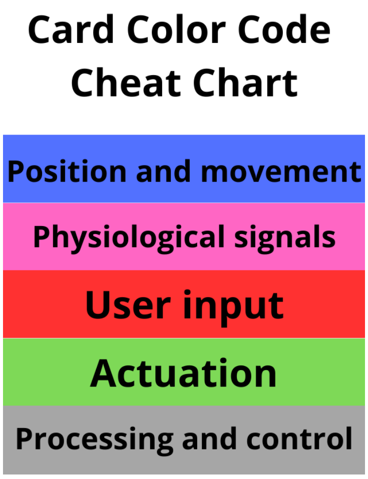
Coding 101
A very important part of getting your arduino prototype to work is to properly code it. While there is not enough space here to go over all the functions in arduino (check out the documentation for that:docs.arduino.cc) This is a list of the most important functions and what they do.

pinMode(pin, INPUT/OUTPUT);	Initialise your digital pins. Analog pins don't need initialisation.
digitalWrite(pin, HIGH/LOW);	Set a digital output pin to high or low.
digitalRead(pin);	Read a digital pin.
analogRead(pin);	Read an analog pin on a range from 0 to

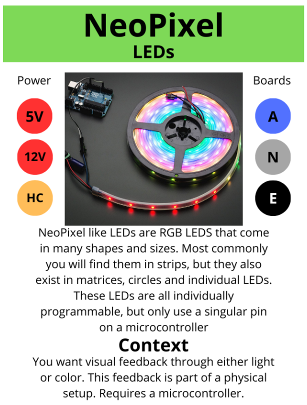
Figure 30: A page in the physical manual

The quick reference cards were colour-coded according to functional categories. These can be seen in Figure 31a. These cards were made for all of the items he has put into the system. The front of the final version (Figure 31b) of his item card contains the colour code for the category, an image of the item, a short description, some context on the item, colour-coded circles for the boards the item can be used with and the power requirements. The back has the QR code to the documentation page on the website and additional pros and cons of the item that can help to make a swift decision.

The QR codes have been generated by the website so they actually link to the correct documentation page. This supports the use case where a more advanced user might not need the additional tools but can benefit from the documentation as discussed in the ideation. The full specification of these cards can be found in his rapport[2].



(a) The color-coded categories of the building blocks



(b) The front of a quick reference card

(c) The back of a quick reference card

Figure 31: Svens's final rendition of a quick reference card

7 Evaluation

The evaluation of the toolkit was done for the toolkit as a whole. The information letter and consent form did not change from the specification evaluation. The information letter can be found in Appendix F.2 and the consent form in Appendix F.1. The goal of this evaluation was to test the usability of the overall system. The evaluation was done with Creative Technology students who have already completed the Research and Design of User Experience project. The participants were found by sending a message in the general WhatsApp groups of second and third-year students of Creative Technology. Through this, six participants were found.

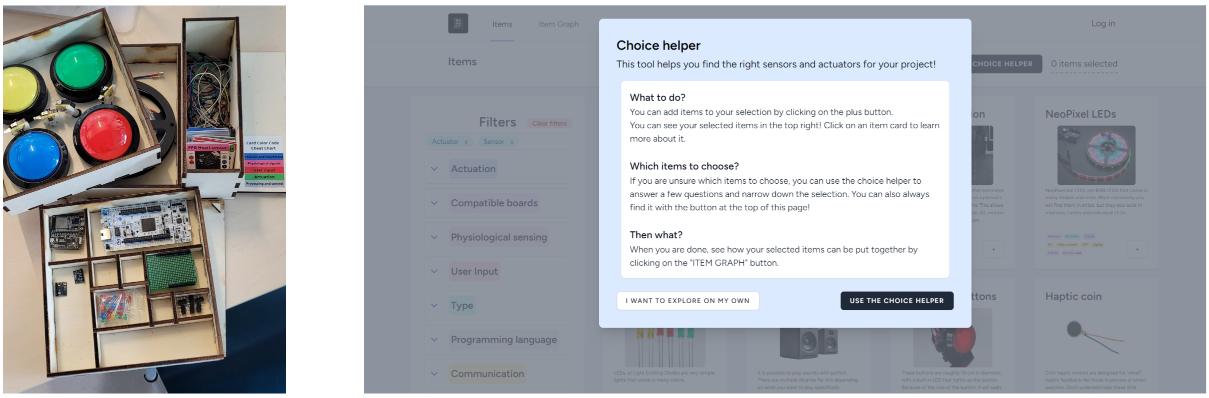
Design prompt

To test the toolkit the following design prompt was used: *"Design a system that creates different sounds or music based on different movements"*. This prompt was chosen because the system contained three items that can be used to measure movement and two ways of creating sound. Both for the movement and the audio one of the items runs in Python, so the possibility that the participant needs a connection between their laptop and Arduino exists. This is important to test the item graph and the connecting blocks.

Procedure

1. Let the participant sign the consent form as found in Appendix F.1.
2. Explain the design task to the participant.
3. Give the participant the laptop and the toolkit.
4. Let the participant work on the task (approximately 45 minutes) and take observational notes. When the participant gets stuck, give them short pointers on how to use the tool or guide them to the right documentation.
5. Perform a semi-structured interview (approximately 15 minutes).
6. Ask the participant to fill out the System Usability Score sheet as found in Appendix subsection F.3.

The participants were given a laptop with the support website and a code editor. To save time this laptop already had the required Python and Arduino libraries for all items installed. During the test, observational notes were taken by the researchers. Afterwards, a short guided interview of around 15 minutes was done and they were asked to fill out a System Usability Score (SUS)[49]. The SUS score sheet can be found in Appendix F.3. The main difference from the setup from the specification is that the participants did not get a walk-through of the system by the researcher, to test if the newly added physical manual and pop-up explainer provided enough information.



(a) The physical toolkit (b) The support website as it would be presented to the participants

Figure 32: The toolkit as given during the evaluation

7.1 Results

As previously mentioned, the evaluation was done with six participants. Overall, the toolkit was received well by these participants. Two participants were even able to have a finished system in the time given. When asked if they could have done it without the kit the answer was a resounding 'no'.

The participants mostly followed the envisioned use case. The users with more technical experience found the questions in the choice helper too simple as expected. The addition of the choice helper allowed the other participants to mostly use that over the filters. The documentation scored as expected. The users used this to both aid in decision-making and implementation. From the interviews especially the included example codes and wiring diagrams are useful.

There were some points of improvement mentioned by the participants. Due to the website being developed as the items were put into the system, the documentation is not consistent yet on all pages. One user thought this was confusing. Also, the participants had ideas for improvement for the questions in the choice helper. Another point of frustration was the website losing the correct state of the selected items when navigating with the browser's back and forward buttons. After struggling with this the participants have been instructed to use the navigation links in the website, which resolves the issue.

The item graph was well received by the participants who used it. However, not all participants were able to find it on their own. This hints at the User Interface (UI) of the website not being clear enough.

SUS scores

The SUS scores of the individual participants can be seen in Table 2. The average SUS score of the evaluation was 78.5. This puts the toolkit as a product in the upper category of the adjective rating good[41]. This is lower than the score the toolkit scored in the specification. This is likely able to be attributed to the parts of the toolkit the participants used.

Not all participants used all parts of the toolkit. Only one of the participants opted to solely use the quick reference cards, and three participants completely missed them. Another part of the system that is not clear enough on its own is the item graph. Two participants missed this feature completely. Not using features had a noticeable impact on the SUS score. The participants who missed the item graph gave the toolkit an average score of 73.75. Furthermore, the participants who missed the quick reference cards gave an average score of 75. This is in stark contrast to the participant who did use the full system and a score of 97.5, only deducting a point for learnability.

User	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Final score:
1	4	3	3	2	3	2	4	3	3	1	65
4	5	2	4	1	4	1	5	1	3	3	82.5
5	2	2	3	2	3	1	2	3	4	2	60
6	4	2	3	3	5	1	5	2	4	3	75
7	5	1	4	1	4	1	5	2	4	1	90
8	5	1	5	1	5	1	4	1	5	1	97.5
										Average	78.3

Table 2: The final SUS scores from the evaluation

8 Discussion & Future Work

The toolkit is a promising product that seems to help students implement high-fidelity prototypes. The toolkit aggregates commonly used technologies and provides tools to help navigate them, implement them and make them work together. It combines existing ideas like documentation, with existing ideas from other fields, like choice helpers, and even has a novel tool in the network graph to combine items we have coined the item graph.

8.1 Functional analysis

As seen in the list below, almost all requirements have been met. The only Functional Requirement (FR) that has not been met is FR 10. Due to the creation of blocks during the development of the website, not all documentation given is consistent. A clear template has been developed, but the older items have not been updated.

Functional Requirements

1	+ The toolkit *must* contain building blocks on a component level
2	+ The toolkit *must* provide documentation about the functional building blocks
3	+ The toolkit *must* aid students with choosing the right building blocks for their project
4	+ The documentation within the toolkit *must* all be in the same format
5	+ The components in the kit must have a(n indirect) way of getting their data to or from Python
6	+ The toolkit documentation *should* follow the finalised template as discussed in subsection 5.2
7	+ The quick reference card for an item should contain the name, picture, short description, QR code to the documentation, category and further context of each item
8	+ The toolkit *should* provide students with functional information about the building blocks
9	+ The toolkit *should* support components that connect to an Arduino
10	– The information provided per building block *should* be consistent
11	+ The toolkit *could* support software running on a laptop
12	+ The toolkit *could* aid the students in connecting the components

From the Non-Functional Requirements (NFRs) two requirements have not been met. From the final evaluation, it can not be stated that NFR 1 is met, as students still had trouble finding and using all functionalities. NFR 5 has also not been realised due to time limitations. More items should be included to include all use cases. For instance, from the Thematic Analysis, it was gathered that unity is used in the project, and a block for this has not yet been implemented.

Non-Functional Requirements

1	– The toolkit shall be easy to use
2 3 4	+ Implementation of a functional building block shall not take longer than a day + The toolkit should be amendable + The toolkit should help the students prototype more quickly
5	– The toolkit *should* support the use case of as many projects as possible, within the scope of the Research and Design of User Experience project
6 7	+ Implementation of a functional building block should be straightforward + The toolkit should be useful for students of varying technical levels

8.2 Limitations

There are some limitations in the evaluation as it was performed. Due to time limitations, only the toolkit as a whole has been tested. While the observational notes can be used to get an idea of the value of the individual components, these could be tested separately. Additionally, the toolkit has only been tested with six students. While the results can be used to get an idea of the state of the toolkit it can not classify it objectively. Also, the toolkit has not been tested yet with actual maintainers on the usability of the administration pages.

8.3 Future work

The toolkit as a whole was evaluated to help the students create a prototype. However, there are points of improvement and opportunities for future work.

User interaction

As discussed in the evaluation, not all participants used the full toolkit. This hints at the manual and the explainer pop-up not being clear and noticeable enough. More research should be done on how to make the steps in the process clear to the users, or the item graph can be incorporated into the main page so it can not be missed. Another pain point here is that the selection of items persists while using the navigation in the website, but breaks when using the browser's back button. This is due to the browser serving a cached version of the page. This could be solved by letting the page not be cached by the browser, or detecting that the browser navigation is used and then reloading the page.

The choice helper

Due to technical limitations, the choice helper can currently only be used for sensors. This is because it sets filters in the filter tool, and the filter tool takes the union of the filters applied within that category. This means once the choice helper sets the filter for Motion tracking, none of the actuators will ever come up again. To mitigate this the choice helper could be split into two parts. One part is for actuators and another for sensors. Also, the answers could be allowed to not only set filters, bu also to remove them.

9 Conclusion

Incentivising the general population to move more will always be relevant, making the theme of the Research and Design of User Experience (ResDexUX) project ever relevant. This continues the challenge for students of Creative Technology to design interactive systems that help people move more or with more proper techniques, and to achieve that they need to prototype their ideas. Prototyping these concepts necessitates a high-fidelity working model equipped with sensors and actuators to test the user experience accurately.

This project has researched how to support the students in creating these high-fidelity prototypes with a design system. This design system has been developed into a toolkit. This toolkit comes with tools that aid in selecting, implementing and integrating the technologies needed for a high-fidelity prototype. The toolkit supports technologies on a component level. The technologies were chosen to cover as wide a range of projects aimed at sports and movement as possible. The toolkit provides ways technologies can be filtered on a functional level.

To help the students choose technologies for their high-fidelity prototype a website was developed featuring a filtering system, choice helper, and extensive documentation. The choice helper asks functional questions to narrow down the selection of components. To help the students implement the technologies the documentation includes wiring instructions and code examples. Lastly, to help the students connect different technologies a novel tool was developed. With this tool, a student can select their sensors and actuators. Then a network graph will be shown with all the micro-controllers and other supporting technologies needed to integrate these components.

User evaluations rated the toolkit well on a System Usability Score, and interviews with six participants indicated that it effectively supports all three aspects of creating high-fidelity prototypes. However, the toolkit can still be improved. The User Interface of the support website can be improved, and the overall clarity of the system still leaves room for improvement. With all of the tools the toolkit includes, it shows promising potential in aiding the Students of Creative technology in creating high-fidelity prototypes.

Acronyms

API Application Programming Interface. 20

CreaTe Creative Technology. 7

FR Functional Requirement. 17, 25, 42

HMI Human Media Interaction. 1, 13

IMU Inertial Measurement Unit. 15

MoSCoW Must have, Should have, Could have and Will not have. 11, 25

NFR Non-Functional Requirement. 17, 25, 42, 43

PHP PHP Hypertext Preprocessor. 31

ResDexUX Research and Design of User Experience. 1, 13, 14, 17, 22, 25, 28, 40, 43, 44

SUS System Usability Score. 1, 12, 28, 29, 40, 41, 44

UI User Interface. 41, 44

UML Unified Modeling Language. 5, 12, 26, 27, 30, 31, 33

Glossary

power-interest matrix A matrix defined by Mendelow[37] that ranks stakeholders on how much power and interest they have over and in a given project. 14

stakeholder (A group of) people who are interested or invested in the process and/or outcome of a project. 13, 14, 17

toolkit A set of tools and resources used for a particular purpose. 2, 12, 13, 18

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A Generative AI directive

During the preparation of this work, I (and my fellow authors) used no artificial intelligence tools.

B Screenshots of the prototypes

B.1 Prototype V1

The public section of the website

This section contains all the pages our users could see during the first round of testing. These pages are available when you are not logged in.

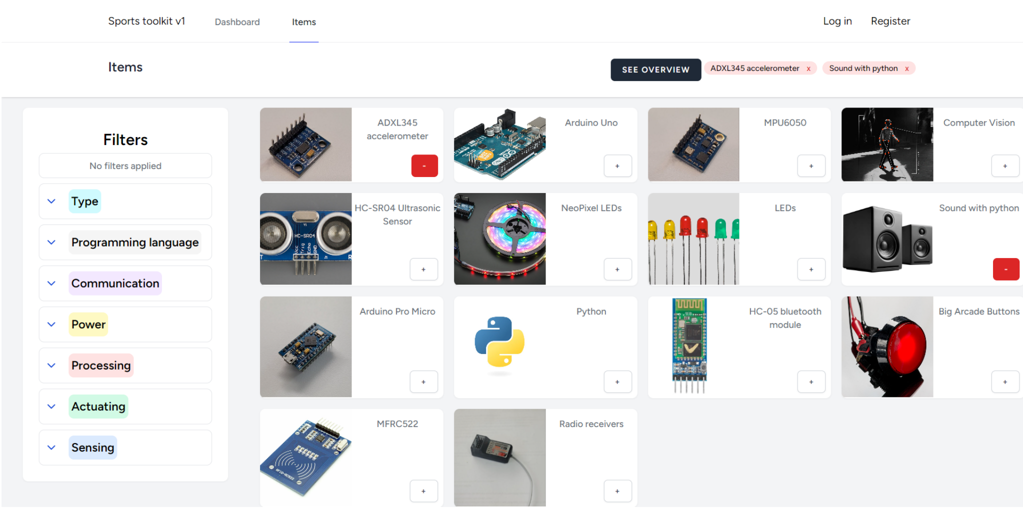

Figure B.1: The main screen of the website.

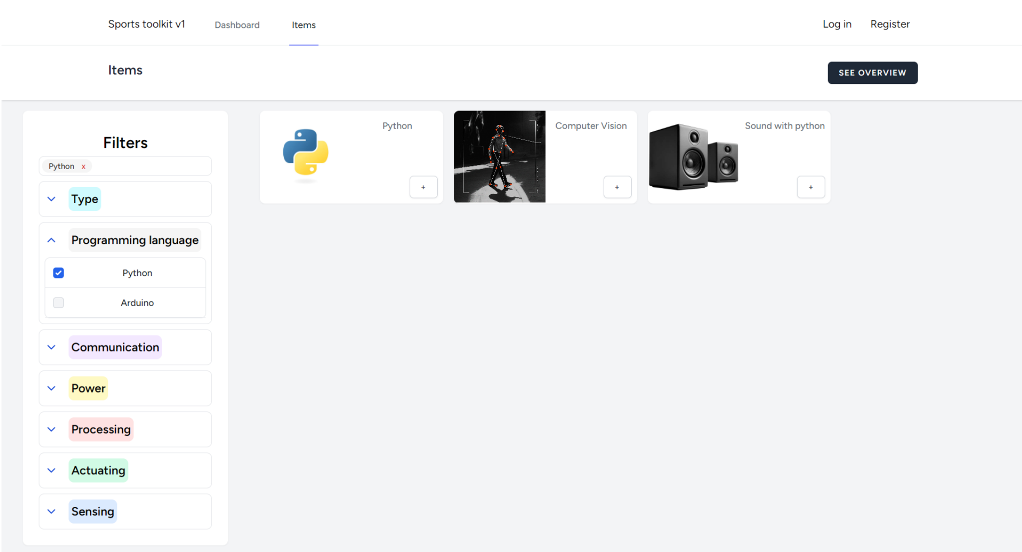

Figure B.2: The main screen with the filter of all items that have to do with Python applied.

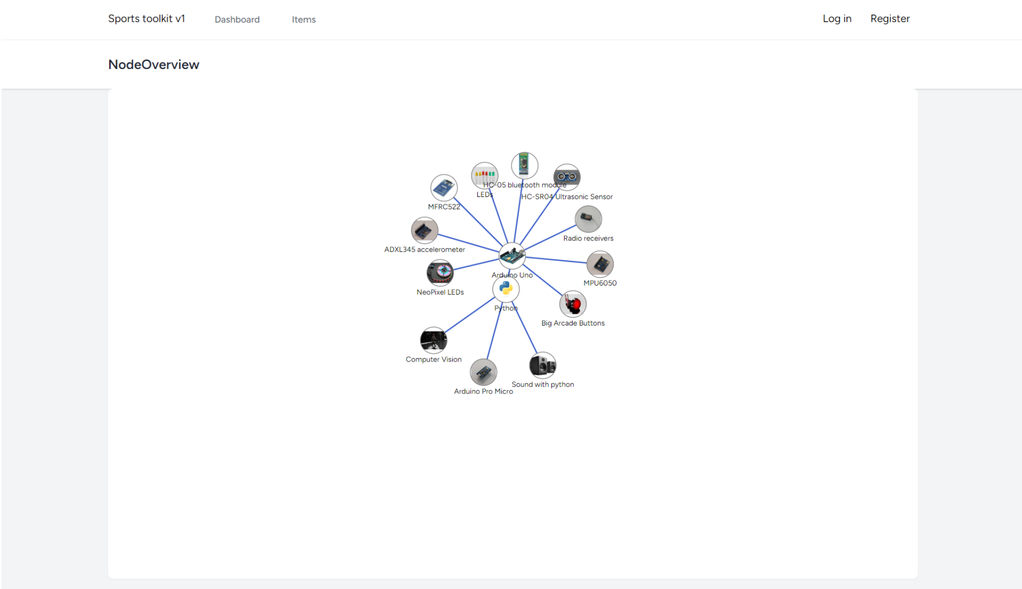

Figure B.3: The graph view without any items selected.

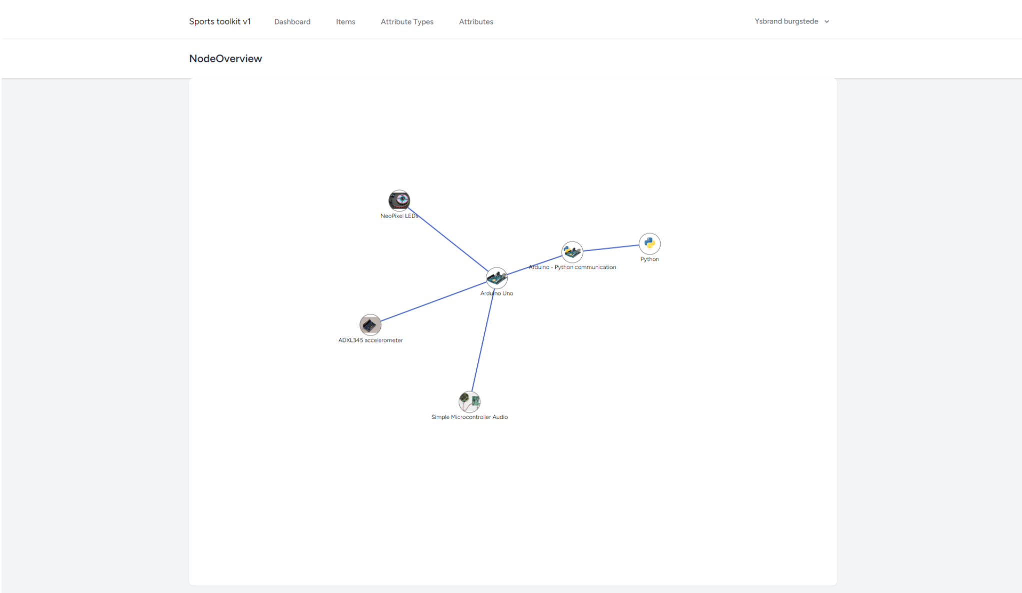

Figure B.4: The Graph view with the ADXL 345 Accelerometer, simple sound with Python and Neopixel LEDs selected.

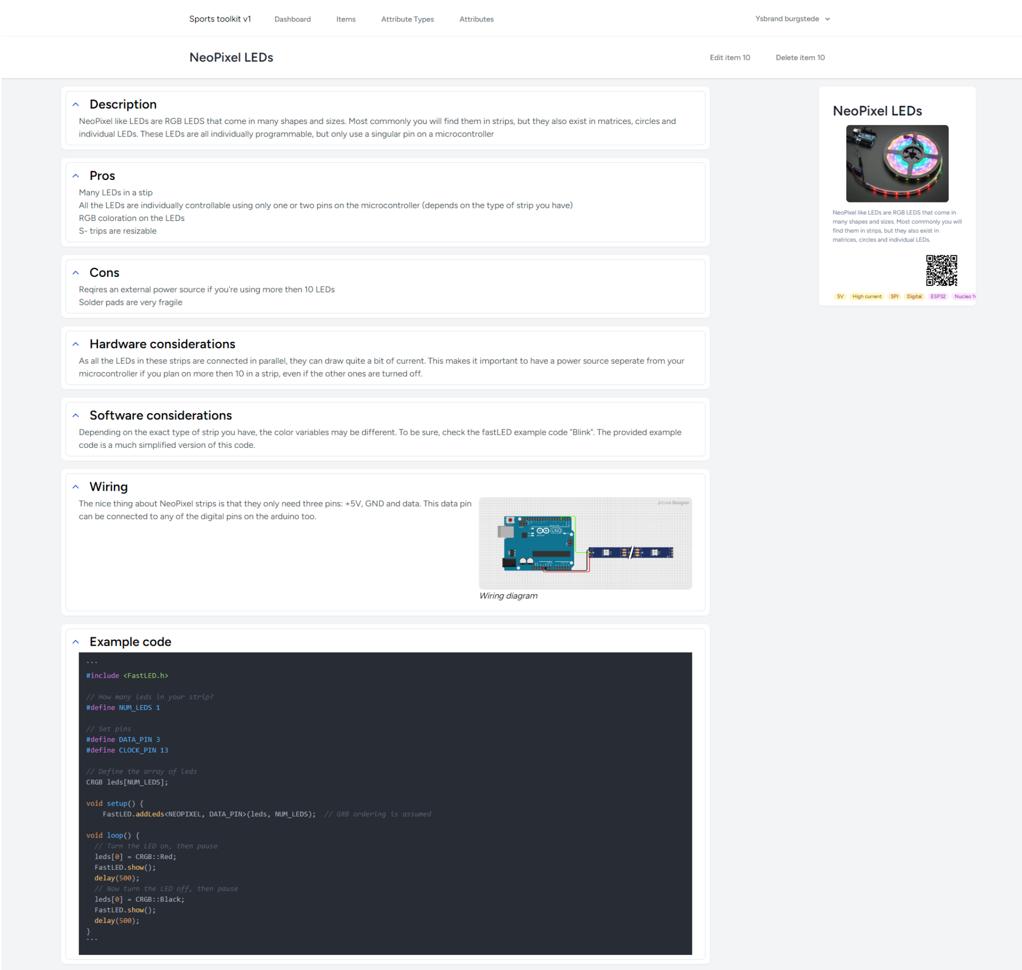

Figure B.5: The information page that is available per item that provides more detailed information. In this case, the information page for Neo pixel LEDs is shown

The maintainer tools in the website

This section contains all the admin pages available during the first round of testing. To access these pages, you must be logged in with a maintainer account. These pages are for managing the items and the information associated with them.

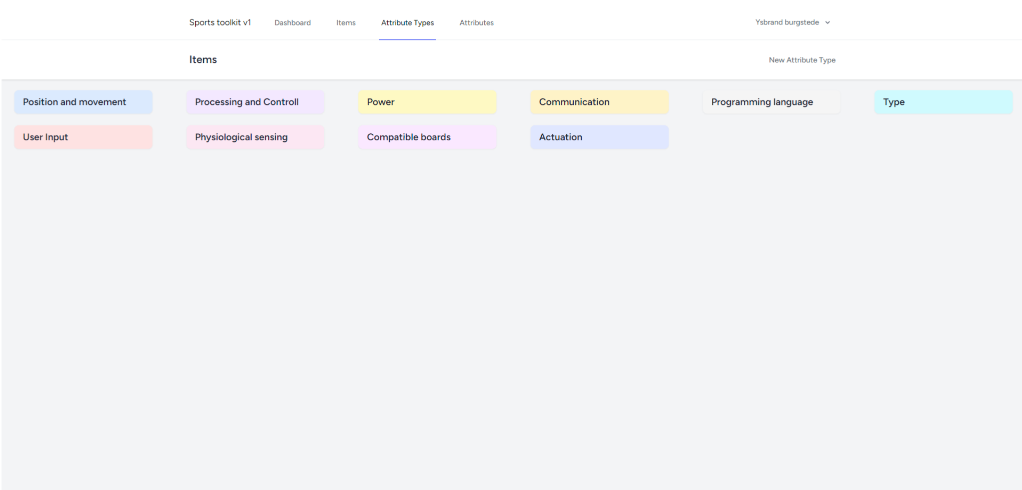

Figure B.6: The overview page where the maintainers can see all existing attribute types.

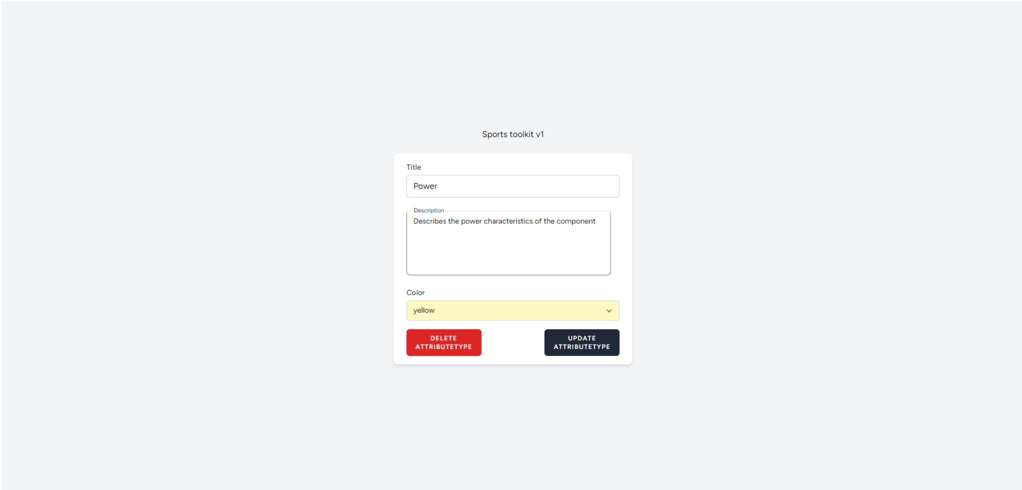

Figure B.7: The edit page where the maintainers can create or edit an attribute type.

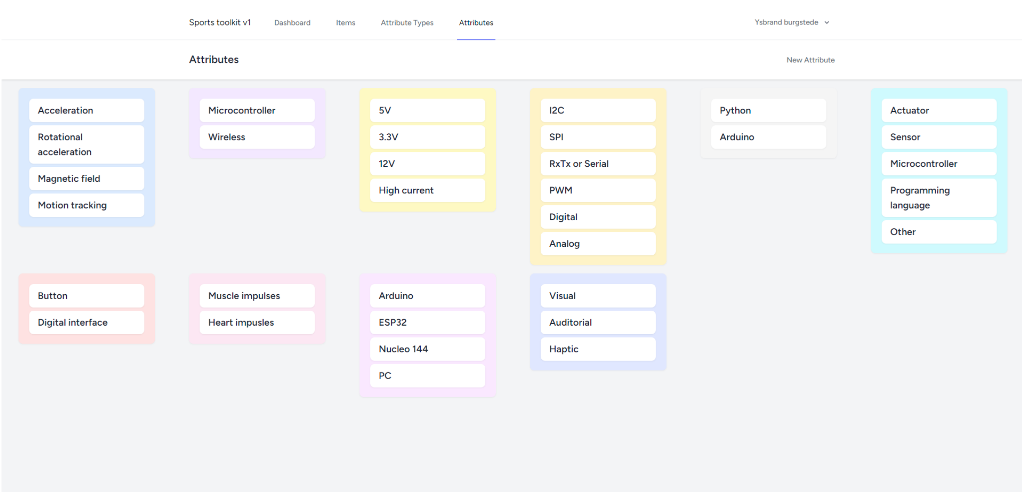

Figure B.8: The overview page where the maintainers can see all existing attributes grouped by their type.

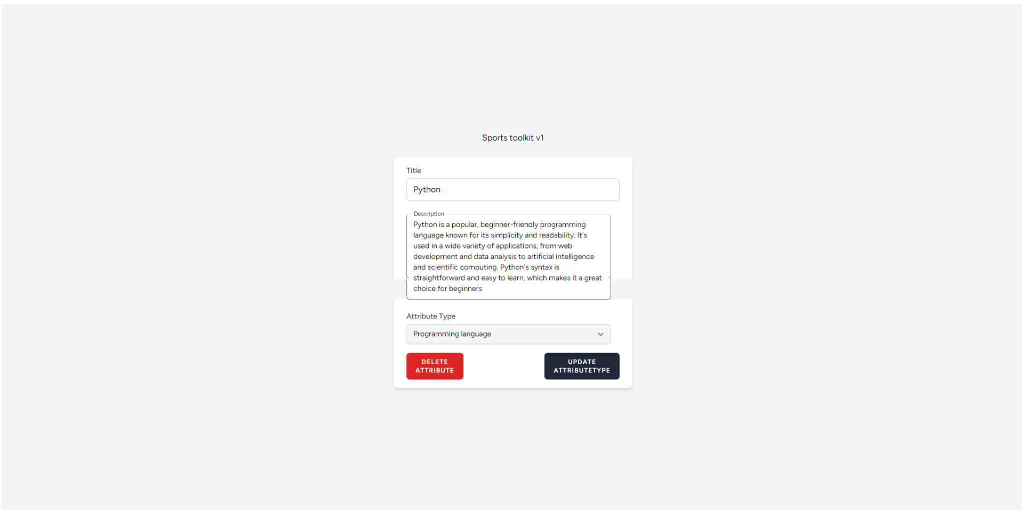

Figure B.9: The edit page where the maintainers can create or edit an attribute and assign it to a type.

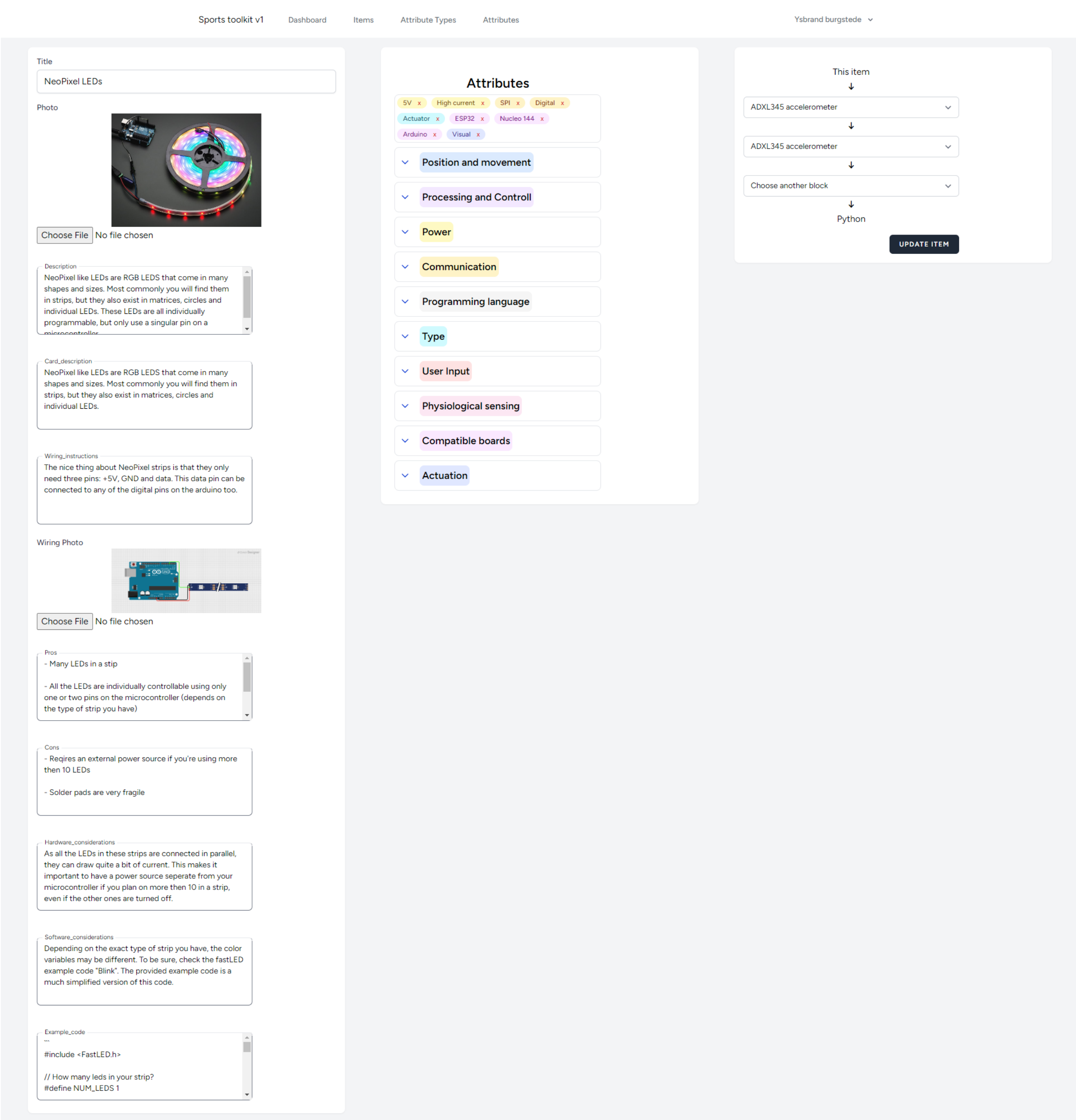

Figure B.10: The edit page for an item.

The edit page for an item where from left to right the maintainers can: edit the text fields for the item, set the attributes for the item and select the path to Python via existing items.

B.2 The final prototype

In this section, the screenshots from the final prototype used during the final evaluation will be included. When a page has not changed since the first prototype it will be mentioned in the appropriate section and not included again.

The public section of the website

This section contains all the pages our users could see during the first round of testing. These pages are available when you are not logged in.
Since the first prototype, two additions were made: the explainer section and the choice helper.

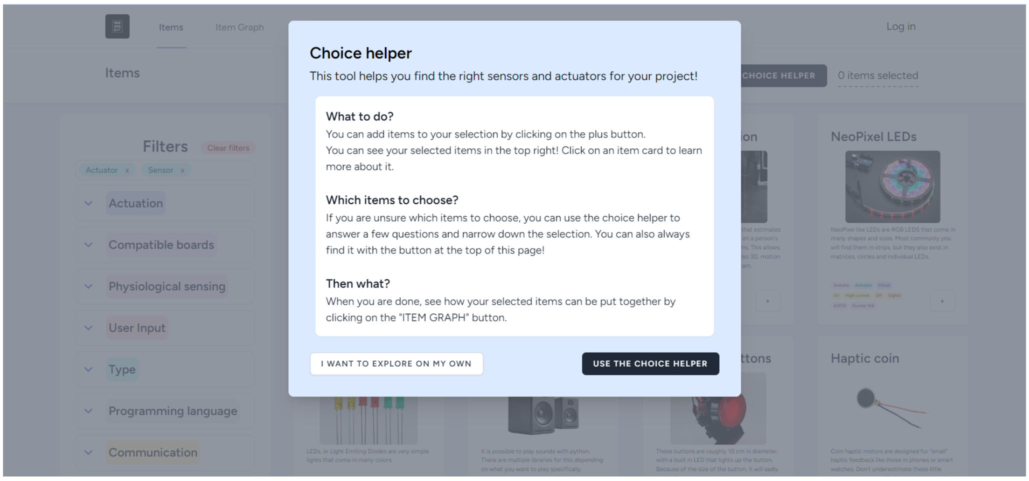

Figure B.11: The explainer pop up on the website.

The explainer pop up on the website. This pops up the first time you visit the website to provide additional info on how the site works and what to do.

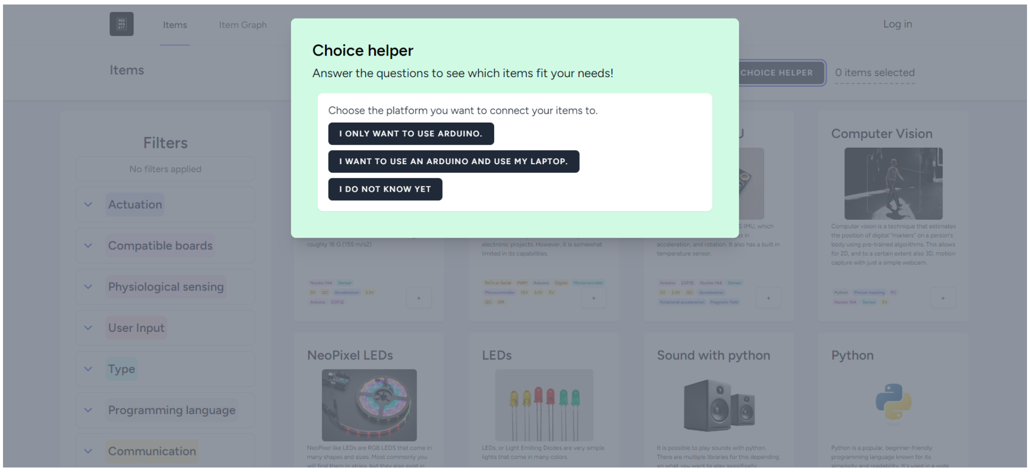

Figure B.12: One of the questions in the choice helper of the website.

One of the questions in the choice helper of the website. Answering this question sets the right filters for the micro controller and power options for you.

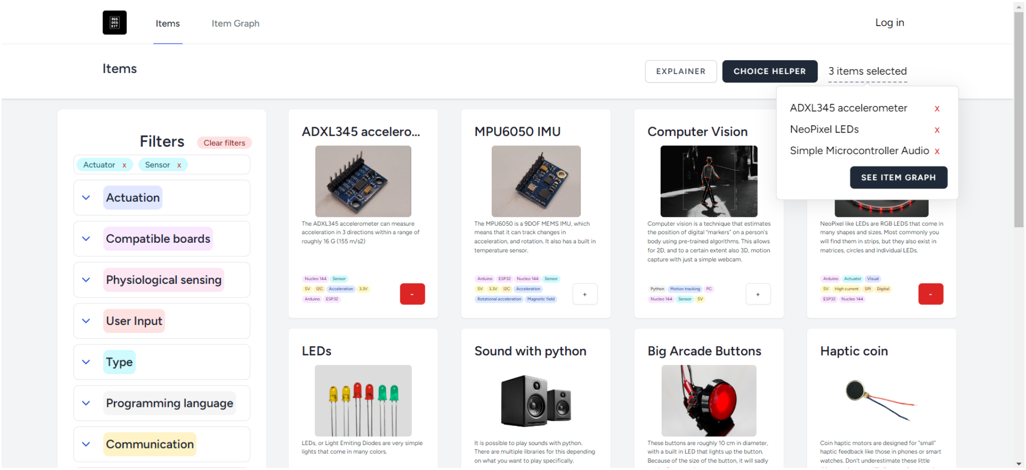

Figure B.13: The main screen of the website.

The main screen of the website. The main differences with Figure B.1 are the addition of the explainer and choice helper in the top bar. Additionally, the item cards have been reworked to show more information, and by default the filters to show only attributes and sensors are set.

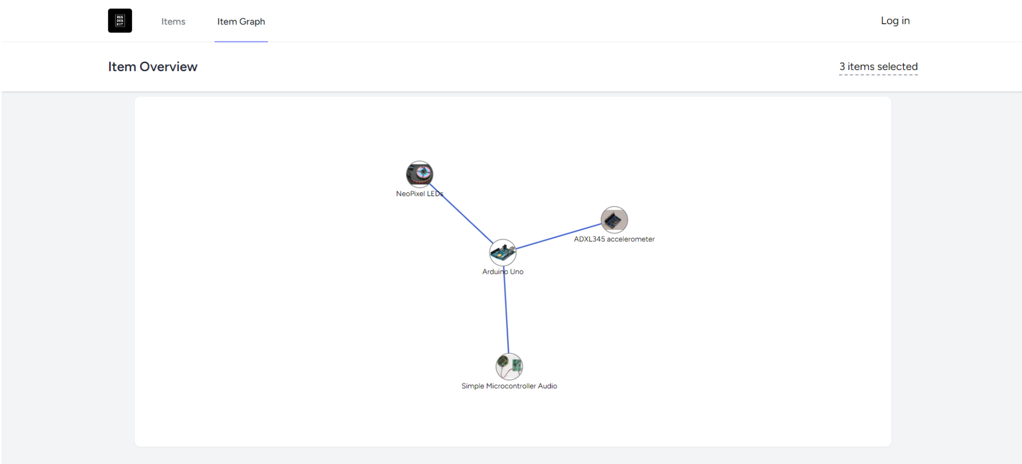

Figure B.14: The new Graph view with the ADXL 345 accelerometer, simple Microcontroller Audio and Neopixel LEDs selected.

The new Graph view with the ADXL 345 accelerometer, simple Microcontroller Audio and Neopixel LEDs selected. The main differences with Figure B.4 are that this page has been changed to show the shortest path between the items (notice the absence of Python), and the selected items are shown in the top right.

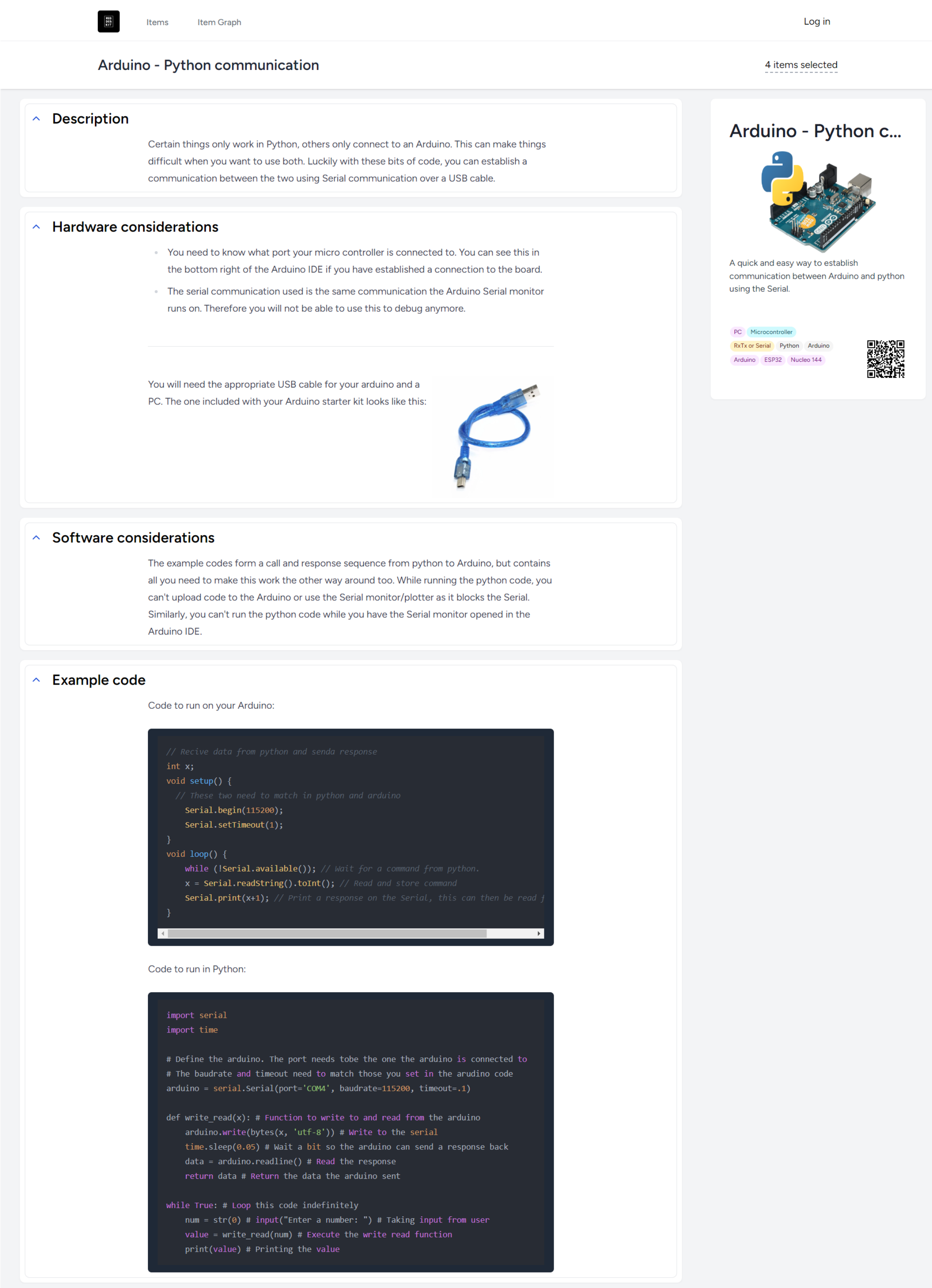

Figure B.15: The information page per item that provides more detailed information.

The information page per item that provides more detailed information. Sections have been made optional as not every item needs every section. In the example, the pros and cons are missing. Also, all fields have been converted to markdown fields. This allows the maintainers to define the markup of a section within the edit fields. This also allows the code blocks to be done in markdown, releasing the constraint of one code block in the example code, and additionally allowing for multiple images on the page outside of the wiring diagram.

The maintainer tools in the website

This section contains all the admin pages available during the first round of testing. To access these pages, you must be logged in with a maintainer account. These pages are for managing the items and the information associated with them.
The page where the maintainers can see (Figure B.6) and edit (Figure B.7) the attribute types, along with the pages where they can see (Figure B.8) and edit (Figure B.9) the existing attributes, have not been changed since the first version. Therefore they will not be included in this section again.

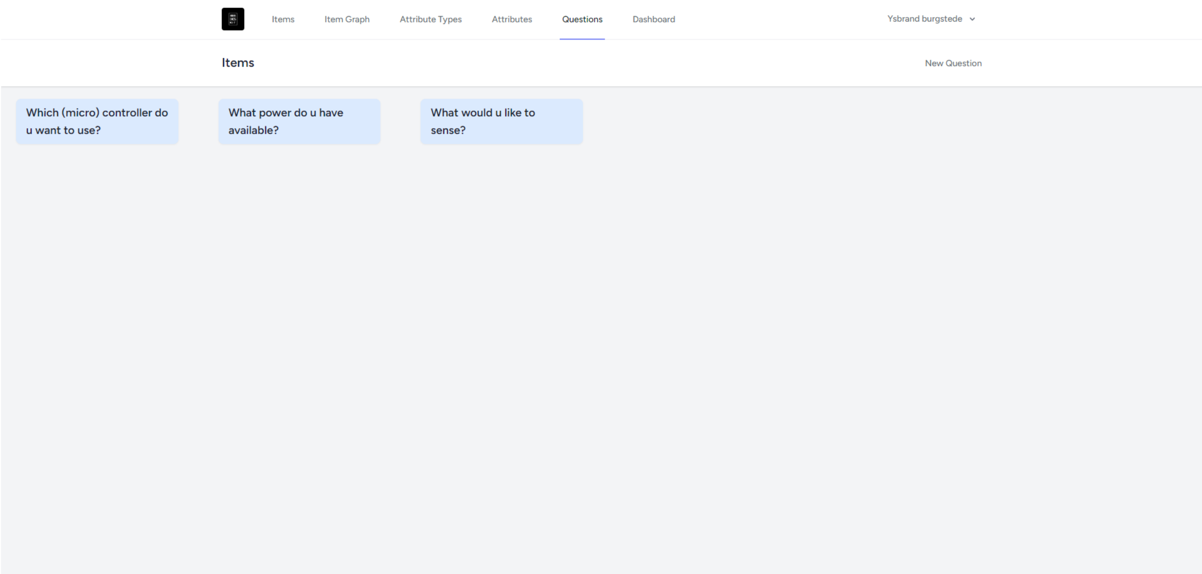

Figure B.16: The overview page for the questions for the choice helper.

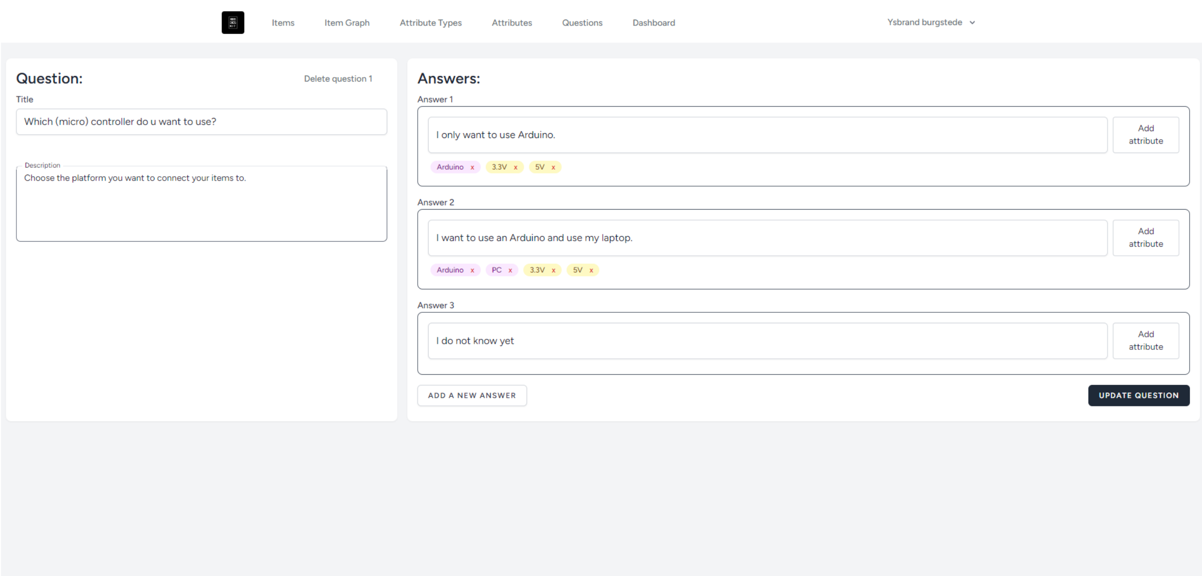

Figure B.17: The edit page for a question.

The edit page for a question. The question along with multiple answers can be created or edited. Per answer attributes can be added. These attributes will be added to the filter when that answer is chosen in the choice helper.

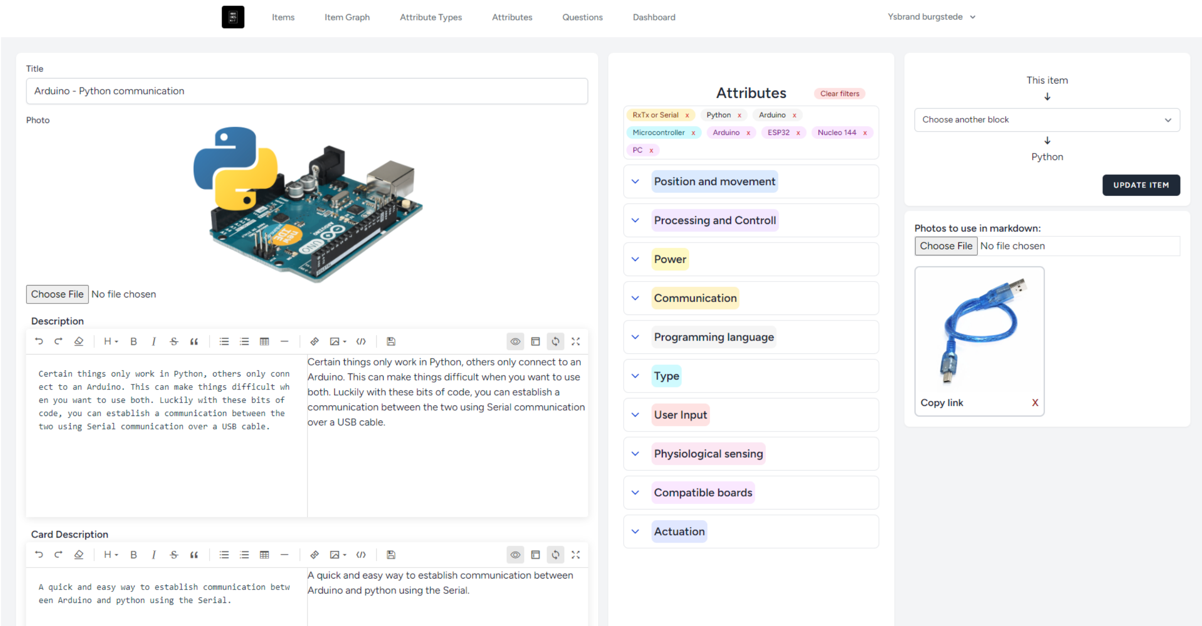

Figure B.18: The edit page for an item.

The edit page for an item. The main differences compared to the first version (see Figure B.10) are the use of interactive markdown field that will show a preview of the markdown in real time, along with the "Photos to use in markdown:" block, where additional photos can be uploaded and then the link copied to be used in an image block in markdown.

C Building blocks

This shows the first iteration of the information that could be provided with a building block.

Ws812b LEDs

What does it do?

The Ws812b LED is an individual addressable LED that works on 5Volts. These LEDs can often be found in LED strips or matrices for quite cheap. The most common form of appearance is the 5M LED strip, as seen below to the right.

Control:

These LEDs have one big advantage over normal LEDs. They each have a small controller on board which makes it easier to control. This controller controls the red green and blue LED in each individual pixel. The individual pixels can be daisy-chained so you only need three wires to a microcontroller to control an entire strip. For 10 pixels or less, you do not even need an external power supply. There even are common libraries to control these pixels for you.

Physical setup

On the LEDs you will find three pins: GND, +5V and Din. To connect to your microcontroller you connect the GND to a ground pin of you microcontroller, +5V to a pin giving out 5V and Din to a digital pin. Keep track of which digital pin as you need to set this in the code!

Arduino/ESP

For the Arduino and ESP-boards this library is called FastLED and can be found here: https://fastled.io/. It can be easily installed via the Arduino library manager. Then the LED strip can easily be controlled with normal Arduino code.

Raspberry pi

With a raspberry pi we can control the LED strip with python. The set up is a bit more complicated. This is because the chips need a precise timing only the audio chip on a raspberry pi can provide. Therefore we need to enable this, and install some packages. This also means the data line of the LED strip can only be connected to certain pins. The safest to use for this is GPIO 18.

1. In a terminal run "sudo apt-get install gcc make build-essential python-dev git scons swig"
2. Then, add this line: "blacklist snd_bcm2835" to "/etc/modprobe.d/snd-blacklist.conf". This can be done by the command "sudo nano /etc/modprobe.d/snd-blacklist.conf"
3. Then in the file "/boot/config.txt". We need to uncomment (take out the # in front of) the following line: "#dtparam=audio=on". This file can also again be edited by putting "sudo nano" in front of it.
4. To load these files again, you need to reboot the raspberry pi with the command: "sudo reboot".
5. Install the necessary python packages by running the following commands:

“sudo pip install rpi_ws281x adafruit-circuitpython-neopixel”
“sudo python -m pip install --force-reinstall adafruit-blinka”

6. Now you can make a python file and open it with an editor! See the example code below to get you started.

Controlling more than 10 pixels

To control more than 10 pixels you will need to use an external power supply.

To do this you will need an external power supply. This can be done by the following steps:

1. Choose a 5V power supply with a sufficient current rating. For example, a 5V 10A power supply can handle up to 100 WS2812B LEDs. You can calculate it, as each pixel can draw 0.06 Amps. So multiply the amount of pixels you have with 0.06 and you have the amount of amps your power supply needs to be able to supply.
2. Connect the Power Supply to the LED Strip:
    - Power Line (5V): Connect the positive terminal of the power supply to the 5V power line of the LED strip.
    - Ground (GND): Connect the negative terminal of the power supply to the ground line of the LED strip. It is also crucial to connect the ground of the power supply to the ground of the Raspberry Pi to ensure a common ground.
    - Connect the Data Line: The data line should still be connected to GPIO 18 when using a Raspberry Pi, on an Arduino pick the digital pin you set in the software.

D Thematic analysis table

Category	***Subcategory***	***Type***	***Item***	***Qty***
Hardware	Lights	light systems	LED strip	2
			LED ring	2
			(Colored) lights	6
			LED unspecified	4
			Light button combo	3
	Buttons	Button systems	Big button that can handle human weight	8
			Small button	6
	sensors	uncategorized sensors	capacitive sensor	2
			pressure sensor	4
			Light sensor	1
			rotary encoder	1
			stretch sensors	1
			ultrasonic sensor as presence detector	1
			hall effect sensor to measure rotational velocity	1
			pedometer (step counter)	1
	motion tracking	motion tracking systems	IMU	2
			Xbox Kinect	4
			depth sensing camera	1
			Optical motion tracking	8
	position tracking	(global) position tracking systems	GPS	3
			GPS beacons	1
			Compass	1
	Audio	systems to provide auditory feedback	Buzzer	2
			headset	2
			Speakers	2
	connections	data connection types between prototypes and other devices or each other	wired connection	4
			WiFi connection	4
			Bluetooth connection	3

Category	***Subcategory***	***Type***	***Item***	***Qty***
Hardware	motors	motor based systems	Haptic motors	2
			motor controllers	1
			On-off motor controller using MOSFETs	2
	processing	main processing unit of the system	Computer as processing unit	9
			Phone as processing unit	1
			Raspberry pi	1
			Arduino	10
			ESP	3
	power	power management of the system	external power supply	1
			Battery power supply	6
			Battery management system	1
			bread board	4
	Displays	screen or image based feedback systems	VR	3
			Projection	10
			Screen	8
	Other		home trainer	1
			smart watch	2
Feedback	visual	visual methods of providing feedback	Light	2
			Color	7
			VR	2
			AR	4
			general visual	6
	audio	auditory methods of providing feedback	sounds	9
			music	5
			Spacial 3D audio	1
	touch	tactile methods of providing feedback	haptic	4
measurements	movement	measurements that can measure the movement of a person	step counter	1

Category	***Subcategory***	***Type***	***Item***	***Qty***
measurements	movement		position measurements	4
			rotational velocity	1
			rotational position	1
			motion tracking	12
	physiological	measurements that can measure physiological data on a person	Oxygen levels	1
			heart rate	3
			breathing	1
	other		presence detection	1
software	interface	ways of interfacing with the system though software	app	9
			website interface	1
	engines	software engines used to code and run the system	Unreal engine	1
			Processing (code language)	1
			Unity	6
	motion tracking	software used for motion tracking	Kinect SDK	1
			Computer vision	4
	other		spotify API	1
			QR codes	1
design considerations	wearables	considerations for wearables	smaller prototype better	4
			integration into fabric	1
	setup considerations	considerations for the (way the system is) setup	wall mounted vs floor mounted	1
			ease of setup	1
			Merging systems to prevent communication overhead	1
			multiple cameras for better motion tracking	1
			wireless capabilities	2

Category	*Subcategory*	*Type*	*Item*	*Qty*
design considerations	Button considerations	considerations for when making buttons	flexibility of implementation	1
			Light and buttons integrated together	2
			extra buttons to add to the interaction	2
			Capacitive sensors instead of buttons because of ease of up-scaling	1
			button strength	2
	Controllers	considerations for designing custom input devices	custom controllers (input device)	2
			hands themselves act as controllers	2
	other		Visibility of feedback	3
			Multiplayer capabilities	2
			Chose one technology and tried to build around it instead of looking at alternatives for that technology	1
limitations	audio		audio quality of the speakers	1
	motion tracking	issues students had while implementing motion tracking	motion tracking had issues with detecting depth movements	1
			motion tracking not working well in low light levels	2
			motion tracking stops working when more than one person in frame	2
	component issues	issues students had while implementing	Battery life	1

Category	*Subcategory*	*Type*	*Item*	*Qty*
		general components		
			GPS module did not work well	1
limitations	component issues		lack of components	2
			waterproofing	1
			long distance wireless components	2
			motor power	1
	system issues	issues with the system as a whole	system not movable	1
			issues with properly powering system	3
	input	issues with (getting) inputs for the system	real time measurement of acceleration	1
			extra buttons for extra inputs	2
other		other	data processing of compound movement in IMUs	1
			addition of random movement to a ball through magnets	1
			desire for the system to work while mounted with magnets	1

E Expert interviews

E.1 Consent form

Consent Form for Developing a rapid prototyping kit for the design of Creative Technology for sports and movement

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated 02/05/2024, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I understand that taking part in the study involves an audio-recorded interview. I understand the audio recording will be transcribed as text and when this has been completed the recording will be destroyed.	○	○
Use of the information in the study		
I understand that the information I provide will be used for the research for the graduation projects of Sven Rozendom and Willem Ysbrand Burgstede. I also understand the anonymised transcriptions will end up in their final write-ups, which will be stored in the Graduation Project database of the University of Twente.	○	○
I understand that personal information collected about me that can identify me, such as my name, will not be shared beyond the study team.	○	○
I agree that my information can be quoted in research outputs	○	○
Consent to be Audio Recorded		
I agree to be audio recorded during the interview.	○	○

Signatures

______________________ ______________________ ________

Name of participant Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

_________________________ ___________________ ________

Ysbrand Burgstede Signature Date

Study contact details for further information:

Sven Rozendom (s.rozendom@student.utwente.nl)

Willem Ysbrand Burgstede (w.y.burgstede@student.utwente.nl)

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

UNIVERSITY OF TWENTE.

E.2 Information letter

Information letter: Developing a rapid prototyping kit for the design of Creative Technology for sports and movement

This letter informs you about the research conducted by Sven Rozendom and Ysbrand Burgstede. The research aims to investigate how we can support the design practices of staff and students aiming to design interactive systems for sports and movement.

The session will take about 20-30 minutes. The participant will take part in an interview with the researchers where they will ask questions related to the research topic. The answers will be anonymised.

The benefit of participating in the research is that the end product from the research will be aimed to help the group of staff the interviewee belongs to in creating prototypes and helping their students.

We do not consider participating in this research to have any risks.

The Interviewee can at any time stop the interview and refuse to answer any questions. They can also request for their previous answers to be deleted. Afterwards, they can contact the researchers by email with a request for their interview to be deleted and not used for the research. (emails listed below)

We will not collect personal information from the interviewees.

The collected data during the interview will be processed by the researchers and afterwards deleted. It will not be made public and will be deleted at the latest when the researchers graduate. The data will be stored on a secure private drive which is only accessible to the researchers. The anonymous transcripts will be included in their final written report and archived on the Graduation Project database of the University of Twente.

If you have any questions or concerns or want to contact the researchers you can do so by email: s.c.rozendom@student.utwente.nl and w.y.burgstede@student.utwente.nl.

If you have any ethical complaints this research is being conducted under the Ethics Committee Computer and Information Science. You can contact their secretary at ethicscommittee-cis@utwente.nl.

E.3 Interview with an assistant professor from the research group Interaction Design

00:00:06 Researcher Let us start with the basics. What do you do and what do you teach here?

00:00:11 Interviewee I am an assistant professor in interaction design and I am teaching in industrial design engineering. I also supervise Creative Technology and I-tech students in their graduation assignments when they are aligned with my research field, and I am also supervising industrial design engineering.

00:00:55 Researcher So you have experience and background working with students themselves?

00:00:58 Interviewee Yeah, seven years to be specific.

00:01:05 Researcher What area of design do you focus on? More on the product side of the design?

00:01:13 Interviewee Yeah, not not physical products only because we call a lot of things as products. An app can be a product. Any technology can be a product, intangible things can also be products. So yes, but also say I am in the conceptual design of the products.

00:01:36 Researcher Do you have experience with low-fi and high-fi prototypes?

00:01:39 Interviewee Yes, I do not actually do low-fi and high-fi prototypes myself, but obviously in the courses that I am teaching, students come up with low-fi and high-fi prototypes.

00:01:51 Researcher And in the courses that you are teaching. What are aspects that you see students struggle with those prototypes with?

00:02:10 Interviewee Hmmm, what do you mean?

00:02:12 Researcher The students in your courses come up with an idea, and then they start to make a low-fi prototype. They iterate on that and then they have to make a high-fi prototype. What are the struggles in that transition?

00:02:20 Interviewee It depends on, of course, the students and their skills. But most of the time I find that students struggle a lot with working with sensors, or let's say from an I-Tech perspective it is more like how can we find the sensors, which sensors should be used, and how do we implement it, and how actually the sensors will work for the purpose of it? Because a low-fi prototype is just low-fi, and you do not really go in dive into the details of the product, whatever it is, if it is like a tangible product, I mean the sensors. But if it is if it is more like an app or let's say online interface, the back end also becomes really a struggle for most of the students.

00:03:24 Interviewee And even if and even worse if there is a tangible and intangible component of the prototype the the challenge becomes how to make the connection between those tangible and intangible intangible means. Intangible like an app or interface and tangible is the physical part.

00:03:44 Interviewee Then how will they communicate with each other? Which mediums, how does it physically connect? How the data will be transferred and that kind of stuff.

00:04:04 Researcher Do you feel like aiding in that aspect will improve the course? Because if understood you correctly the focus of these courses often is not the technical implementation but the end product, right?

00:04:21 Interviewee No. Yeah, I think it again depends on the context of the assignment that the students are working on, in some courses they do not even develop a prototype. But when I talk about, let's say GP or Creative Technology and I-Tech graduation assignments. I think that becomes kind of the last moment. Then the students still struggle because if it is a group project, most of the times within the groups they they find their ways, but when it becomes an individual assignment, it becomes kind of an into their face. Oh, actually, I cannot do this or I do not know how to do that.

00:05:02 Interviewee And that comes kind of at the wrong moments and it becomes really stressful. So I think in the educational setting we have enough knowledge transfer during let's say the the courses, but it might be because of the form of the education or the form of the projects. They are mostly group projects.

00:05:32 Interviewee But when it becomes an individual assignment it becomes kind of challenging or an anxiety/frustration moment for many students to realize that their skills are maybe not up to the level that they should be prototyping, and in those in those moments, what I generally do is say: OK, just go to this person or get help here, because I cannot help. First of all, I do not have time.

00:05:54 Researcher Is that also a big aspect of it? Because then the time spent on the technical side would rather be spent on developing the product that the user experiences?

00:06:02 Interviewee Yeah. So sometimes students learn when they are developing those. I mean, if it is an individual assignment, they learn on the go, which is not bad because then your skills will be aligned with whatever you are doing.

00:06:20 Researcher And do you feel like this student you supervise have all the tools necessary to make the step from low-fi to high-fi? Or is there a disconnect?

00:06:27 Interviewee Not always, not always. I think it very much depends on the students interests in the first place. Some students are really invested in prototyping and you know, using the materials and going to design lab and, you know, exploring things. But some students are a bit afraid of doing prototypes of high-fi prototypes. So the entry level then becomes like, not even not equal, the entry level of prototyping. So then those less secure students will need more help and assistance, but again that the assistance will be probably in the design lab or lab people.

00:07:13 Researcher Is that confidence only on a social level? Or does the technical level there also matter?

00:07:22 Interviewee Yeah, I think the technical level is is is very important. I mean if they do not feel competent. I think competence is very important, like feeling that I am competent in doing this.

00:07:41 Researcher So I already explained shortly that we would like to help students with some sort of toolkit with sensors and sort of a starting off point like where do you go from your low-fi to your high-fi prototype. If such a tool would magically exist tomorrow, where would you think it would make the most impact?

00:08:12 Interviewee Yeah, I think it should be. First of all, easy to use. As I said, some of the students are quite skilled. Some of the students do not need much input to start with prototyping. On the other hand, not everyone is taking the same courses sometimes, and for Module 6, they are taking the same course, but still they are hesitant to start. For those students, the entry-level should be easy, so how compatible I am in this task, perceived control, kind of. If it is like I have high perceived control then those students are just independent, they just do it. But I think the most impact that you can have is those students who have low competency or low perceived competency.

00:09:14 Interviewee That is why the toolkit that you design should maybe start like plug and play. These kinds of toolkits should really easy to set up, easy to understand, and easy to understand the logic behind certain prototyping aspects.

00:09:33 Interviewee For example in IDE I think in the past there are some other toolkits. There is one big box that consists of all the small sensors and everything and it is so easy to plug and play together and you can create your own prototypes really quickly and easily, and you do not need programming, for example. Those kind of small simple toolkits and then learn: If I do this, then I need to have a different maybe sensor to make it a bit more advanced. I will look up the name of this toolkit for you. You can continue with the next question and in the meantime, I will look up the name.

00:10:39 Researcher We are also looking at the level of abstraction that it would need. So you mentioned a toolkit that you would not need programming for. As a teacher. How important do you think it is that the students also learn to use these tools? Or is it okay to abstract that away into a toolkit?

00:11:16 Interviewee I think both are important. We have certain learning goals in every course and we want if the learning goal is to really prototype and ways to prototype, then the toolkit should really foster having multiple prototypes at the same time. But for me I think the most important thing is because this is also kind of a learning process still at the university, the end result, the end goal is not to come up with the most fancy prototype. I think the way to the way to prototype is more interesting and important than the end prototype.

00:12:23 Interviewee The toolkit is called Little Bits. So there is a board and small sensors and you can expand the sensors and there is also like these wires. And there is like starter kit and a bigger one. You have a lot of sensors and you can connect these sensors and make your first prototypes and this is so easy because you just really plug and play and see: when I have this temperature sensor together with noise sensor they work together to measure this. So I think the toolkit should have these kinds of easy entry points.

00:16:21 Researcher So if the students have this kit of hardware options, what effect do you think that will have on their final prototypes in regards to creativity?

00:16:36 Interviewee I think they will focus a lot more on their creativity than on the technical aspects. Well on one side it might limit because the the toolkit will also have some limitations, but because it is going to be easy to to use and easy to prototype, the high-fi prototypes, they will focus more on the creativity then the technical aspects, I think. Because most of the times students lose their time in coming up with this really high-fi prototype and get drawn into the technicalities, and the creativity then moves to the second place in the priority list. So that can actually really foster their creativity.

00:17:26 Researcher Would there be a concern that a bit of that creativity is lost because they are pushed to use the sensors in the toolkit.

00:17:38 Interviewee So that is why the the census and the toolkit should be chosen in a way that maybe that will be like every module or depending on the project the sensors will be predefined in a way that the students can really start with their prototyping.

00:17:58 Interviewee And then they will explore what are other sensors, what are the possibilities for expanding this prototype. I think the in such a toolkit, the focus will be really on making something work and then expanding it with how can we make it better? But if you cannot just start with something in hand, it is always difficult to see where this prototype can go. There might be a limitation, then it is probably up to the module teams who will select some of the sensors maybe.

00:18:56 Interviewee Especially in Bachelor education, I think we need to limit the students in a way that it is not always sky is the limit, because then it is really frustrating. And there are some moments the sky is the limit and there are some moments that it is not. So maybe this low-fi to high-fi prototyping is where the sky has some limitations.

00:19:56 Interviewee You need a starting point. It can not always be like I can do everything.

00:20:00 Researcher Do you think the most value would be in the providing students with the starting point.

00:20:05 Interviewee I think so, yes.

E.4 Interview with a professor from Biomedical Sensor and Systems (Dutch)

00:02:14 Researcher Wat is jouw rol binnen de UT?

00:02:23 Interviewee Ik werk hier bij de Biomedical Systems and Signals group als associate professor. Heel breed gezegd op het gebied van meten aan bewegen. Eigenlijk bewegingsanalyse in sport en revalidatie. Mijn onderzoeksteam werkt aan het meten van bewegen, het identificeren van interessante parameters in beweegpatronen. Bij voorkeur met inertiële sensor technologie met als doel om blessures te voorkomen en prestaties te optimaliseren. En ook bij voorkeur In de meest sportspecifieke setting, dus We hebben heel veel metingen die we hier in het lab doen, maar idealiter willen we eigenlijk In de natuurlijke wereld meten.

00:03:36 Interviewee Dus dat is eigenlijk het onderzoek wat ik vooral doe en daarnaast geef ik onderwijs binnen de BME, een vak over technologie om prestatie in sport te kunnen meten. Ook in CreaTe trokken bij het Biosignals Medical Electronics vak. En veel samenwerking. Ook met met interaction technologie in in projecten.

00:04:05 Researcher Werkt u in deze projecten ook met studenten?

00:04:08 Interviewee Ja hoor, zeker ja. Het is een beetje afhankelijk van van welk project. In principe hebben we per project over het algemeen een promovendus, maar daaronder zie je vaak kleinere studentenprojecten. Dus We hebben op het moment binnen de onderzoeksgroep ik denk wel 8 masterstudenten en 3 bachelorstudenten.

00:04:40 Researcher Dan om daar een beetje op aan te sluiten.

00:04:45 Researcher Waar ziet u dat studenten er moeite mee hebben om zon project uit te voeren?

00:05:10 Interviewee We werken heel veel met met inertiële sensortechnologie, eigenlijk primair met inertiële sensortechnologie en daar kun je gewoon standaard softwarepakketten gebruiken. We werken veel met met x-sense, Movella hardware Omdat het een spin off is van deze vakgroep en nogsteeds dichtbij zitten. Dus dat is een makkelijke verbinding en die hebben wel een analyse software pakket. Alleen dat geeft heel veel informatie waarvan je eigenlijk moeilijk kunt identificeren welke data is relevant, en je hebt totaal geen controle, het is een soort Black box dus. Als je dat pakket gebruikt dan kun je redelijk eenvoudig aan data komen. Dan weet je niet die de waarde van de data goed te schatten. Dus wat we bij voorkeur doen is met losse sensoren werken en dan moet eigenlijk moeten al die stappen die in die software voor je gedaan Worden moet je zelf doen en we lopen er tegenaan dat in het huidige BME curriculum, waar de meeste van onze studenten uitkomen eigenlijk heel weinig kennis wordt overgedragen of dat dat type signaal verwerking en analyse. Dus die stappen, dus het komen van de ruwe data van die sensoren tot zinvolle interpretatie van parameters die iets zeggen over het beweegpatroon, en dan even naar hardlopers waar we het meeste naar kijken, omdat dat een basismotor programma is voor heel veel sporten. Het is lekker cyclisch, het is relatief eenvoudig, bijna iedereen kan het, dus dat is een makkelijke sport om makkelijk beweegpatroon om te studeren. Om daar relevante parameters uit te halen als je gewoon start from scratch met met met een aantal inertiële sensoren, en bij voorkeur zo weinig mogelijk. Dat is de grote uitdaging.

00:06:51 Researcher Werken jullie dan met jullie eigen ontwikkelde sensoren, of is dat ook een kant en klare oplossing?

00:06:58 Interviewee Dat varieert. We gebruiken vooral het Link systeem van XSense, een half pak, dus een lower body plus sternum configuratie. Daar kunnen we eigenlijk alle relevante parameters voorhardlopen kunnen we uithalen. Voordeel daarvan is dus dat je maar één bodypack nodig hebt, dus je hebt een iets handzamer systeem. Het pak gebruiken we niet. Dat is eigenlijk voor de meeste metingen die we doen gewoon niet niet handig, veel te warm, oncomfortabel. Dus het typen de sensor vaak gewoon zo op het lichaam.

00:07:33 Interviewee Maar vooral voor bepaalde onderzoeksprojecten. Nou, We hebben heel veel studies naar sensor reductie, dus dan plakken we naast een MVN Link systeem nog gewoon een los sensorsysteem. Een de dot sensoren worden daar veel voor gebruikt nu, maar je ziet dat dot sensoren weer andere kenmerken hebben. Die hebben een lagere samplefrequentie, hebben andere range, die hebben andere filtering op de sensor dus die vereisen weer een andere behandeling feitelijk.

00:08:01 Interviewee En voor een aantal studies gebruiken we eigenlijk weer custom made sensoren. Die maken we wel samen met met XSense, dus dan hebben we eigenlijk gewoon een deel van de XSense-sensor waar we meer controle over hebben. Dus we proberen wel altijd te zoeken naar een meet setup waar we zoveel mogelijk controle over hebben. In plaats van de blackbox die Movella aanlevert.

00:08:32 Interviewee Je vroeg naar de eigen sensoren, want bijvoorbeeld het CreaTe BME vak, daar worden gewoon relatief eenvoudige IMU's gebruikt die met een eigen behuizing. Voor onderwijs toepassingen gebruiken we die wel maar voor onderzoeksdoeleinden worden die eigenlijk bijna niet gebruikt.

00:08:50 Researcher Om dan wat meer naar dat onderwijs te gaan, u geeft dus ook les over hoe je die signalen interpreteerd. Vanuit uw oogpunt, als je een student zo'n sensor geeft, hoe loop je dan door de stappen heen om dan ook daadwerkelijk dat signaal bruikbaar te krijgen?

00:09:24 Interviewee Het ligt een beetje aan waar je waar je in geïnteresseerd bent. Een IMU bevat een accelerometer, een gyroscoop en een magnetometer en je kunt eigenlijk gewoon naar die 3 losse signalen kijken, en voor een heel aantal studies is dat voldoende. Ik kom net van een presentatie van een Italiaanse promovendus, die doet hele leuke studies naar herstel na voorste kruisband reconstructie, en die kijkt alleen maar naar acceleratie en de hoeksnelheid. Dat is relatief eenvoudig. Kun je hele leuke parameters uithalen, maar voor heel veel andere studies waarin je eigenlijk kinematica, dus je wil de gewrichtshoeken bepalen, dan zul je een aantal stappen door moeten. Hoe ga je dat eigenlijk doen? Je zult eerst een sensor, en een segment kalibratie moeten doen. Je moet zorgen dat wat die sensor meet dat het representatief is voor het segment. En dat kun je op verschillende manieren doen.Maar dat is eigenlijk stap één. Dus die sensor en segment kalibratie is stap één. Vervolgens kun je een aantal voorgedefinieerde bewegingen uitvoeren, een squat beweging bijvoorbeeld, of het voorover buigen zodat je eigenlijk de verschillende assen van die sensor bepaalt, en dan kun je je 3D biomechanisch model opbouwen, dus dat zijn eigenlijk de eerste stappen die je doorloopt om van ruwe sensordata te komen tot zinvolle interpreteerbare data.

00:10:43 Interviewee En een beetje afhankelijk dus van de onderzoeksvraag. Kijk, We zijn heel vaak geïnteresseerd in hoe verandert het beweegpatroon over tijd? En daarvoor zul je gewoon kinematica moeten hebben. Je zult de gewrichtshoeken moeten hebben in dimensies. San zul je die sensor een segment kalibratie kunnen doen. Aan de andere kant hebben we ook studies waarin we kijken naar bijvoorbeeld de acceleratie op het tibia. We nemen aan dat acceleratie die op het tibia gemeten wordt een maat is, een surrogaat voor wat er in het bot gebeurt. De belasting op het bot. We weten dat dat niet zo is. Maar dat hebben we heel lang aangenomen en dan kun je dus eigenlijk alleen maar naar de acceleratie waarde van die sensor kijken. Dat is een stuk eenvoudiger, dus het is een beetje afhankelijk van de onderzoeksvraag die je hebt. Want die onderzoeksvraag, die stuurt eigenlijk je data analyse stappen, en dus ook waar je in stapt of niet. En afhankelijk van onderwijsdoeleinden, als we even kijken naar een bachelor project in in 10 weken kun je niet verwachten dat een student al die stappen zelf doorloopt. Dus dan zul je die data al eigenlijk verder verwerkt moeten aanbieden, en dat dat geeft ook een beetje de keuze voor het systeem aan, want een MVN analyse of MVN Link systeem met MVN analyse software geeft al die parameters uit. Dus voor veel Bachelor projecten gebruiken we dat gewoon.

00:11:59 Researcher Ja en dan ja met het oog op onderwijs, het liefst zou je Natuurlijk hebben dat studenten het volledige de volledige blackbox begrijpen in die 10 weken. Dat is vaak inderdaad niet mogelijk. In hoeverre is het nuttig dat ze wel de parameters van zo'n systeem begrijpen, dus is het bijvoorbeeld ook belangrijk daarin om de sensor te begrijpen om te weten wat je ermee kan?

00:12:39 Interviewee Ik denk dat het altijd belangrijk is om te om te begrijpen wat zo'n sensor doet om om een beeld te hebben van de verstorende variabelen. Er zijn heel veel factoren die invloed hebben op hoe nauwkeurig die sensor meet en om dus waarde te kunnen schatten wat er uit zo'n sensor en dus uit zo'n Black box software komt moet je wel weten wat er aan de voorkant gebeurt. En, Ik denk wat het wat er misschien te vaak wordt gedaan, niet per definitie in onderzoek, maar wel in de praktijk is: je hebt gewoon een systeem dat data uitgeeft, bijvoorbeeld een een Link pak, dat wordt aangetrokken, er komt data uit, en die data wordt gebruikt. Maar op het moment dat jij niet weet welke stappen er zit er tussen die ruwe data verzameling en en uiteindelijke presenteren van die gegevens, kun je ook niet zien wanneer er iets misgaat. Er zijn magnetische verstoringen, sensor drift. soft tissue artefact. Je kunt genoeg verstorende variabelen bedenken. Als je die stappen ertussen niet kent, weet je ook niet dat dat kan gaan gebeuren en dan kun je dus ook nooit eens je je data op waarde schatten. En, Het is altijd lastig, want zeker in bachelor projecten, hoe ga je dat in 10 weken aanbieden? Dat kan je wel doen door bijvoorbeeld de dataverzameling gewoon met het met het eenvoudige systeem te doen en dan kleine stapjes daartussen aan te bieden waarin de student wel zicht krijgt op wat dan ook gebeurt in zo'n sensor en de data hoe die verwerkt wordt.

00:14:05 Researcher Hoe doen jullie dat vaak bij de onderzoek? Hebben jullie bijvoorbeeld per sensor dan een soort informatiesheet met hoe kalibreer je deze sensor?

00:14:17 Interviewee Ja eigenlijk voor de systemen. We gebruiken dus verschillende sensorsystemen, en bijna altijd gebruiken we meer dan één sensor. Dus een configuratie van sensoren. Het minimum waar we over het algemeen mee meten is drie. Daarvoor hebben we een soort van beschrijving hoe daarmee gewerkt moet moet worden ja.

00:14:38 Researcher En is dat over het algemeen informatief genoeg dat je een student, zeg maar een sensor en zo'n sheet kan geven dat hij dan aan de slag kan of komt er meer bij kijken?

00:14:50 Interviewee Ja idealiter wel, want je wil ook dat de student zelf daar een soort van controle en eigenaarschap over krijgt. Dus dat lijkt tot nu toe best goed goed te werken.

00:15:15 Researcher Het belangrijkste, waar wij nu nog mee zitten, is inderdaad. In hoeverre geef je die informatie? En in welke mate geef je die controle.

00:15:25 Interviewee Ik denk dat het ook weer verschilt. Of dat een Bachelor project is of een master project. In een masterproject heb je de tijd om al dat soort dingen gewoon zelf uit te gaan zoeken. En dan kun je eigenlijk beginnen met: Dit zijn de sensoren, kijk maar eens, probeer maar te vinden hoe je die gaat verwerken. Ik heb een student die heeft een project gedaan bij op de ijsbaan bij schaatsen. Die heeft het NVM Link pak gebruikt om de schaatstechniek te analyseren en een Dot setup, de meest uitgebreide Dot setup van 7 sensoren. En probeer uit die Dot sensoren, maar is dezelfde informatie te halen uit het Link systeem. En dan moet je dus al die stappen door. Je referentie heb je, maar je moet wel al die stappen daarna gaan doorlopen. Je kunt steeds kijken of het goed gaat omdat je die referentie hebt. In een masterproject, kan dat, want er is daar voldoende tijd voor, maar in een bachelorproject kun je dat eigenlijk niet niet aanbieden.

00:16:15 Researcher Jullie hebben dus meerdere van die systemen. Hoe begeleid je een student erin, naar welk type systeem ze toe moeten? Is dat een logisch vervolg of is er een soort keuzes systeem?

00:16:31 Interviewee Daar hebben we niet een soort van keuzemodule voor. Ik denk dat dat gewoon per project eigenlijk bepaald wordt. Vaak wordt dat denk ik ook wel voorafgaand bepaald door de begeleiders. Of het is een subproject van een project dat al loopt waarin al die keuze is gemaakt. Maar ik denk niet dat we daar zo een soort van stroomschema voor hebben, zo van bij deze onderzoeksvraag wordt het automatisch dit systeem? Ik denk dat dat gewoon elke keer per project wordt wordt bepaald en uiteindelijk hebben we ook niet zo heel veel keuze. In principe gaat het we gebruiken MVN Link systeem voor de gecontroleerde metingen en de Dot sensoren voor de metingen in de wat meer ongecontroleerde setting. Eigenlijk denken we in de basis het Link systeem gebruiken, eventueel aangevuld met Dot sensoren. Daar komt het denk ik op neer. We hebben nu een van de promovendi die werkt in een project met custom sensoren, vooral met een veel hogere samplefrequentie, omdat dat een van de onderzoeksvragen was. En dat zijn geen sensoren die je makkelijk in een bachelorproject inzet.

F User evaluation

F.1 Consent form

Consent Form for Developing a rapid prototyping kit for the design of Creative Technology for sports and movement

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated 27/05/2024, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I understand that taking part in the study involves interacting with the prototypes made by the researchers and doing an audio-recorded interview about the interaction. I understand the audio recording will be transcribed as text and when this has been completed the recording will be deleted.	○	○
Use of the information in the study		
I understand that the information I provide will be used for the research for the graduation projects of Sven Rozendom and Willem Ysbrand Burgstede. I also understand the anonymised transcriptions may end up in their final write-ups, which will be stored in the Graduation Project database of the University of Twente.	○	○
I understand that personal information collected about me that can identify me, such as my name, will not be shared beyond the study team.	○	○
I agree that my information can be quoted anonymously in research outputs	○	○
Consent to be Audio Recorded		
I agree to be audio recorded during the interview.	○	○

Signatures

______________________	______________________	________
Name of participant	Signature	Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

_________________________	___________________	________
Willem Ysbrand Burgstede	Signature	Date

Study contact details for further information:

Sven Rozendom (s.rozendom@student.utwente.nl)

Willem Ysbrand Burgstede (w.y.burgstede@student.utwente.nl)

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

UNIVERSITY OF TWENTE.

F.2 Information letter

27-5-2024

Information letter: Developing a rapid prototyping kit for the design of Creative Technology for sports and movement

This letter informs you about the research conducted by Sven Rozendom and Ysbrand Burgstede. The research aims to investigate how we can support the design practices of staff and students aiming to design interactive systems for sports and movement.

The session will take about an hour. The participants will take part in a user test and subsequent interview with the researchers. Here they will interact with the prototypes made and be asked questions related to the research topic and prototype. The answers will be anonymised.

The benefit of participating in the research is that the end product from the research will be aimed to help future students during their design process for the Research and Design of User Experience project.

We do not consider participating in this research to have any risks.

The interviewee can stop the test and interview anytime and refuse to answer questions. They can also request for their previous answers to be deleted. Afterwards, they can contact the researchers by email with a request for their interview to be deleted and not used for the research. (emails listed below)

We will not collect personal information from the participants.

The collected data during the interview will be processed by the researchers and afterwards deleted. It will not be made public and will be deleted at the latest when the researchers graduate. The data will be stored on a secure private drive which is only accessible to the researchers. The anonymous transcripts may be included in their final written report and archived in the Graduation Project database of the University of Twente.

If you have any questions or concerns or want to contact the researchers you can do so by email: s.c.rozendom@student.utwente.nl and w.y.burgstede@student.utwente.nl.

If you have any ethical complaints this research is being conducted under the Ethics Committee Computer and Information Science. You can contact their secretary at ethicscommittee-cis@utwente.nl.

F.3 System Usability Score Questionnaire

System Usability Scale

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5