# Sense

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**Title:**

Sense - A data logger for the iOS platform.

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CD with CAD-files and Xcode project, digital edition, and presentation website.

To get an idea of what the project is, it is recommended to first familiarize with the product through the presentation website. Which can be found on the cd/homepage.html

## Resume

Gennem dette projekt bliver der udviklet en data logger til iOS platformen. Projektet starter med en afgrænsning af brugergruppen for derefter at fokuserer på tekniske aspekter indenfor udviklengen af produktet. Projektet berører emner indenfor: industriel fremstilling, business models, design af elektroniske produkter, samt sammenspil mellem hardware og software.

*Morten Ydefeldt*

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## Introduction

This chapter outline the project. An introduce the topic of the project.

As long as science has been recognized as a field, data logging has excisted. From astronomers mapping the motion of the planets in our solar system to physicists measuring the gravitational force of the earth by letting objects fall and measuring the time it took before impact. In the early days data logging was performed with pencil and paper, but with the arise of the computers more and more of the sensors became digital, and could be read by a computer.

Data logging is nothing more than just collecting data from a quantitative sensor, this can be a standard thermometer where someone simply write the temperature down on a piece of paper in an interval over a period of time.
Now, in 2012, everyone uses data logging every day in cars, digital cameras, refrigerators and air conditioners. Data logging monitors values which are important to get a piece of hardware functioning. Data logging is used to make sure that the production always has optimal conditions for producing everything from cars, microprocessors and medicine to chairs and plastic parts.

In the Danish education system digital data logging is being used for experiments to acquire more accurate data in less time. If this process is made user-friendly and easy to understand, the likelihood of a higher understanding of the scientific fields goes up for the students.

The aim of this project is to develop a data logger for use in science classes in high schools to provide the students with the opportunity of a higher level of understanding of the scientific fields.
Working with a merge between the fields of design and science can be interesting considering the nature of the fields. Science traditionally has been driven by dedicated knowledge gained from experiments and empirical experiences. These experiments have been performed without acknowledging the reader and the user of the actual knowledge — the science itself was the product and the result. The traditional field of design has focused on involving the user and providing awareness to the optimal way of communicating and guiding an experience to the end-user. In our modern world end-users have grown used to this guidance that is provided when the users interact with everyday products.

In the following chapters the context and product constraints and requirements will be reviewed to start the design process of the data logger.

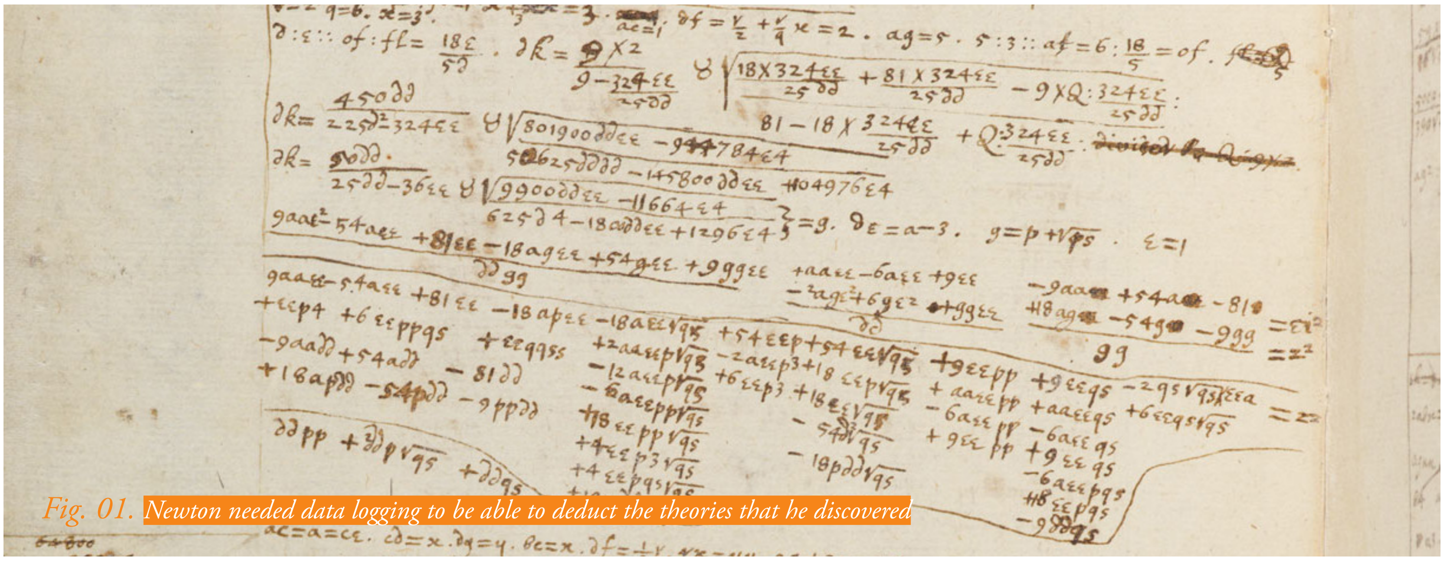


*Fig. 01.* Newton needed data logging to be able to deduct the theories that he discovered

*Fig. 02.* Newton needed data logging to be able to deduct the theories that he discovered

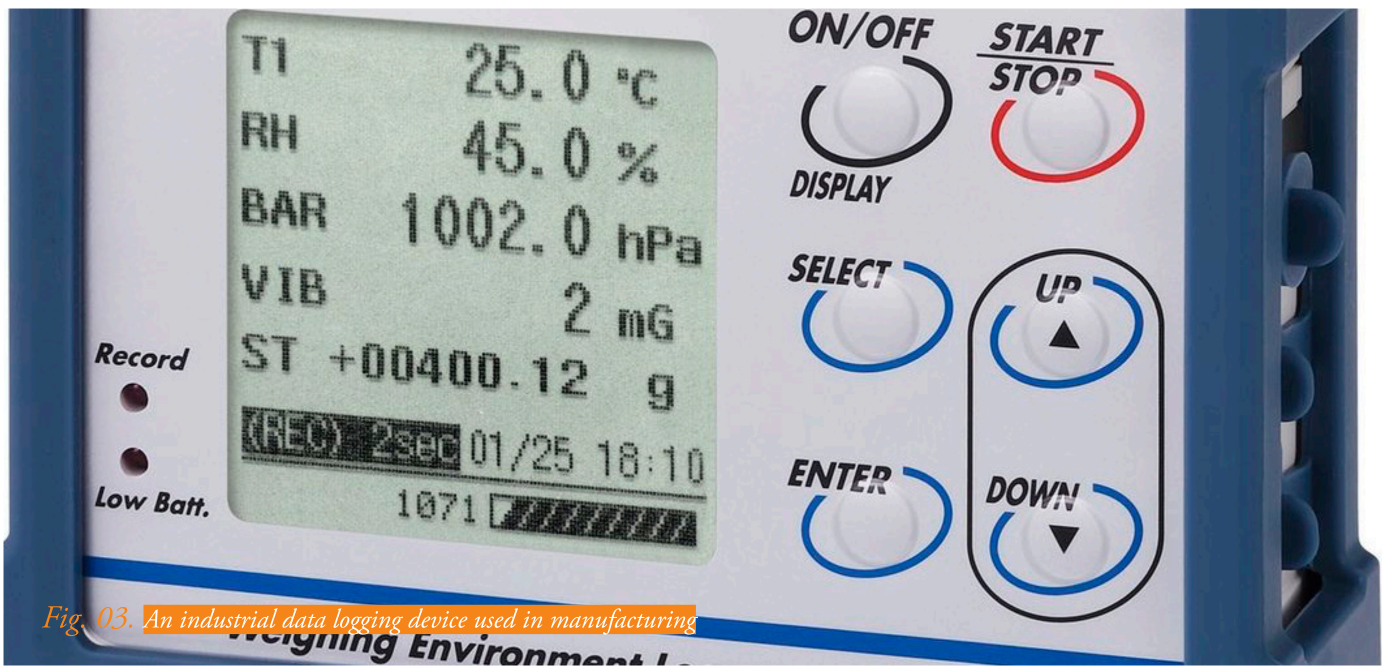



*Fig. 03.* An industrial data logging device used in manufacturing

## Reading guide

The process of this project is first to conduct user research and general research on the field, this will lead to a number of design specifications. Then a prototype is developed at an early stage, to get more practical knowledge on the field. Then the process is split up in the in three analysis and afterward their solution. This lead to a process where I will shift from analysis to development throughout the project, starting with the electronics, then the physical form of the products and last move over to the user interface.

Even though in the process these are spitted up this was not the case when the development was actually made, the different parts was developed simultaneously to obtain an integrated final solution.

Readers of this project should first familiarize itself with the presentation website, which is available on the enclosed CD.

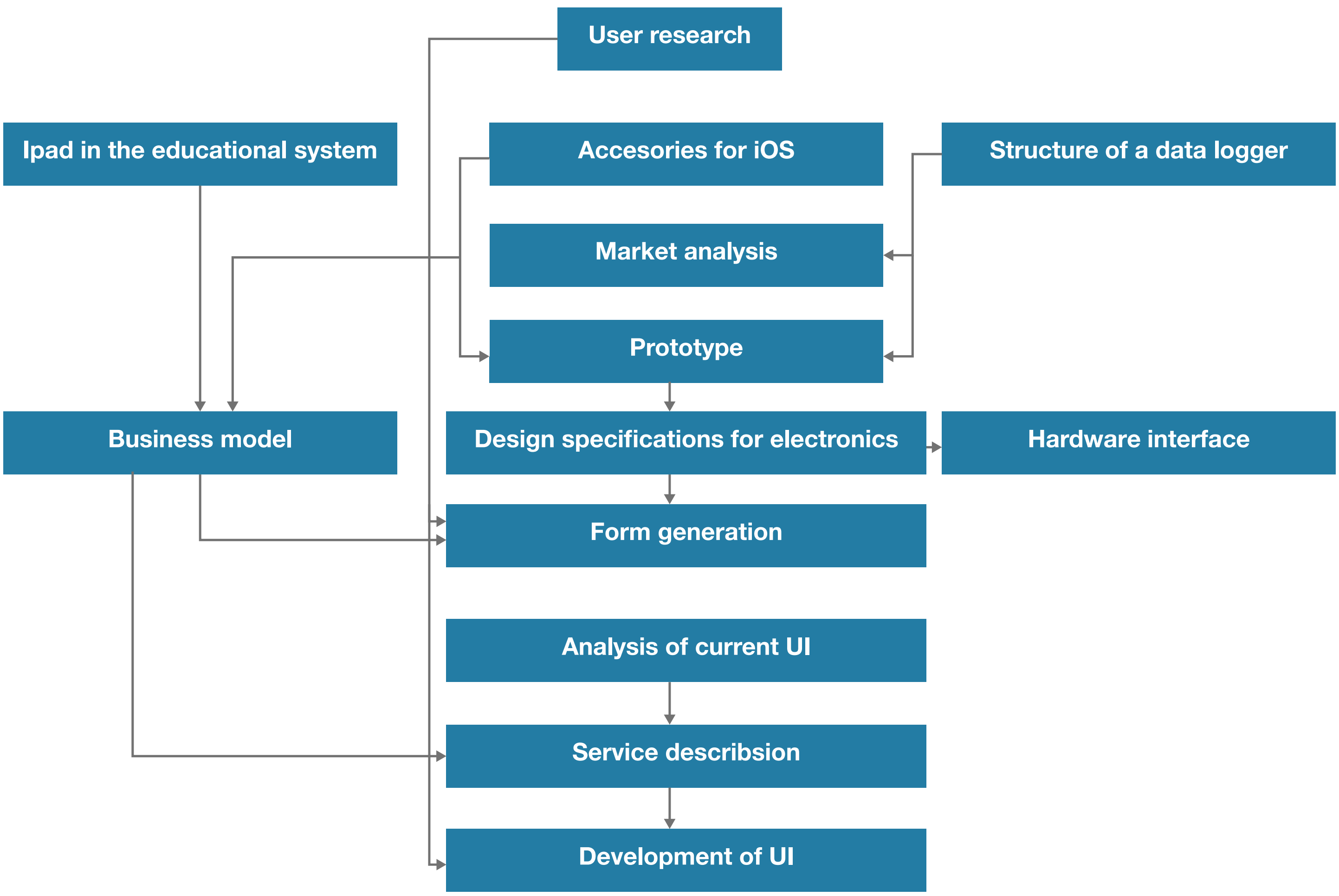



*Fig. 04. An industrial data logging device used in manufacturing*

## User research

Visiting an HTX class to get a view on the current products on the market, and how they are used by students.

The two main users of a data logger in the context of a high school are the students and the teachers. Both of these groups haft to have a good understanding of the product to use the data logger's functionalities optimally. The teachers need to have an understanding of what the product is capable of to be able to create experiments that fit the product's capabilities. The students are in a position where they haft to be able to under- stand the theory behind the experiment through the product.

To gain a better understanding of how the teachers and the students perceive and use a data logger, a high school class is visited while the class was performing a science experiment using their current version of a data logger. As a part of this research it was important to map how the current products are used by students as well as teachers.

The class visited was a HTX 3rd year class in Frederiksberg, Copenhagen. The experiment was about understanding how a puffer solution is able to contrain the pH value, while adding a base or an acid to the solution. The students had to measure the pH value using a solution from Venier called Lab Pro.
The first observations was made in the class room, before the students entered the laboratory;

### Briefing

The teacher asked how many students had actually installed the software. This had been a part of student's homework. It turned out that only 3 out of 24 students had installed the software. The ones that had tried to install the software were not able to make the serial code from the school work. One of the 3 that had installed the software had installed the wrong ver- sion of the software, causing the hardware not to work.
So even before the hardware has ready to use, a lot of problems had pre- sented themselves.

These problems are not ones that the users can solve. The problems are caused in a creation and systems level. It should not be possible to install a wrong version of the software which causes the hardware not to work. High school students should not need to consider versions of the soft- ware. The current versions are not providing the user with any information about the improvements (i.e version 3.6.1 versus 3.6.8.1) and therefore it seems irrelevant to the users which version they install.

When the software was installed the students could enter the laboratory.

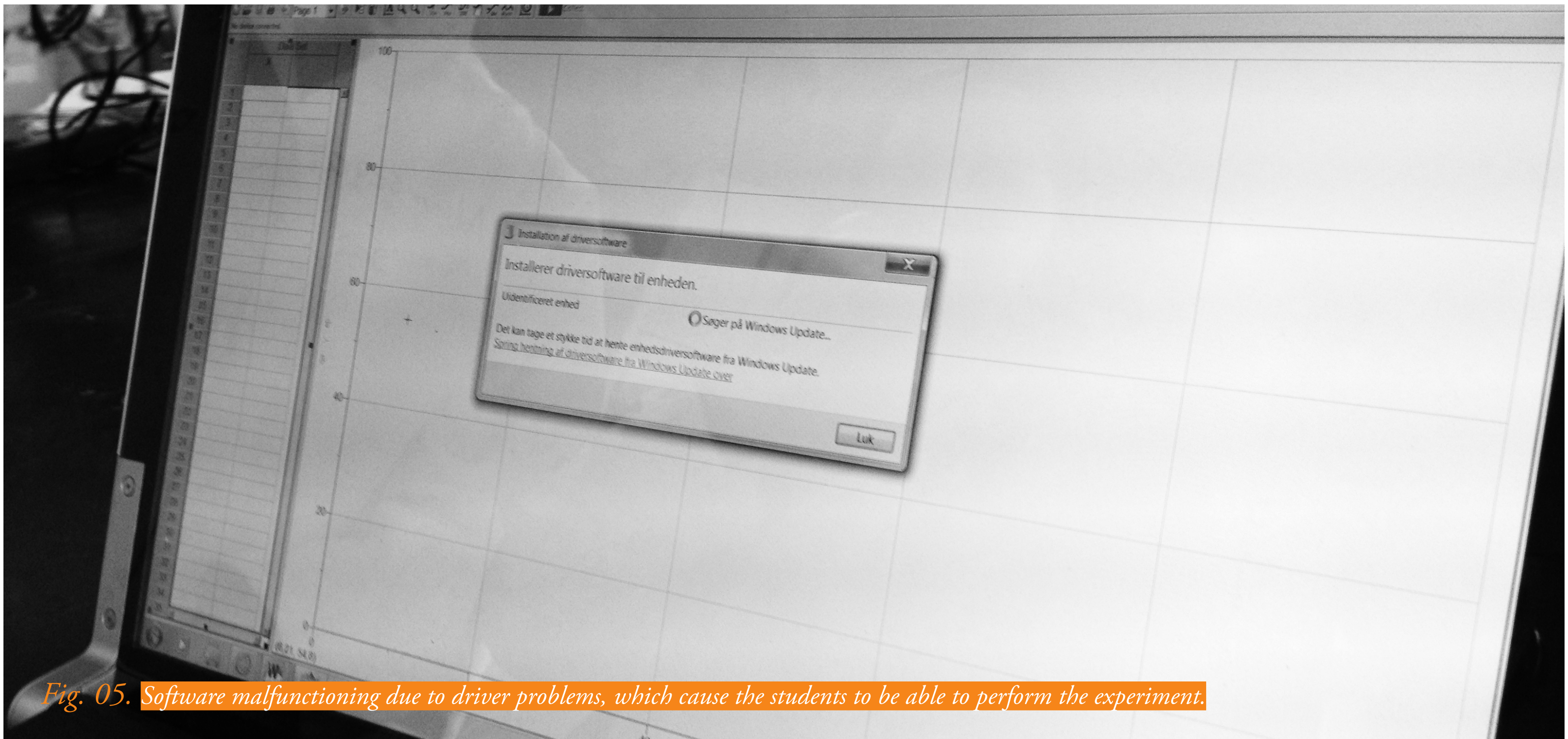


*Fig. 05.* *Software malfunctioning due to driver problems, which cause the students to be able to perform the experiment.*

*Fig. 06.* *Students cleaning up from spilling a NaOH solution on the table with data logger, computers, and cables all over the place.*


*Fig. 07.* *Students performing the experiment with a pH-meter submergered into a puffer solution while tritrating with NaOH.*

### Teacher as technician

In the laboratory, there were still problems in regards to getting the soft- ware to communicate with the hardware. This scenario revealed something interesting about the teacher. The teacher really tried to figure out how to solve these problems, but it was not really her field of expertise and the solutions she came up with to solve the problems were simple trail and error. The problems turned out to be due to some drivers which were not installed correctly. The teacher had tried interchanging the hard- ware but this would not solve the issues.

It should not be the teachers responsibility to know in technical details why a data logger is not working. The data logger should be able to communicate to the users what is wrong in the setup.

### Calibration

When using a pH meter it needs to be calibrated every time it is used to provide accurate results, because the refrence current is needed in order to process the data. When the students connected the pH meter there was no indication guiding the students in how to calibrate the sensor. The students had to manually enable the calibration feature, and because the students is not used to working with this kind of equipment it is not obvi- ous to them how to proceed. When the software and hardware was functioning, the experiment could start. The students were measuring the pH in the buffer and added NaOH (strong base). Adding NaOH should increase the pH if you think of it from a logic point of view, but since it was added to a puffer system, it should not increase pH that much, if even at all.

### Insecurity

The students did not fully understand the theory of puffer systems and did not know that the pH value should not change, when adding this strong base/acid. So the students started considering whether they had done something wrong or if it was the hardware that failed to measure correctly. In this case the hardware and software was actually performing correctly but because of previous challenges with the data logger and because of the lack of communication the students did not know whether they could trust the data logger.


*Fig. 08.* *Accidents happen.... The solution should be aware of that.*

*Fig. 09.* *Calibration of the pH-meter. This is not a feed forward operation*

*Fig. 10.* *Creating a mess when both the laptop and the data logger needs external power does not leave space for working.*

## Summery of user research

A summery of the user research is deducted.

By researching students working in the laboratory with the current data logger from Vernier, the following product constraints can be extracted. The constraints will be utilized in the development of the new data logger.

### Setting up the data logger

The problems with installing the software and maintaining with system updates can be addressed in the choice of platform. The iPad has a built-in control over things like versions through the App Store. The user will still need to approve the system update, but the software will notify (i.e through push notifications) the user when a new version is available for the iPad.
Handling drivers is an issue that can be solved by simply avoiding the drivers. This will automatically happen by utilizing the iOS platform, because the driver would be embedded into the application.

### During Use

It should not be necessary for the teacher to introduce the data logger to the students. The data logger (i.e physical devices and the software interface) should be intuitive and therefore not need an introduction.
Guidance in the product is necessary for the students to be independent of the teacher and 'understand' the hardware. The more of the steps the students can overcome successfully, the more they will understand of their experiment. The new data logger should provide feed forward during use, especially on the inevitable steps such as calibrating sensors.

It is important to create a setting where the teacher is empowered and can provide the expertise of his/her field of study. It should not be the teacher's responsibility to know how and why a computer is not working. Therefore, the product solution should be transparent in it's communication. Then the students will be able to trace hardware or software problems (if they should they occur), and resolve them without the assistance of the teacher.

During the research the data logger was drawing the student's attention regarding hardware and software issues. In a best case scenario the data logger should not take focus off the actual science theory which was the important part to learn from the experiment. Therefore, the hardware should be transparent in terms of use and only provide relevant information to the students. This will help the students stay on topic without distractions caused by a malfunctioning data logger.

### Environment

For the data logger to work in a laboratory, it should be able to withstand an environment with chemicals and equipment. It is important to consider minimizing the amount of physical devices that are necessary to run an laboratory experiment.

## Design specifications

The user research is condensed further down, with the additional initial analysis and thereby design specifications are defined.

The design specifications will be updated throughout the project , but from the user research the following specifications are conducted:

- Materials should be considered, in order to make sure that the product can withstand the environment in which it is present.
- The product should consider a way for the student to be able to get the data off the iPad, to further work with on a desktop computer.
- The user interface should emphezise the use of feed forward, to make sure that the user is sure in knowing what is happening.

## Vision

*How can a new data logger and data logging process be designed so that the collection of data becomes clear to the user, and so that the interaction with the product becomes manageable, in order for the user to focus on the actual theory to be learned.*

The vision will be the basis for the development further in the process of the conceptualizing the product developed in this project.
The main criteria in this project is to make a solution which make sure that the user learn the theory of the class, because that is the important part.

## Example experiments

Explore different experiments which is currently used along with a data logger.

In order to know what types of experiments that is currently utilizing data loggers, these are explored by looking into experiment guides. This should give a bigger understanding of what a data logger really is, and how it is used in schools, and what kind of theory the experiments can explore. The followings experiment could be an experiment which a group of student would perform, and afterwards write a report on the theory, and compare with the results found in the experiment.

### Friction

This is a physics experiment which is exploring what friction is, and how it affects real world objects. On Fig. 111 a mass with a sandpaper on the bottom is attached to a force sensor, which of course is then attached to a data logging system. Then the mass dragged by hand, by applying more and more force until the mass moves and maintain a constant speed.

The force is plotted as a function of time on a graph, which will then look similar to the graph on Fig. 12.

The graph will represent that it takes more force to start the movement than maintain constant speed. The first part of the graph is called the static friction, after the static friction is eliminated it does not take that much force to pulled the mass forward.

This is one experiment which is much easier to do with a data logger which constantly plot the data, in opposition to using a standard newton meter (Fig. 13) which should be read manually.

So this is a good example of an experiment which really benefits from using a data logger and where the student can focus on the theory of friction, instead of focusing on using how to use and read a newton meter which would be the alternative.

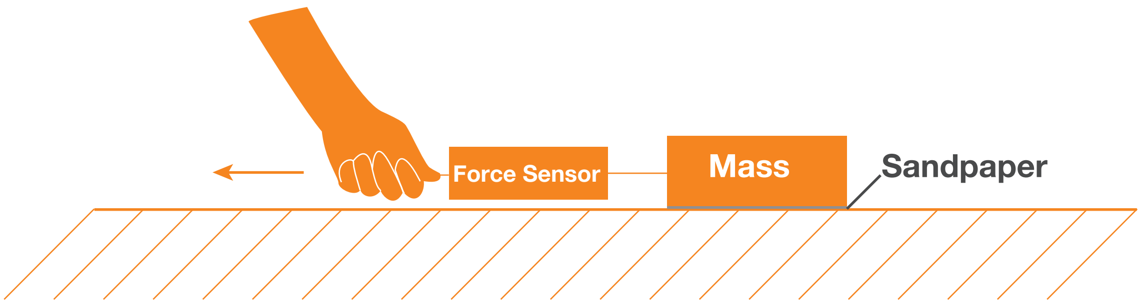



*Fig. 11. Experiment which let the students explore the theory of friction between two objects.*

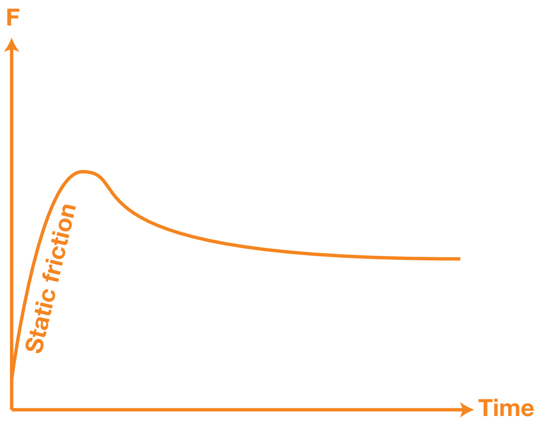



*Fig. 12. A plot of force over time, which show that it takes more force to overcome the static friction of an object, than maintaining the speed of a moving object.*

*Fig. 13. A newtonmeter which could be used to perform an experiment with friction, but it would be much harder to get accurate data and thereby understand the theory of friction..*

### Temperature

A simple chemistry experiment which can explore how different chemical reactions either can be exothermic or endothermic. Exothermic reactions are reactions which produce heat, where endothermic reactions absorbs heat from the environment.

A reaction between the juice of a citrus fruit and baking soda is performed while a temperature sensor which is connected to a data logger in the reaction. This would show that the temperature decreases while the reactions is taking place, and thereby that the reaction is endothermic. The same setup is performed with hydrochlorid acid and magnesium and it would increase the temperature, meaning that this reaction would be exothermic. In Fig. 14 a simulation of how the two plots would look like is shown.

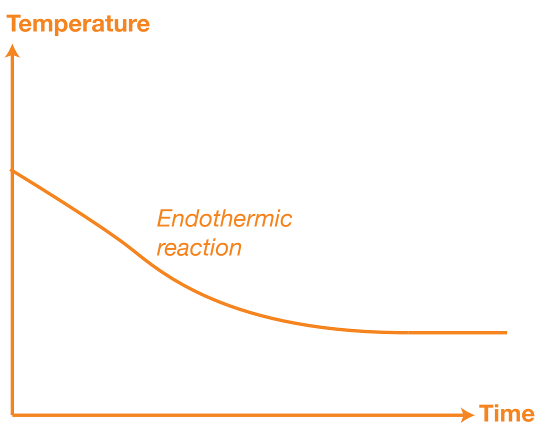
When this experiment is performed with a data logger it is possible to find the maximum and minimun values. The maximum values of the expthermic reaction would show how much engery that is released in the reaction, and the minimum value of the endothermic reaction would show how much energy that is absorbed from the environment during the reaction.

This would give the students an idea of that different reactions either produce heat or absorbs heat (get cold). The reactions could be analysed on a theoretical level to analyze if the theory corresponds to the actual practice.

### Summery

These two experiments are only explored in order to let the reader of this report get an idea of what sort of experiments and theory that could be explored using a data logger.

In the process of a students performing such experiments it is important that the data logger that is used is trusted 100% by the student. This does not only mean that the actual values showing on the graph should be accurate, but also that the student understands the product that orbitain the data and thereby trust the data. It is really important to stress that trusting the product is more that just getting accurate data.



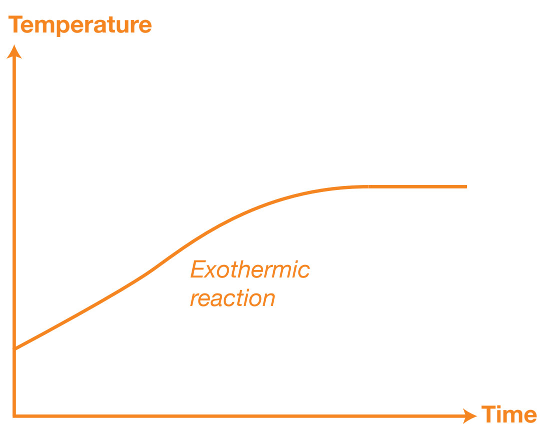




*Fig. 14. Left: A simulation in a plot of temperature over time while a endothermic reaction is taking place, such as an reaction between citric acid and baking soda.*

*Right: A simulation in a plot of temperature over time while a exothermic reaction is taking place, such as an reaction between hydrochloric acid and magnesium.*

## iPads in the Education system

Because the product relies on the use of iPads in schools, an overview on how iPads are currently being implemented in school are made.

To gain an overview on why the iPad is implemented into the Danish educational system and thereby how big the market potentially could be a data logger, an quialitative analysis is made in the following chapter.

Since the iPad was introduced in 2010 the use of the tablet has been expanding from personal use, to doctors, flight entertainment systems and recently it has been used by students and teachers in schools. This report will cover some of the initiatives taken in Denmark in terms of introducing iPads into the educational system.

*"Today children use a big part of their spare time on electronic and digital devices.... Odder municipality wish to reflect that in their education"*

The above is one of the arguments that the Odder municipality stated when they, as the first municipality in Denmark, in 2011 bought 2.580 iPad for use in schools[1] . This is the biggest investment in Denmark regarding iPads in schools. Even though these iPads were for primary schools and the focus of this thesis is high schools, it is an interesting shift that will mean that the children become familiar with using the iPad for learning.

The iPad offers a different way of learning than a traditional book. The iPad software used in the schools is more interactive and playful than traditional books. One example of this is the Danish project Meebook[3]. Meebook is an educational system where the literature, notes, classes, submission of homework is gathered in one single application. This moved the possibilities to a whole new level of engagement.

If children are getting used to learning with this kind of software, the likelihood of them wanting to go back to traditional books and systems in high school is low. The students may not be satisfied with a book, when they can engage in a more interactive learning process.

Ørestadens gymnasium in Copenhagen is likewise experimenting with iPads. Students can choose to buy an iPad or a PC when they start at the gymnasium[2]. A study has been made comparing the use of iPads and PCs in the high school. The study states that one of the advantages with a PC is that it can be used for all the tasks required at the school, but the

*"iPad is cheaper, easier to carry around, more mobile and flexible and way better for reading"*[2]

Since these iPad advantages are important to the students and the schools, it is necessary to make the iPad as useful as possible during their school time. The students should be able to do all of their work on an iPad, and not have to switch between devices and systems.

Some of the high schools in Denmark which have bought iPad includes the following: Hjørring gymnasium, HTX-Næstved, HTX-Viborg, Odder gymnasium and Birkerød Gymnasium. This shows a tendency to move over to using iPads in the Danish education system. These examples only focus on the danish context, but the use of iPads in an international context is progressive drastically as well. This has led to 'Family Kids and Youth research agency'[4] to make a study of how the tablet is used and perceived in schools. They have generally a positive attitude towards using iPads in education in their research, the main concerns from this study, is that the content which is available through the App store is sometimes lagging in quality, this is not a show stopper for this project because this is the objective, to get more good content for schools on the App store.

*Fig. 15. Creating a mess when both the laptop and the data logger needs external power does not leave space for working.*

The final concept developed in this project should not require every individual students to have their own iPad, the product should be developed in a way such that it is possible for the a school to buy the product without having invested in iPads for all students. It might be the case where the school have invested in a number of iPads for the laboratory, and let the students use these iPads for the collection of data and then it should be possible to export the data to another device for further data analysis.
This is important that it is possible for the student to perform the experiment on an iPad which is not their personal, because some school start out by buying a class set of iPads, and not giving every student their personal iPad.[5]

## Possision of the iPad

In this chapter it is dicussed how the product should react to students which does not have their own personal iPad.

## Current iPad accessories

In order to understand the eco-system of the iOS devices, an analysis of hardware accessories is made to get a picture of what they did right when they developed the accessories and learn from that.

When developing anything for the iOS platform you not only compete against other products in your product category, but with all the accessories available for the iOS platform, because they are all sold through out the same store. In this chapter I will make an analysis of different accessories for the iOS platform, and try to see what they have in common, and what benefits they have by utilitizing an already exsisting product.

When Apple opened the iOS platform for developers on March 6, 2008, a whole new eco-system of apps and micro payments was instantiated, 650.000 thousand apps is currently available through the App Store at July 2012. But even though Apple opened up for making software for the iOS platform not all developers only made software, a lot of companies have developed hardware for the iOS platform which either is connected though a physical interface (dock connector or microphone jack) or a wireless protocol (Wifi or Bluetooth). It is interesting to make an analysis on these kinds of products to get idea on the similarities which cover all of them and consider those similarities in the further work with my data logger.

It is a lot different to design hardware for the iOS platform than design it for standalone use or desktop computers, the reason for this lie in the hardware interface on touch screen devices, this defines exactly what you can and can't do, an example is the use of multiple windows which is not possible in the same way, on a tablet, as on a desktop computer, and thereby the hardware should be connected and design in a way which does not require these kinds of interface elements. In many products the way from concept to reality is smaller, than if it should be developed in a standalone package, this is due to that the display, wifi, computing power, and so on, is not required to be within the hardware itself, but is provided by the tablet instead. I will show that this is indeed the case at least for some products for the tablet platform.

The product developed in this project will of course utilitize the display of the iPad, but another important part is to integrate the data connection which is availible throgh the iPad. This can make sure that the application which is developed is connected to the cloud and thereby the data that is collected is not limited to stay on the iPad. It will be discussed later in the project how these features should work.


*Fig. 16.* *Withings*
*This product is mesuering bloodpressure, and logging the data onto an iOS device. It can tranfer the data to your doctor directly, and if this should be done with standalone hardware it would not be possible to keep it as small and clean as it appears.*


*Fig. 17.* *WeMo*
*Enables the user to turn on and off electric equipment in their home directly from their phone. Helps to conserve energy.*


*Fig. 18. Square is a point of sale terminal for the iOS platform. Which has transformed a former stand alone product to iOS.*


## Square

An interesting product which has taken a traditional standalone product and ported it to the mobile platform is the product Square. It should be considered a service and not a physical product, even though it includes a physical device which is recommended in order to use it the original intended way (it is now possible to use without any hardware). Square has developed a solution which can completely subtitute the traditional credit card terminal and instead use a mobile device (iPhone, iPad, or android device). This product takes advantage of the touch screen for signing payment, internet access for confirming payment ect. The Square is made adressed both for businesses and individuals who just want to be able to collect payment through credit cards. If Square had tried to develop a standalone personal credit card terminal they probaly would have had a hard time selling it, because it would be a lot more expensive and thereby require that people to buy the hardware. Now the Square hardware is free due to the low cost of production, and Square is earning money on every transaction made. Not to neglect that Square has developed a complete point-of-sale system and thereby eliminated the need for a traditions cash register.

## Summery

One of the main reasons for these accessories being effective and powerful is that people often carry their iOS devices with them. This means that the devices and the accessories are always easy accessible and can be used anywhere. Another reason is the fact that the iOS device do not require to be turned off between every use—an iPhone or iPad is often in standby-mode, and therby mentally very close to the user. If it was necessary to turn on a computer every time you wanted to change the channel on the TV, the likelihood of this action is very low. But with the iPhone or iPad within reach this action is more likely to occur, when using the UnityRemote shown on Fig. 19.

This is one of the advantages of developing a data logger for the iPad, because the students will use this device in every class whenever it is chemistry, mathematics, physics or biology all these classes try to implement the use of iPads, and therefore it is very familiar to the student to use their iPad for data logging. They already know the interface, and thereby will be up and running much faster than if they should also familiarize themselves with a new product, every student knows where the dock connector is, and have doubt in how to connect something to that, and what to expect if they do so.
It is also a way of minimizing the time spend on installing drivers and software on the PC, which is a major issue and a lot of time is spend on that because usually the teachers do not have the technical knowledge to resolve the problems and this can result in the students never get to do the experiment due to technical issues.
So the student will be familiar with the platform already and thereby have a better chance of understand the theory they should learn better.


*Fig. 19. UnityRemote*
*Enables the user to control various AV equipment from their phone or iPad. In the old days we should pair up the remote with our old one, but due to the iOS devices we can search for a specific TV model and then all the buttons are programmed.*

## Introduction to further development

Now the initial analysis and exploration over, and the project will focus more in depth on data loggers and how they work from a technical point of view.
First of all the different parts of the data logger is identified and a terminology is established. After that is established the current market for data loggers is explored, and on the basis of that a prototype is developed, the things learned from this prototype will lead to some additional design specifications, and the product will be developed on basis of that.
First the physical hardware is developed and then the user interface is developed.

## The elements of a data logger

The different part of a digital data logger is identified and the terminology is determined. The three parts are; Data logger, probe, sensor.

### Data logger

Before analyzing the already-existing products on the market it is important to gain an understanding of the elements a data logger consists of. The terminology will likewise be introduced here and used throughout the report. It is important to state that these terms are only defined within this project, and thereby the termonology used is not universal. Different manufactures of probes would probaly call them sensors, so these terms are only valid within the project.

### Probe

One of the vital parts of a data logger is the probe. The probe is the electronic part which measure temperature, humidity, distance, pH and light. The probe is not functional on its own, it has to be connected to an electrical circuit in order to function. A system can have more than one probe depending the system's need. Probes are not product specific, meaning that different data loggers all use the same probes. Probes are standardized items, which would in most cases be bought off the shelf.
Different probes send out their measuring of data in different ways. Some probes generates a small current and some change their resistance, which allows them to be read directly by an A/D conveter, which is a microchip that tranlates a current to a digital number.
But because there are many probes which cannot be read directly another level needs to be added, and that level will be called a sensor.

### Sensor

When a probe is connected to a circuit which translate the data to an actual useful value, which can be used further in the process of logging the data. This part is referred to as a sensor (Fig. 21), meaning that the sensor is directly connected to a hub (explained later) and consists of a probe and a circuit that translates the value.
Different types of sensors can have different hardware interfaces to the hub, which is independent of different producers of data loggers, meaning that one sensor can not be physically connected to other producers data loggers. Some examples of such interfaces could be jack, RJ45 or USB. The sensors also have a protocol which is how the sensors transfer their value to the hub, this can be done in a lot of different ways depending on the physical interface and how many connectors that are available in that. The aspects of different interfaces and protocols will be discussed later in the project.

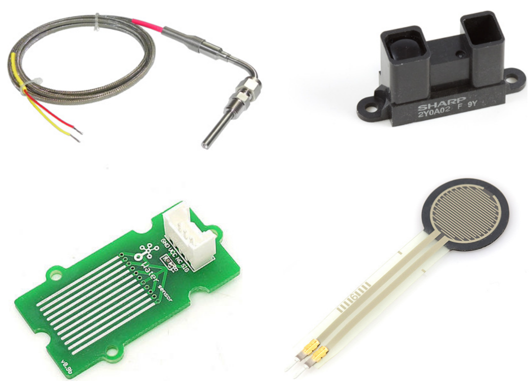


*Fig. 20. Withings 4 probes. Top-left: Temperature probe; Top-right: Infrared distance Probe; Bottom-left: Force-probe; Bottom-right: Water sensor.*
*All of these sensor would require additional hardware in order to function in a data logger system, because a system only relying on analog sensors would not be very adaptable.*

### Hub

A hub is the physical device that the sensors are connected to. This device can gather data on to a SD card or transfer it to a PC or an iOS device. If using the SD card the hub can display the data on its own screen as a part of the hub. If the data is transferred to a PC or iOS device the data can be shown on those devices displays. The data can be transferred wireless or wired. The hub just needs to support the physical interface and the protocol of the sensors to be able to transfer the data. There are many functions which can be supported in this part of the data logging system, and this will be explored further in the development of the product. An example of hub can be seen on Fig. 22, which is a hub from Venier.


*Fig. 21.* *A gas pressure sensor from Venier which can be plugged directly to their datalogger*

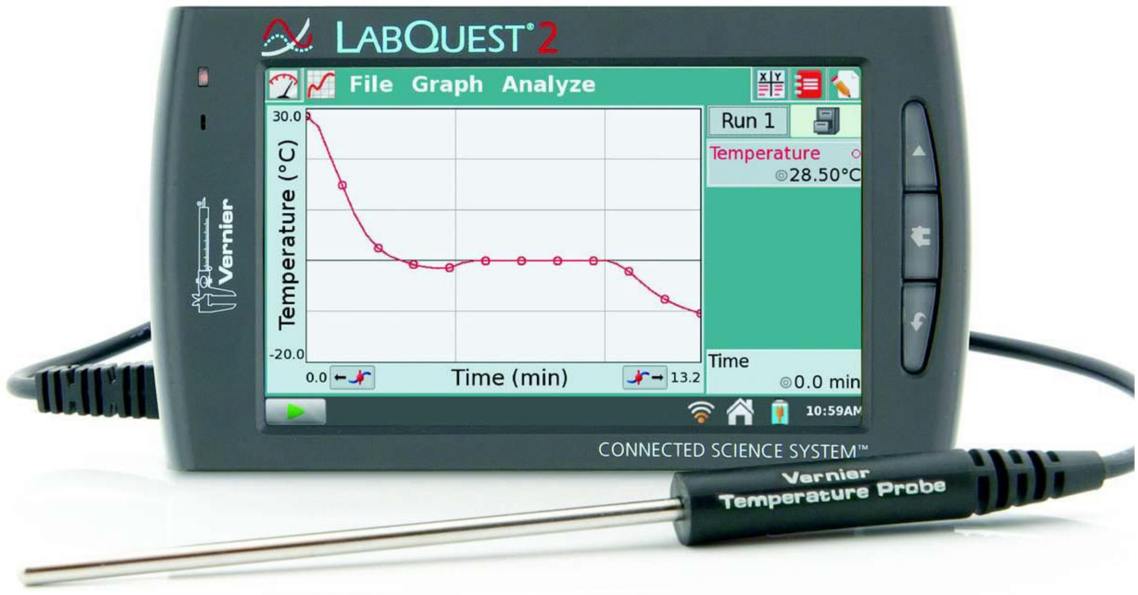



*Fig. 22.* *A hub from Vernier which shows the data directly on the device itself.*

## Analysis of current product on the market

The different part of a digital data logger is identified and the terminology is determined. The three parts are; Data logger, probe, sensor.

There are 2 mayor companies which produce solutions for data logging in high schools and primary schools. They are called Pasco and Vernier. For this project only the Pasco solution will be analyzed into depth. The two solutions are considered comparable in terms of use for the end-user. They both compete within the exact same market and their products are on a structural level almost identical.

Pasco's primary product is the Pasport Probeware. The Pasport is a system that includes sensors and hubs which can all be interconnected. Pasco also supports a high-end market with their ScienceWorkshop hardware which also includes sensors and hubs. The only difference between the Pasport and ScienceWorkshop product family is the accuracy of the sensors and the rate of data logging. For this project the Pasport family is the most relevant considering the focus on high schools. The ScienceWorkshop is marketed primarily to universities.

The Pasco system has an extensive hardware portfolio which will be mapped to gain an understanding of which kind of products the Pasport system consists of.

Pasport Probeware is Pasco's trade name for their school series. The Pasport Probeware includes sensors and products that are able to collect data and save the data from sensors. The sensors in the Pasport system are all structured the same way.

### Physical interface

One of the parts which is shared for all the sensors is the VIVO interface which connects the different sensors to the hub that supports the Pasport platform. The VIVO (Fig. 24 & on the right end of Fig. 25) interface consists of 9 pins (the number of metal parts that can transmit data, for instance a standard networking cable

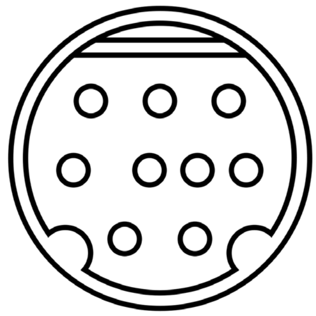


*Fig. 24. The VIVO hardware which is orientation dependent, meaning that it is not possible to plug it in the wrong way.*


*Fig. 23. 'Pasport' sensors, Left to right bottom row: Distance, temperature, sound level, light, voltage. Left to right top row: Current, Chemistry Sensor, Physics Sensor.*

got 8 pins), it is quite hard to tell why there is a need for so many pins, because most transfer protocols do not need that many pins to transmit data (protocols will be exploned later in the project). It might also have been chosen for other reason which is not directly obvious.

One other important aspect from an end-user's perspective is the fact that the VIVO interface is orientation dependent. Being orientation dependent means that the connector only supports one orientation and therefore needs to be placed correctly by the user.

Pasco has made this issue smaller by ensuring that the embodiment of the sensors and the data logger only fit in one orientation, and thereby physical embodiment unsures that it cannot be oriented in the wrong way.

### Electronic structure of sensors

Due to the high number of pins in the physical interface, it is expected that the communication between the sensor and the hub is beyond a standard serial connection.

It shows by breaking apart a temperature sensor that it contains a micro controller. A micro controller is a IC (integrated circuit, which is sometimes be refereed to as computer chips) that in itself is a whole computer, it contains memory, processor, and pins that is controllable through software.

It is expected that the other sensor contains a micro controller as well, because all the sensors probably communicates with the hub in the same way.

A micro controller, in this case a PIC16C63, ensures that the data is transferred to the hub with an identifier so that the hub know which sensor that is attached and the sensors current value. Which exact protocol is which is used it unknown.

The total number of sensors which Pasco produces is around 80, and that is also a reason for Pasco to have a microcontroller in every sensor. Every probe delivers their data in a different way and it needs to be processed and formatted before it can be understood by the hub device.

By having a micro controller in every sensor it is possible to process the data and send it to the hub in any protocol supported by the hardware. This methods is also future proof because if a new probe is supposed to be supported, the micro controller in the sensor can be programmed to support the way that the probe communicates.

### Multi probe sensors

Most sensors only support a single probe for measuring temperature, voltage, current or distance, but since all the sensors contain their own micro controller, some sensors support multiple probes without a problem. Pasco's chemistry

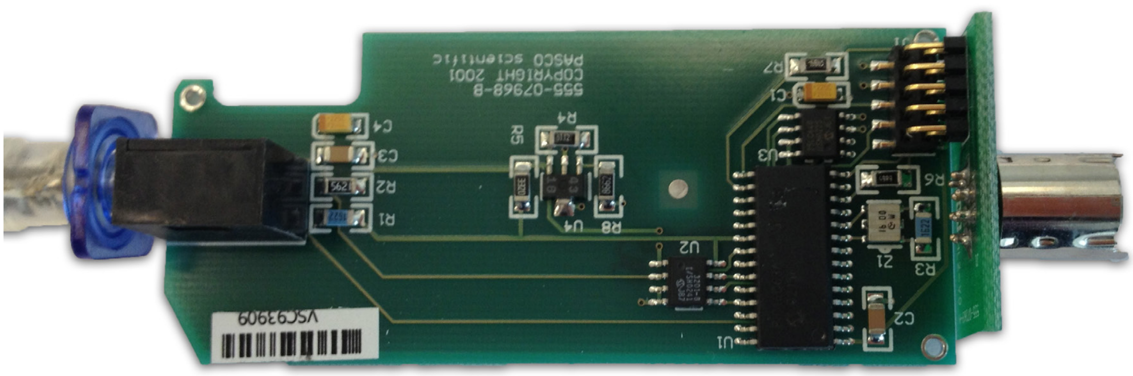


*Fig. 25. Internal parts of a temperature sensors, the big IC is the PIC microcontroller*

sensor has a temperature probe, pH probe, absolute gas pressure probe, and voltage measuring. The support of multiple probes allows the hubs (which does not support multiple sensors) to receive data from multiple inputs simultaneously. An example is the USBlink, which is described later in this report.

On problem with sensors that got multiple probes is that a sensor which is able to capture only temperature got almost the exact same appearance as one which is able to capture temperature, pressure and pH. This also tell the user on a subtle level that the temperature sensor which only can capture one thing can be made smaller or more optimal.

### Physical appearance

All of the single probe sensors in this system are all contained within the same physical embodiment (The plastic shell around the circuit), this is probably chosen to reduce the amount of tooling required in order to produce the sensors. The problem with this is that the circuit inside the hub could be reduced significantly in size, and thereby it would be possible to reduce the overall size of the sensor, allowing it to be less bulky. It might be the case that when the sensors was originally designed there was a need for the physical size of the sensor, but now this could be made much smaller.

The circuit boards rattle inside the embodiment because of poor fitting of hardware, this does not feel very satisfying, or reassuring when using the sensor, and does not contribute to the user trusting and feel comfortable with the product.

### Modularity of sensors

When the sensors was originally designed they might have been an optimal solutions, but now the sensors seem bulky and far from optimal. This is one of the dangerous aspects of designing a modular system, the thread is that the system become so big that at some point in time it is very expensive to kill the modular system for another modular system which is better. The thoughts about designing a modular system for the sensors is a good idea, it just seem that time have passed the sensors of the Pasco system.

One thing to notice from the physical properties of the sensors is the thread that allow the sensors to be attached to additional lab equipment in an experiment, this is a very important aspect.


*Fig. 26. SPARK*

*Fig. 27. Xplorer GLX*


*Fig. 28. 850 Universal Interface*

In addition to the sensors Pasco also produce hub solutions. These are the hub solutions available form Pasco;

**SPARK** Fig. 26
SPARK is a tablet inspired interface which can connect to Pasport sensors. On this device it is possible to log the data, perform analysis such as curve fittings, and assessments. SPARK is an all-in-one package where nothing else is needed in order to perform experiments.

**Xplorer GLX** Fig. 27
Xplorer GLX is a 'low-tech' version of SPARK. It is also possible to log data and view the generated graphs. The device can be connected directly to a HP-printer and print the graphs or the device can be connected to a computer through USB and process the logged data or use it as a USBlink and log the data directly to a computer.

Connecting to a computer solutions:

**The 850 Universal Interface** Fig. 28
The 850 Universal Interface is a hub for connecting 4 digital and 4 analog sensors and logging the data directly to a computer. This solution supports ScienceWorkshop sensors and Pasport sensors.

**SPARKlink**
The SPARKlink supports 2 Pasport sensors and logs the data to a computer.

**USBlink** Fig. 29
The USBlink is just like SPARK, but this solution only supports a single sensors, but this sensor can be a multi-probe sensor, and thereby enables the logging of data from multiple sensors.

**AirLink** Fig. 30
The AirLink system offers an opportunity to collect data over the air with bluetooth enabled devices, like and iPad. It works just like the USBlink except it is wireless.
The iPad software for the AirLink will be discussed later in the project, when the UI is designed.


*Fig. 29. USBLink*


*Fig. 30. AirLink*

## Design Specifications

The design specification is updated to add the things which is learn from the analysis of the Pasco products

Based on the analysis of current data logging products additional design specifications are extracted to provide guidance when designing the new data logger. These specification will be added to the list of specifications which is conducted through the analysis.

### Sensors

- In order to keep costs down it is desired to design a modular system for the sensors, but in order not to be stuck with a modular system it should be possible to update the system without having to dismiss the old sensors.
- Orientation independent physical interface.
- All of the probes should be single purpose, and thereby not include multiple probes, this will make a more transparent product to the end-user.
- The user should be able to plug in a sensor and be able to tell what kind of sensor it is from the iOS device. Meaning that if a temperature sensor is connected it will show a temperature symbol on the ipad for instance.
- A mounting solution should be present in the final solution.
- How the sensor should transmit their value will be discussed in the next chapter when different approaches to this is explored through development of a prototype.
- Sensor form should not come in the way of the use of the sensor. Meaning that the temperature probe should not be larger than necessary, because this could come physically in the way if the probe end of the sensor is to bulky.

### Hub

- Because the sensor should only be single purpose it should be possible to connect multiple sensors to the hub.
- The hub should only transmit the value from the sensors to the iPad and thereby not have any display to show the values The iPad is a requirement in order to collect data.
- It is chosen at this stage that the product developed in this project should not be a wireless solution from the hub to the iPad. The problem with wireless solutions is that the hub should then contain batteries, and these would have to be charged in order for the hub to be able to collect data.

## Prototyping
## 0.1

## Prototype software

A prototype of the new data logger is created early in project process to get a hands-on understanding of the technical challenges that occur when developing and designing a data logger. An overview of the model and a description on how the product is working is made.

### Development platform

Apple has a special program, called the MFI (Made for iOS) program, that developers have to enroll when they want to develop hardware for any iOS device. Developers have to enroll in order to get access to the resources and get hardware tools for developing and testing. This is true if you want to develop hardware which is connected through the 30 pin dock connector or Bluetooth 2.1 + EDR, if hardware only need to be supported for newer devices bluetooth (4.0) is free to use as an open API which does not require MFI program. But as it is not chosen to use wireless communication for this product, this solutions is not an option.

It is not easy to get enrolled in the MFI program you have to be representing a serious company with a serious product concept. For this project the enrollment has not even been tried. But instead another solution was found.

### Redpark

Redpark has developed a 30 pin dock cable (Fig. 21) with the prober identification chip that is authenticated by iOS devices and Apple. Along with the cable Redpark has developed an Objective-C library which provide the necessary functionality in order to communicate through TTL from a piece of hardware to an iOS device.

### Objective-C

The application is written as a native objetive-c iOS application. Even though all this code was a big part of the project it is not chosen to discuss the software development into detail. The x-code project is available on the enclosed CD. Just to give an idea of how the code is it is possible to see some of it in Fig. 32.

*Fig. 31. The Redpark TTL-Serial cable*


*Fig. 32.* *Screenshots from x-code showing a small amount of the objective-c code, that made the functional prototype.*

# Prototype hardware

## Development

The first consideration when starting to develop the prototype was how to structure the data logger on the levels of electronics. It was given that the only way to communicate with the iPad was to go through the Redpark which only supported a standard serial connection. The Arduino platform was chosen as micro controller in the hub, because it got the sufficient I/O pins and is easy to program out of the box.

## Sensors

It was important to use quite simple probes in order to eliminate as many points of failures as possible, therefore two different kind of probes was chosen, a temperature probe and a light probe. These sensors are analog sensors and therefore easy to read directly from and A/D converter, in a micro controller like the atmega328.
The temperature probe and the light probe are basically both resistors which change their resistance according to the temperature and the amount of light.
The probes are placed in series with a resistor (), then +5 volt is added from the arduino, and then it is possible to measure the current between the probe and the resistor. This results in a voltage division that will produce a voltage between 0 and 5 volts. This current is then read by the Arduinos A/D converter and thereby translated into a digital value between 0 and 1024 (because the Arduino got an 10bit A/D converter), from this value it is possible to determine the temperature.
As stated earlier it is a specification it should be possible to determine which kind of sensors that is connected to the hub directly from the iPad, the iPad should display a symbol or something to indicate that a sensor of a specific kind was plugged in. The way the prototype identifies which sensor is connected is by using a voltage divider. Two resistors are placed in series and the voltage in-between is measured by the arduinos A/D conveter. Then the two resistors can be varied by changing the value of the resistors , and that would change the voltage between the resistors, and thereby the A/D converter in the arduino would generate another digital value. It made so that the two temperature sensors generate a value of 140, and the light sensors a value of 50. Then the software on the iPad checks if the value is around 140 then it is a temperature sensor that is connected and a symbol for that is shown, if it is around 50 a light symbol is shown.

So in the prototype the sensors have the following 4 pins:

- +5 Volt (provided by the hub)
- GND (provided by the hub)
- Sensor Value Output
- Identifier Output

## Hub

The hub in this prototype is an arduino or more precise an atmega328 micro controller, this provide the +5 volt and the GND to the sensors and get two inputs back, which are the sensor value and the identifier, these two input are processed by the A/D converter in the micro controller which have 10 bits of accuracy.
The the data, of the 3 ports which are the amount available in the prototype, is packed into an array containing both identifier and values, and send through TTL to the iPad which then process the data further to show the graphs.

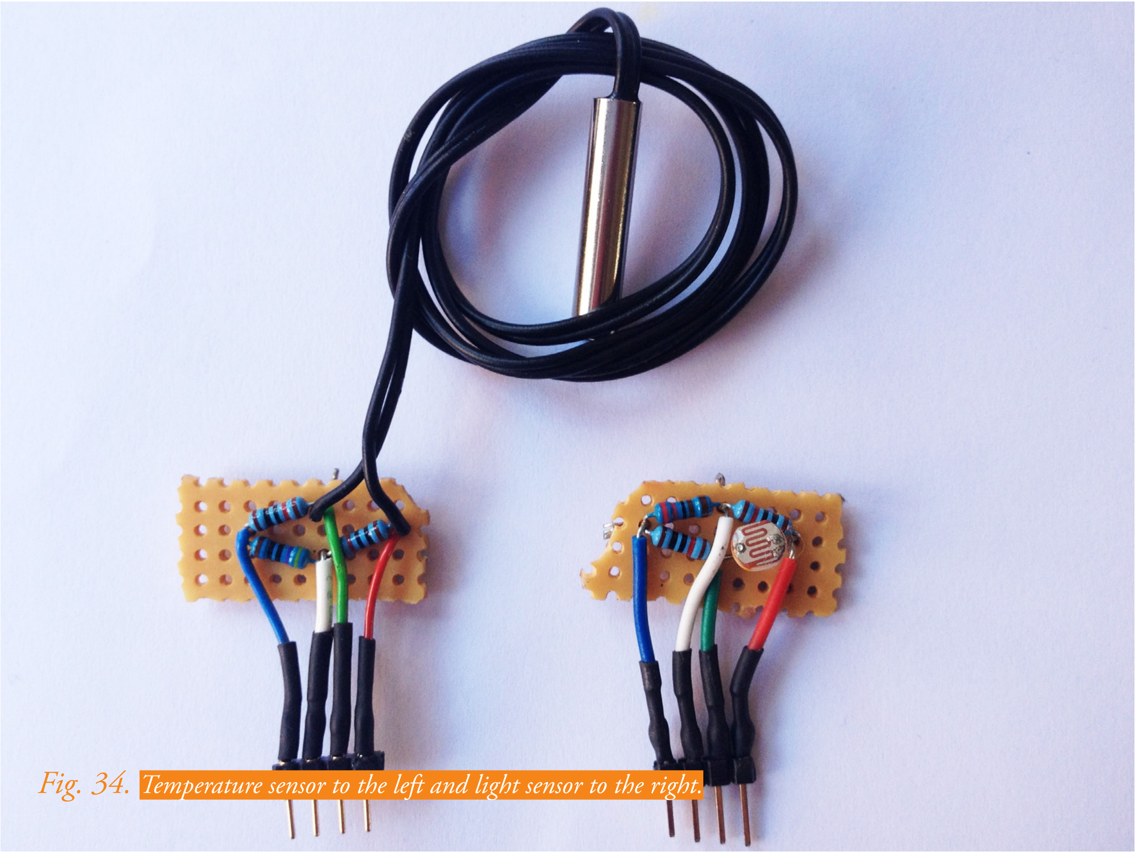


*Fig. 34.* *Temperature sensor to the left and light sensor to the right.*

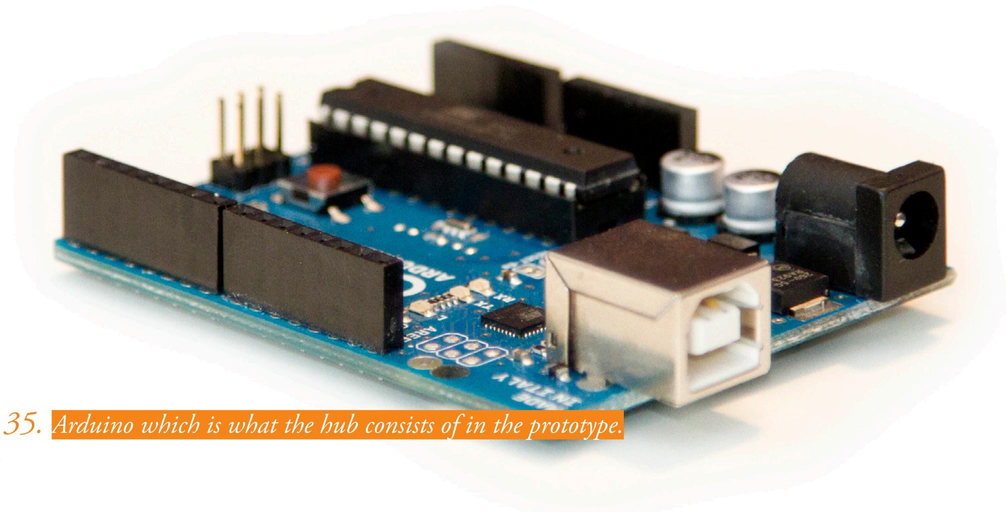


*Fig. 35.* *Arduino which is what the hub consists of in the prototype.*

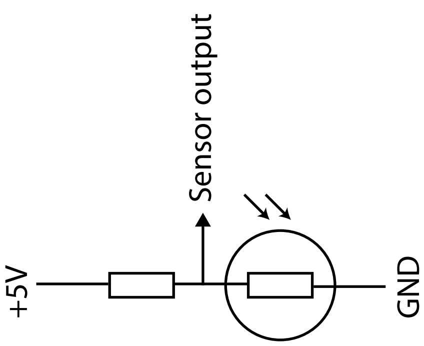



*Fig. 33.* *Diagram of the light sensor output.*

## Video of prototype

A video demonstartion of the prototype can be found at the CD or through the QR code in

There will be no further description of how the prototype is working in technical detail. After the prototype was developed a much better general understanding of electronics and software was obtained.
This will have a great impact on qualifying the next chapters in the project, specific outcomes of the prototype is described by updating the and further develop the design specifications.

Also availible on the enclosed cd /video/prototype

## Electronics in the final concept

The different types of probes which should be supported is explored in this chapter.

Now the final specifications for the electronics will be discussed, this will make a base for the development and design of the physical hardware.

To know how to structure the sensors in the final concept, it is necessary to know which kind of probes the data logger should support, this is decided with advices from a teacher at HTX-Næstved.

In the first prototype there are only implemented temperature and light sensors because these are really simple to read values off. It is really simple to change the temperature or change the amount of light in a room and thereby these sensor can be good for development. But the final sensors should be able to support a larger amount of probes. Here is a list of the different probes which should be supported in the final concept, and how to read values of such probes.

| Type | Data collection |
|---|---|
| Temperature | Readable directly with an A/D converter |
| pH | Requires op-amp and then analog readable |
| Light | Readable directly with an A/D converter |
| Sound | Readable directly with an A/D converter |
| Distance | Measure time between pulses (Ultrasonic range) |
| Voltage | Readable directly with an A/D converter |
| Ammeter | Readable directly with an A/D converter |

*Fig. 36. Table of different kinds of probes and how data can be read out of them.*

With the knowledge from prototyping the data logger, the structure of the electronics has shown to be a challenge. The challenge is that some of this different types of sensors are not directly readable from an A/D converter. Additional hardware would be require to make the sensors readable. Now I will try to explore the different ways the data logger could be structured in order to find this most suitable for this purpose.

### Analog reading

Directly connecting the different probes to an A/D converter in the hub (as done in the prototype) creates various problems because the different sensors measure different values in various ways. For instance, to measure distance is done by sending out a sound signal and waiting for the sound signal to return after hitting an object. The distance to the object is then calculated by knowing the speed of sound. This means that what is measured is timestamped and this would not be smart to take through a A/D converter in the hub, but rather communicate through a serial connection to the hub.

There are also problems with identification which would require a second circuit, like it is done in the prototype.

### A/D converter in each sensor

Since it necessary to build circuit boards into the individual sensors, a method for overcoming some of the problems with different sensors would be to have an A/D converter in each sensor. The A/D converter would be able to communicate with the hub's micro controller through a serial protocol. The serial protocol that could be used is the 1-wire protocol. The advantages of using this protocol is that all 1-wire products have an identifier hard coded onto the silicon of the chip. This identifier is send along every time a value is requested, and thereby it would be possible to identify which sensor type it was.

If using RS-232, the A/D converter would not be indication which kind of sensor it was. This would have to be identified using additional hardware.

One of the advantages of this method is that A/D converters are available in any desired accuracy, and this could be necessary later in the project but from the sensors that are used now 10-12 bit is enough.

The problem with using an A/D converter in every sensor is that it still would require some of the sensors to have additional components such as the pH-meter which would require an OP-amp to work.

### Micro controller in every sensor

The last alternative that is explored in this project is adding a microprocessor into every sensor. This is a very flexible solution that would be capable of communicating with the hub in different ways based on what type of sensor is used. It is also possible to let the microprocessor communicate with the probe to do some of the data analysis directly in the sensor and thereby not taking process cycles from the main micro controller in the hub, but distribute it out to the different sensors. This could also be the examples with the distance sensor where the sensor would be able to compute the distance to an object and send that value to hub.

In terms of identification it would also be very flexible to use a micro controller because it would be able to pass a string to the hub identifying which kind of sensor it is.

## Structure

How to structure the sensors in terms of electronics.

## Hardware interface & protocols

Different solutions to the hardware interface between the hub and the sensors are explored and discussed, in relations to that potential protocols are also discussed.

In order to further specify the product in order to apply form to the sensor, the physical interface of the hub/sensor is explored.

### Physical interface

Because this is a product which should be able to compete with other iOS accessories there are some things which is very important to discuss in terms of use of the product.

The current data loggers on the market uses either their own or quite unknown interfaces (like the VIVO interface), which is not considered a good solution, specially due to the orientation dependency of the interfaces.

The challenge is that the more parts of a product which is new to the user, the more things they have be aware of, and do not understand, the more is there to be uncomfortable of. If the hardware interfaces is known and there is no doubt where to connect the sensor, and which way to connect the sensor, the user has a higher likelihood of being sure that the parts are prober connected. All of the users in this project's target group have tried to connect a pair of headphone to a headphone jack and all of the them know when the headphones are connected in a proper way, because they already know the feeling of connecting such a device.

The chosen hardware interface for this product is jack connectors. Jack connectors are known to the user. The jack interface support up to rings (similar to pins), and they are not orientation dependent. In addition to the physical size of the jack connector is also quite small (Ø 3.5 mm) which is also a good thing in terms of keeping the size of the embodiment small.

The jack connector will make the product feel more familiar to the user and thereby not create the alien feel of the current products which was seen when observing users perform an experiment with the current solution. This is important because the user might not understand the theory which they try to prove through an experiment and thereby have to be secure in using the data logger and secure in knowing that the values they get are correct and trust them. This will be general consideration in all the aspects of this project. To make the user secure in using the data logger.

### Protocols

Now that the physical interface is know, different protocols to communicate through is discussed and explored.

A protocol is a convention of how to communicate between hardware. There are a lot of protocols to communicate between hardware components such as $I^2C$, SPI, TTL, 1-wire and can bus, just to name a few. Different protocols is used for different applications based of the amount of wires available, transfer speeds, wire length and so on.

In this particular case I have 4 pins in total from the sensor to the hub, but the circuit in the sensor would need power in order to work, which means that 2 of the 4 available pins would be required for +5 volt and ground. This leaves the communication protocol to work with 2 pins to transfer the data. Which specific protocol to use would depend on which micro controller that was chosen in the hub, but a protocol which could be used was the $I^2C$, this only requires 2 wires and can run for about a meter in length which is sufficient.

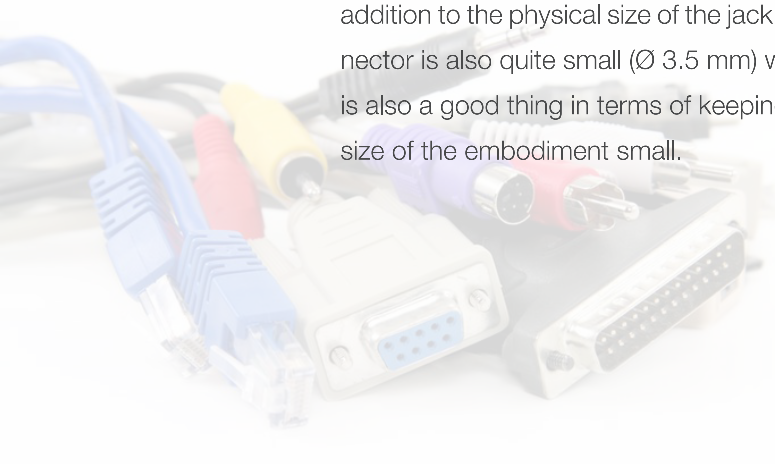


*Fig. 37. Different physical interfaces which all have their specific value and qualities for different purposes.*

## Specification of electronics

### Sensor

Which specific microprocessor to use in the sensors is not possible for this author tell, because it would be defined by an electronic engineer and depending on the amount of sensors which should be made it might be best to design a custom micro controller. But an example of a micro controller which could suit the purpose could be a ATtiny45 from Amtel. It has the sufficient amount of I/O pins.
Some of the probes would still need an op-amp to work, but this is inevitable no matter what solutions is chosen.

The PCB (printed circuit board, the often green board where chips are soldered onto) in the sensor is not designed in this project, but it is estimated how big it would need to be in order to be realistic. The size is necessary to know in the further development of embodiment of the sensors.

The size of the IC itself is 6,2mm x 5mm x 1,75mm[6]. With the additional print of other components to attach it is estimated that the print to make the sensor work would be around 20mm in diameter.

### Hub

The circuit of the main hub is not designed either. The size of this board however is defined by the size of the micro controller which would be around 9mm x 9mm x 2mm and the size of 3 jack connectors, which is 20mm x 6mm x 6mm. Additional hardware would be required in order to produce this product for an iOS device, but specifics around this cannot be explored further because these are under the NDA of Apples MFI program and thereby not public. But the overall size of the print

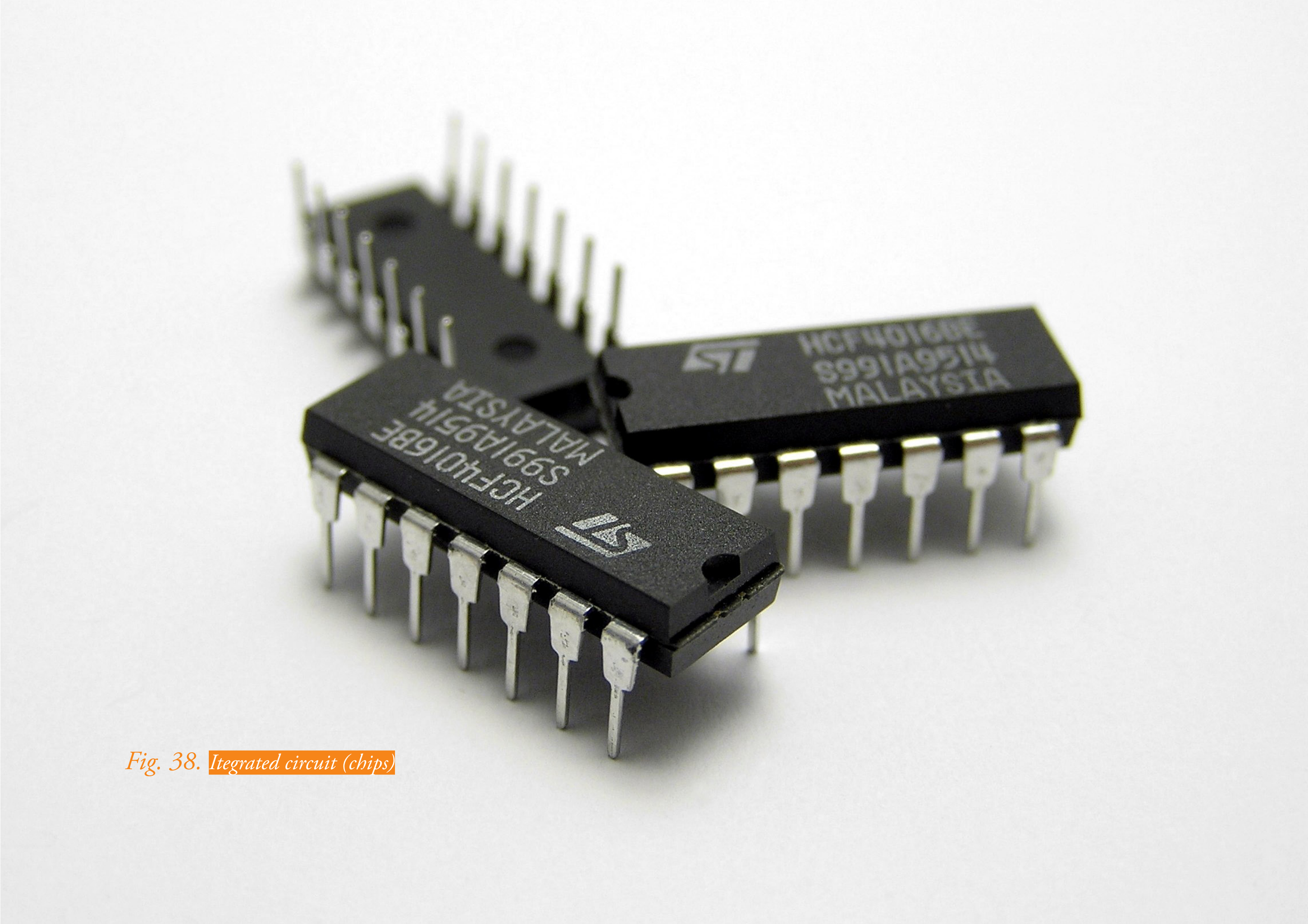



*Fig. 38.* Itegrated circuit (chips)

## Business model

It is discussed in this chapter how it is possible to earn money of a product whith both an application and a piece of hardware.

When designing a product like this data logger for high schools, it is important to consider how to make the product profitable by considering the actual business model for the product. It is important to do this before the actual design process is entered, because it will give additional specifications that is important to consider when designing the product.

Since there is a physical product involved the main profit should come from the sale of the physical hardware. But there is also an iOS application that can create an income for the business, I will not try to give an example of a company that sell hardware accessories for iOS and does exactly that.

This method of having a physical product in addition an application to both make profit from is what iRig does. iRig is a piece of hardware that enables an electric guitar to be connected to the iPad, and different effects and be applied. When a user buys an iRig they have a limited amount of effects in the application, but additional effects can be bought. It creates a bad experience for the user, because they have already paid for the hardware, and now they are supposed to pay more in order to use the hardware optimal! This is not considered a good solution from a user perspective.

The data logger should primarily be sold to high schools and the school should own this hardware so many students can use the products. And from a sales point of view it would be hard to convince a school to buy a data logger, and they say: "If all the students are supposed to use this application on their iPad, additional app needs to be bought", it is considered much more elegant to earn the money on the hardware alone.

When users download the iOS application for free from the App Store, the data logger should be 100% functional. By having all the features, the student would have the best experience of the product, which is good for a company in the long term.

It is expected to sell the hub in packages with sensors, but it should also be possible to buy the sensors separately, and this is where it is possible to earn extra money.
From this point of view the part which should seem the most expensive are the sensors, and not the hub which might be the obvious choice. It should be possible for the school to feel they are buying something more than just a regular probe, which they would for instance to a regular pH-meter (see . It should be possible to see that a pH-meter for Sense somehow does more than the other.

The hub on the opposite should be secondary in form of the product because this is just something that should connect the sensor to the iPad, it should seem like the sensor would almost work by itself. (Of course this is not possible with the current choice of electronics).

There are a lot of opportunities in terms of earning money on services around this product, but because the project is at an early concept stage it is not possible to know that much about at what cost this would be in order to create such services, and thereby where it would be possible to earn money.

But this product should from the users point of view be seen as a physical product first and foremost, in order to get this product to work an iPad with the application is required, but the user should not consider that application to be part of the product they are buying when buying the data logger, it should simple be part of it.


*Fig. 39. Fig. A guitar interface for iOS, where the user can buy additional effects after they have bought the hardware.*

*Fig. 40. A standard pH sensor which would be bought for a pH-meter. This would with the BNC connector be possible to use this probe with almost any pH-meter.*

## Product name & logo

The name of the product was chosen at an early stage of the development, it eased up how it was possible to talk with third parties about the project, and frame it as a real product instead of an Arduino board attached to a breadboard. The name that is chosen is Sense. It relates to the senses of the human body, which is really what a data logger is—a quantitative version of the human senses. From this point in the report the product will be called Sense. A logo is also developed which can be seen below

## Introduction of final concept

The following chapter will show the process of how the physical hardware of Sense was developed during the project. The hardware was designed along side with the software and services around the product, but for the ease of reading, the processes of the different aspects of the product are described separately.
First the hub is designed and then the sensor is designed, the primary focus is chosen to be on the hub and the sensors, the remaning parts will be described on concept level.
The primary focus of the form development is that the parts should be injection molded, due to the low price of this process.

## The hub

Through out the project the design specifications have increased and now it is time to give them form in an actual hub.

One of the first thoughts when the initial ideas to Sense was conceived was to develop a new type of physical interface from the sensor to the hub, a concept of this was modeled and rendered, which can be seen on Fig. 42.
But as described after visiting the high school and interacting with the users, this did not seem like the best solution, because it could make Sense unfamiliar to the students even before they had set up the experiment.

So the jack connector was chosen, and then the way to connect the sensors to the hub was explored. One approach was to place the jack connectors all around the product for a higher degree of flexibility, whereas the other approach was to attach the jack connectors to a single edge of the product.

A render of the situation where the sensor is placed all around the product is seen in Fig. 43. It was chosen not to go in the direction of placing the jack connectors around the edges, because it is a rare situation where it is necessary to have sensors align so that it would make sense. It would also have a larger footprint of the table.

On Fig. 43 it is also possible to see how the hub got curved edges and is smoothed out. After the business model was made it was made clear what the hierarchy of the hub and the sensors should be, that the hub should be perceived as secondary in comparison to the sensors, the hub should be redesigned to be more simplistic and anonymous. It was chosen to go for a simple geometric solution with no soft edges, and this can be seen on

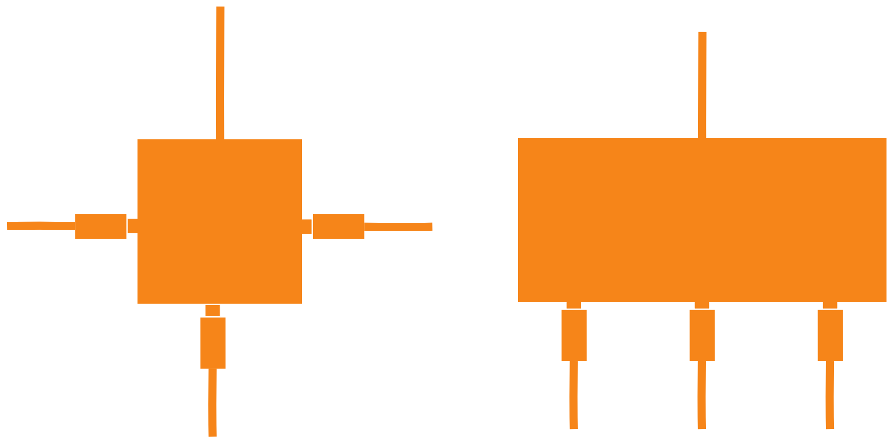


*Fig. 41. Different concepts of how to connect the sensors to the hub, either along on edge or all the way around.*

*Fig. 42.* *Before the first prototype was developed this concept was developed, the thought at that time was to develop special designed connector from the sensor to the hub.*

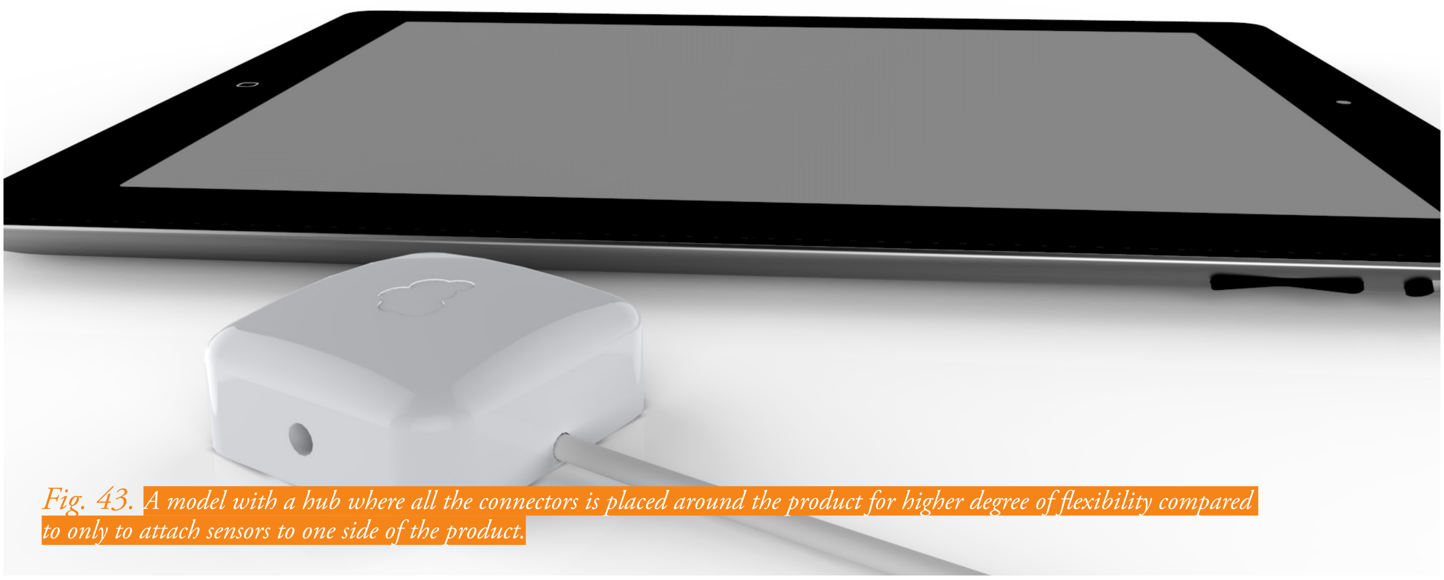


*Fig. 43.* *A model with a hub where all the connectors is placed around the product for higher degree of flexibility compared to only to attach sensors to one side of the product.*

*Fig. 44. The more simplistic and geometric solution was chosen in favor of soft edges and curves.*

## Datailing

Different aspects of design for manufacturing of the hub is discussed in this chapter.

The final form concept of the hub is chosen to be the one on Fig. 44, then the detailing of the product could start.

The challenge with producing this concept is in the detailing to stay true to the specification that the product should be anonymous and clean. Things such as flashes on the side or a split line are not part of such specifications and are tried to avoided. Since the surfaces of the product should stay consistent and clean any shrinkage is tried to be avoided as well. These are the two main issue when the detailing is started.
Since no flashes and split lines should be visible, there is only one option how to divide the shell. And that would be as shown on Fig. 45 with the top part being attached to the sides.
The immediate first challenge with the top part are the holes in the side of the product, it is necessary to use a core in order to make these holes in the mold. Another methods is to machine the holes afterwards, but this decision on which method is best would be the tool makers.

The bottom part of the hub needs to be attached to the top part, two different methods is described and compared.

The first would could be done simply by constructing mounting bosses on the inner top part of the hub and the use screws from the bottom part to secure the parts together.

The other solution is to secure the bottom part with snap-fits which attaches to inner sides of the walls of the top part as shown on Fig. 46. This does however required a more expensive molding tool for the top and bottom part due to the requirement of cores in both tools. This method with snap fits would probably also need to be glued together in order to ensure that the product does not come apart if the snap fits fail.

If this product was supposed to be produced, there are issues with both methods to consider:

The first construction concept could potential have problems with shrinkage on the top of the product where the mounting bosses are attached, due to the change in material thickness.

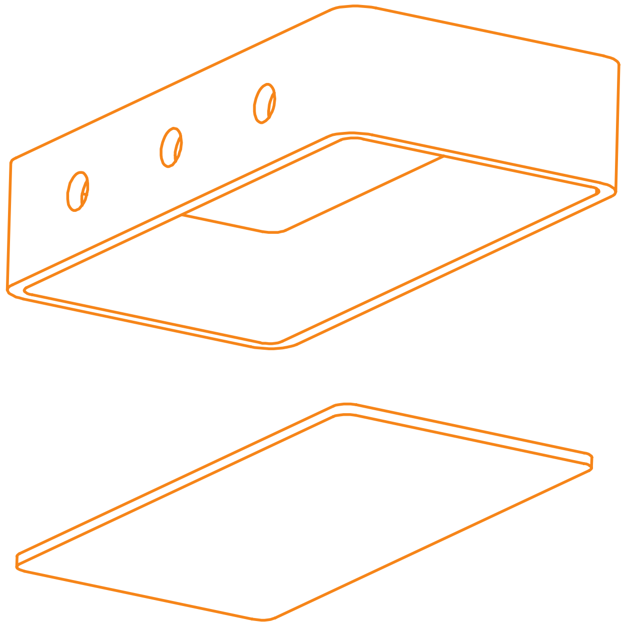


*Fig. 45.* To avoid a visible split line this is how the shell is split.

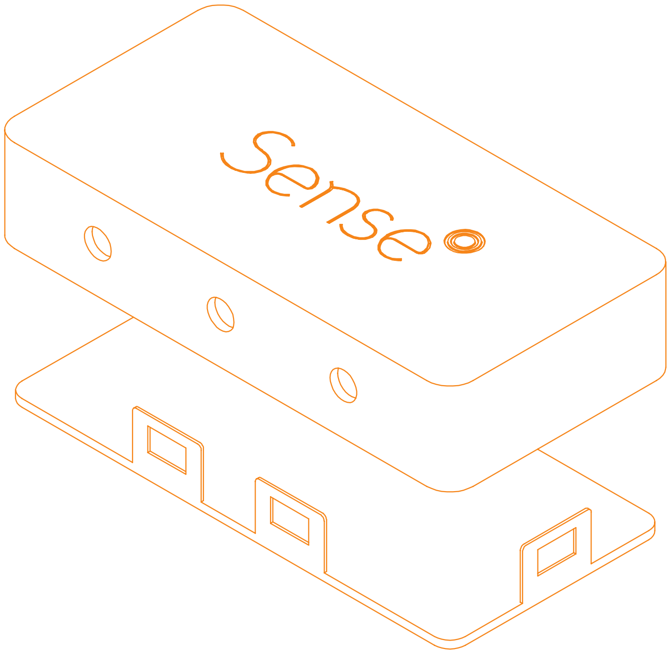



*Fig. 46.* Designing snap fits in order to secure the bottom part to the top. This would in addition to the snap fits require glue in order to work.

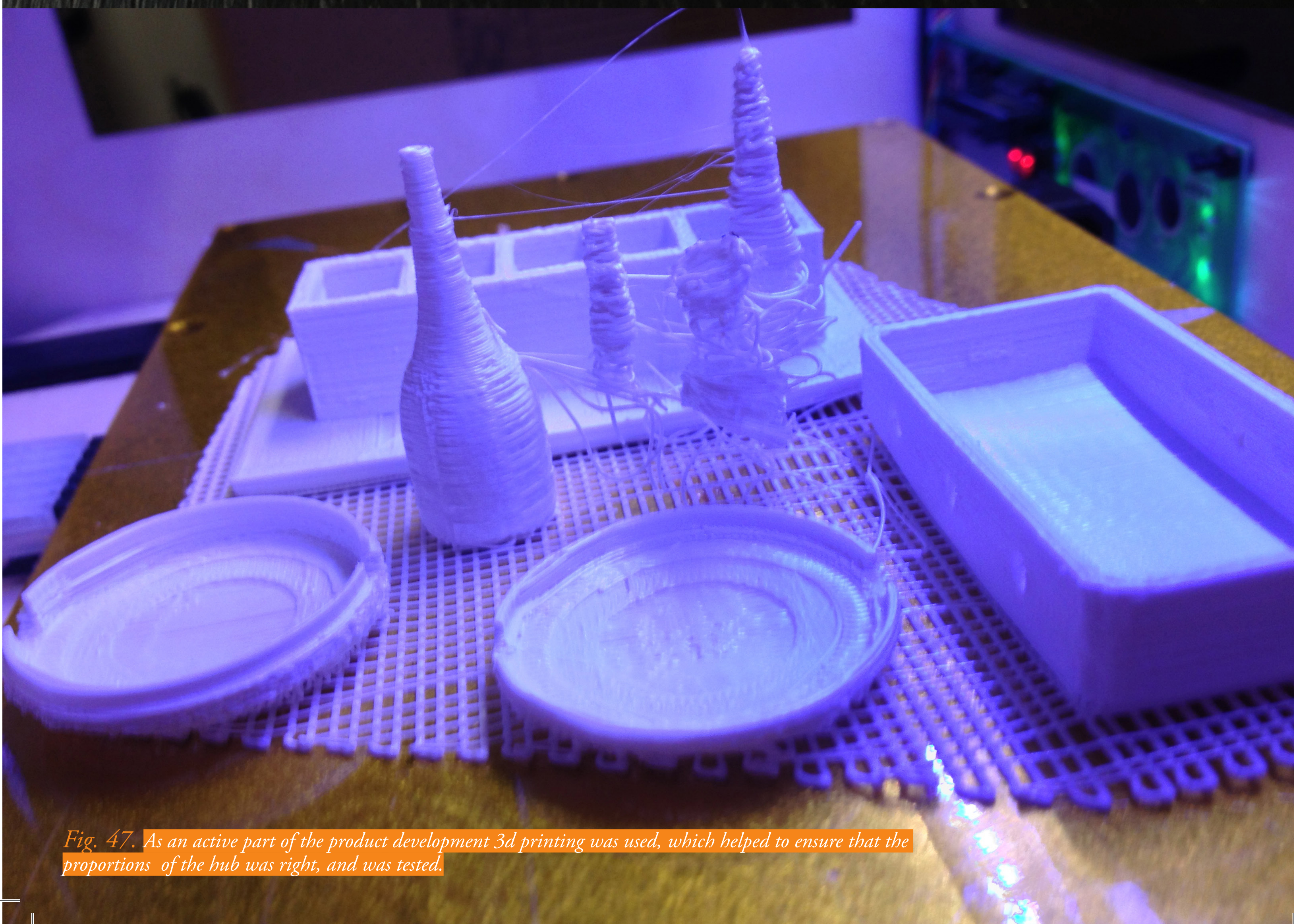


*Fig. 47.* *As an active part of the product development 3d printing was used, which helped to ensure that the proportions  of the hub was right, and was tested.*

The other construction concept have an equal layer thickness on the top surface and thereby avoid this issue. This means that if the shrinkage could be controlled an minimized on the first construction concept this would be the one in favor, because the tooling would be much less hard. Again it is impossible to tell which concept is best, this would be a tool makers decision, if it is possible to mold the first concept without shrinkage, if that is possible it would be preferred.

On the bottom part of the hub it is decided to apply rubber material to ensure that the product stays on the table. It is preferred to mold the rubber part and glue it on the bottom of the bottom part of the hub. The reason for gluing is that it would ensure that no screw heads is visible on the product.

The bottom part of the hub would also be where the electronics is attached, they would simply be attached with screws in mounting bosses on the bottom part. In the design of the circuit board there would of course need to be placed holes where the mounting bosses from the top part goes through. The final hub can be seen on Fig. 48.

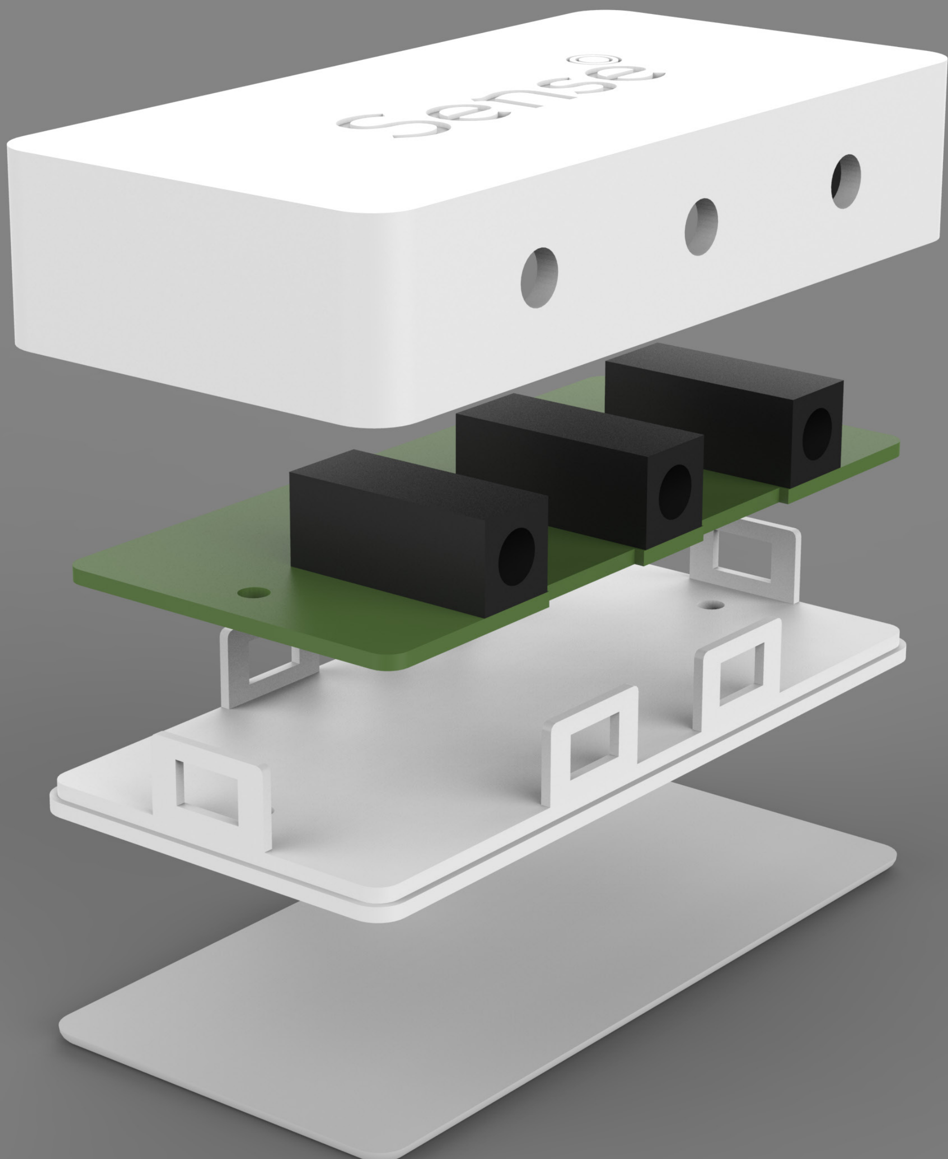



*Fig. 48.* The final hub

## Sensors

In order to incorporate the electronics into the sensor different approaches are explored, and these will be described in the following chapter. This part should in contrary of the hub have more character in the form, and no be as anonymous as the hub. The first thing to explore is where to try and mount the electronics.

There are 3 things which are always present on a sensor—the probe, the cord and the jack connector to the hub. It is important that the way the electronics is incorporated is the same on every sensor both due to standardization in terms of production and to recognition for the user, so the user know how to connect a any sensor if they have tried to connect one.

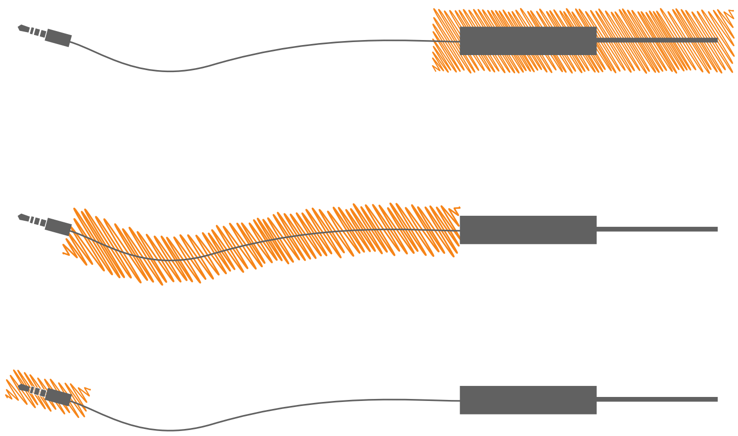


*Fig. 49. The 3 places where it is possible to place the electronics in the sensor. The probe (In this case this is illustrated as a temperature probe), the cord (which is universal for all sensors), and the jack connector (which connects the sensors to the hub and is universal for every sensor).*

It is not considered a good opportunity to incorporate the electronics together with the probe, this is because the different probes have different form factors, and it will inevitably make the probe's end of the sensor bigger. And thereby it might come in the way of doing the experiments.

As stated earlier the jack connector is used both because it fulfills the requirements on a technical level, but also because it is a well-known connector, and it should continue to be that way, so the form factor of the jack connector should not change very much from what is know. Incorporating the electronics would increase the size of the jack connector.

So the last opportunity is to implement the electronics onto the cord, because this is the last part which all the sensors have in common.
This is also in contrast to Pascos solution good, because it will enable the device on the cord to change over time, without necessarily changing the rest of the sensor.

Since the sensors are considered the main object in the Sense system, there are some features which are important to make sure is present in the sensors.

Identification of different sensor types, meaning that it is possible to look at a sensor and with out knowing anything about probes be able to tell what that sensor can be used for.

Branding of Sense is important to make sure that the user know that the specific sensor belongs to the Sense system. If the probe is anonymous some students might think that it will work with other systems as well.

# Placement of the Electronics

The overall shape of the part that contain the electronics can be seen on fig. 51. It is more organic and rounded than the hub, and does more express that it want to be touched and used. It is still kept in a geometric shape - a circle.
It is not possible to hide the split line of this part and it is chosen to construct a groove and a lip so that the split line is placed on the middle of the product.

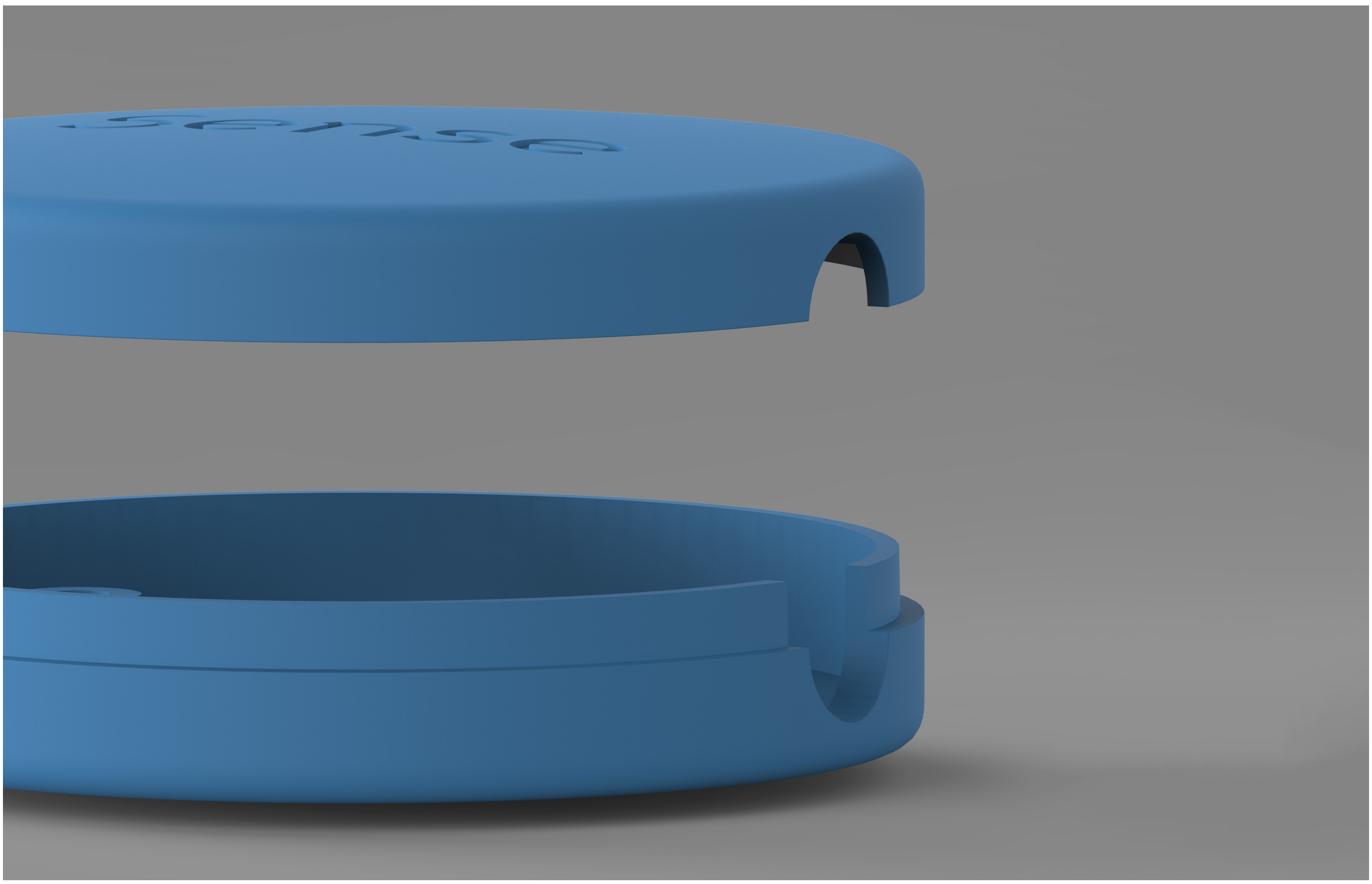
In order to make sure that the cord on the sensor is protected there should be a rubber part where the cord meets the sensor and the jack connector, this is constructed as shown on Fig. 50

The pcb is mounted with mounting bosses in one of the shells like shown on Fig. 50.

## Identification of sensors

In order to identify the different sensors from each it is decided to color code the pucks on the sensor, so each kind of sensor got their own color, this would not require any additional tooling. It would also help the students to be guided in the process of setting up their experiment if the sensors could be referred to as a color. This is also interesting in terms of software, because these colors can be used in the software to identify which sensors are attached.

The end of the sensor where the probes is attached are designed specific for each different probe. They are held in a organic form factor and can be seen on fig. 51. The construction of these would depend entirely of which specific probes that would be used, and I have chosen not to focus on this part in the detailing.



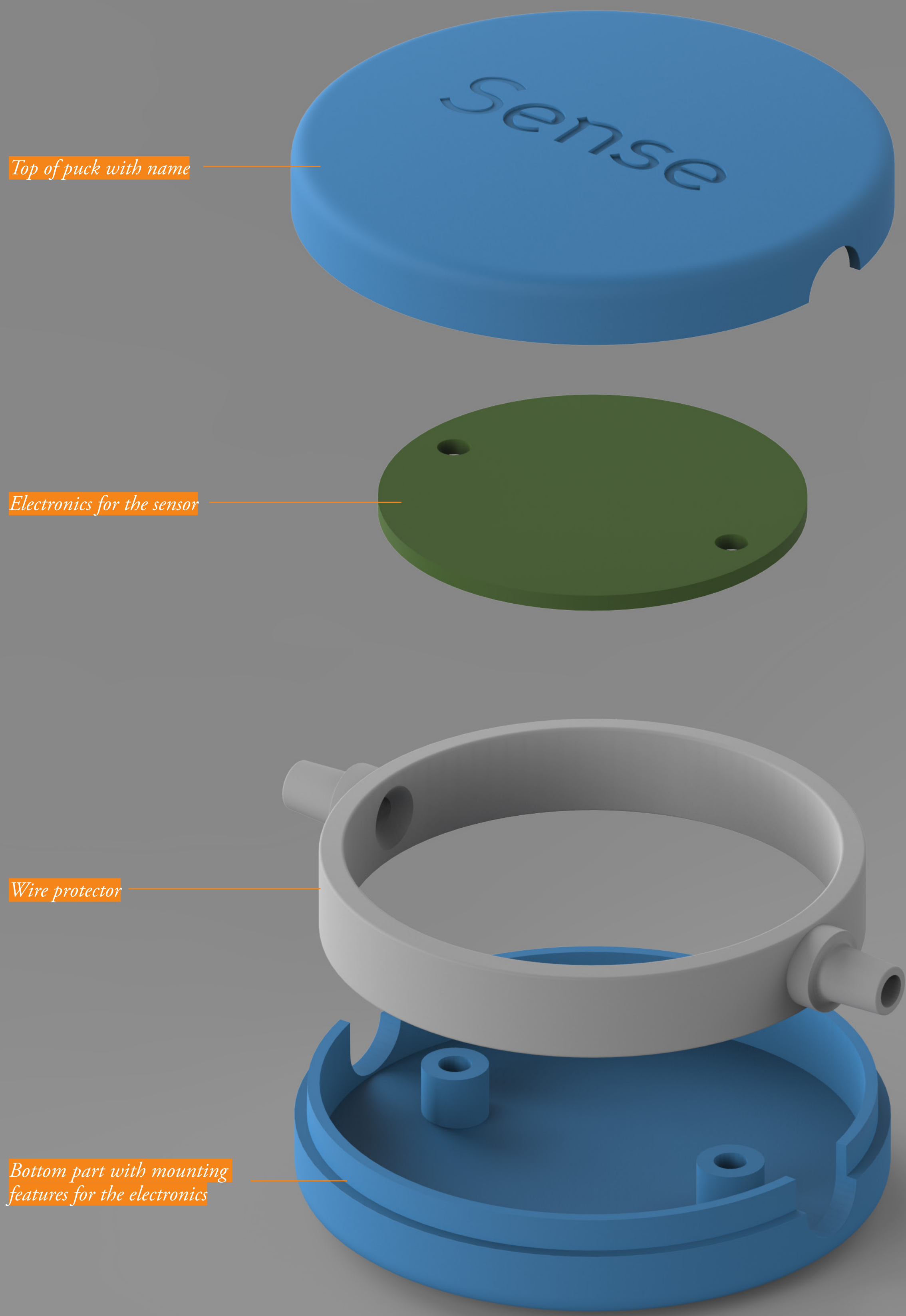



Fig. 50. Final puck of sensor

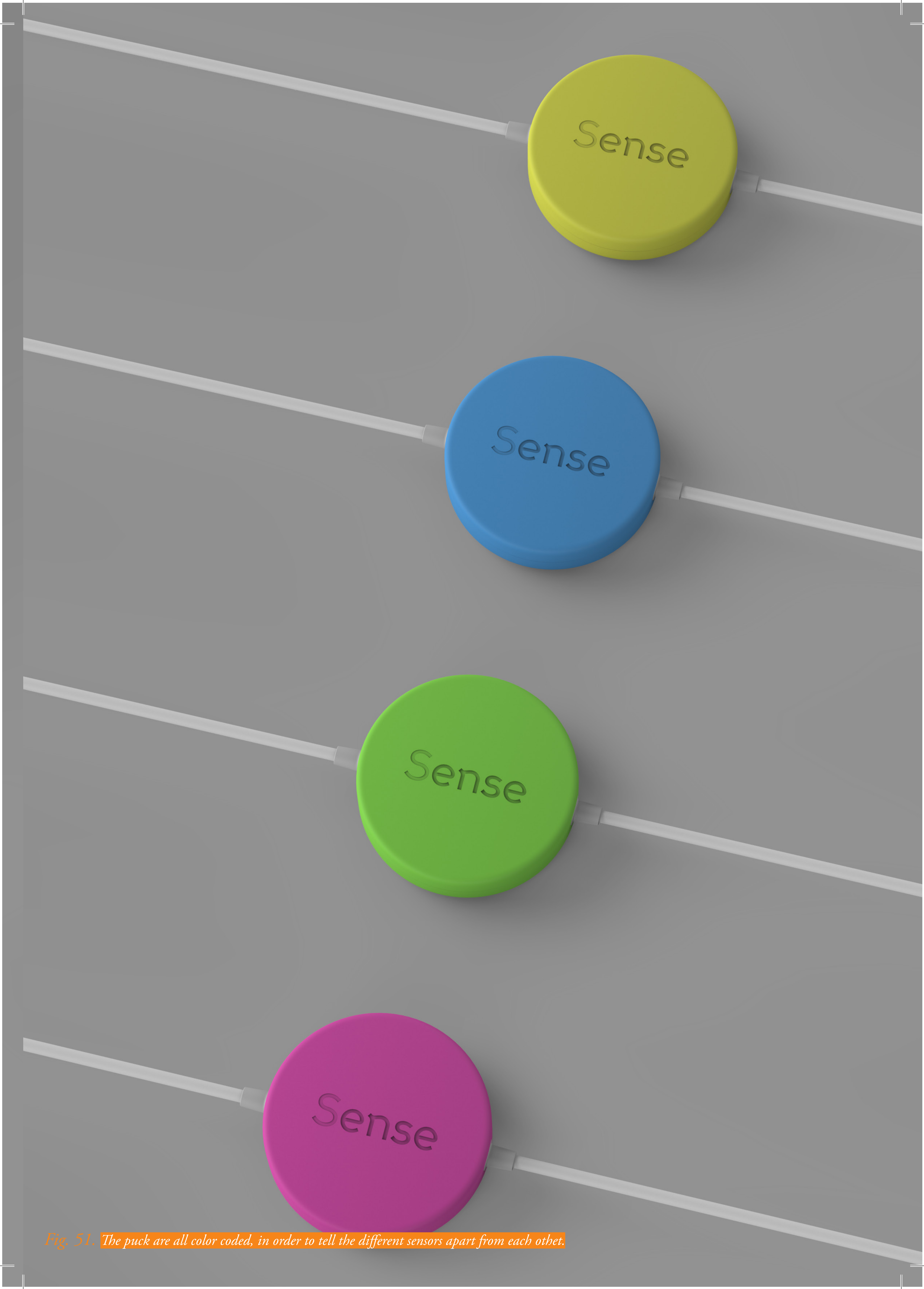



*Fig. 51.* *The puck are all color coded, in order to tell the different sensors apart from each othet.*

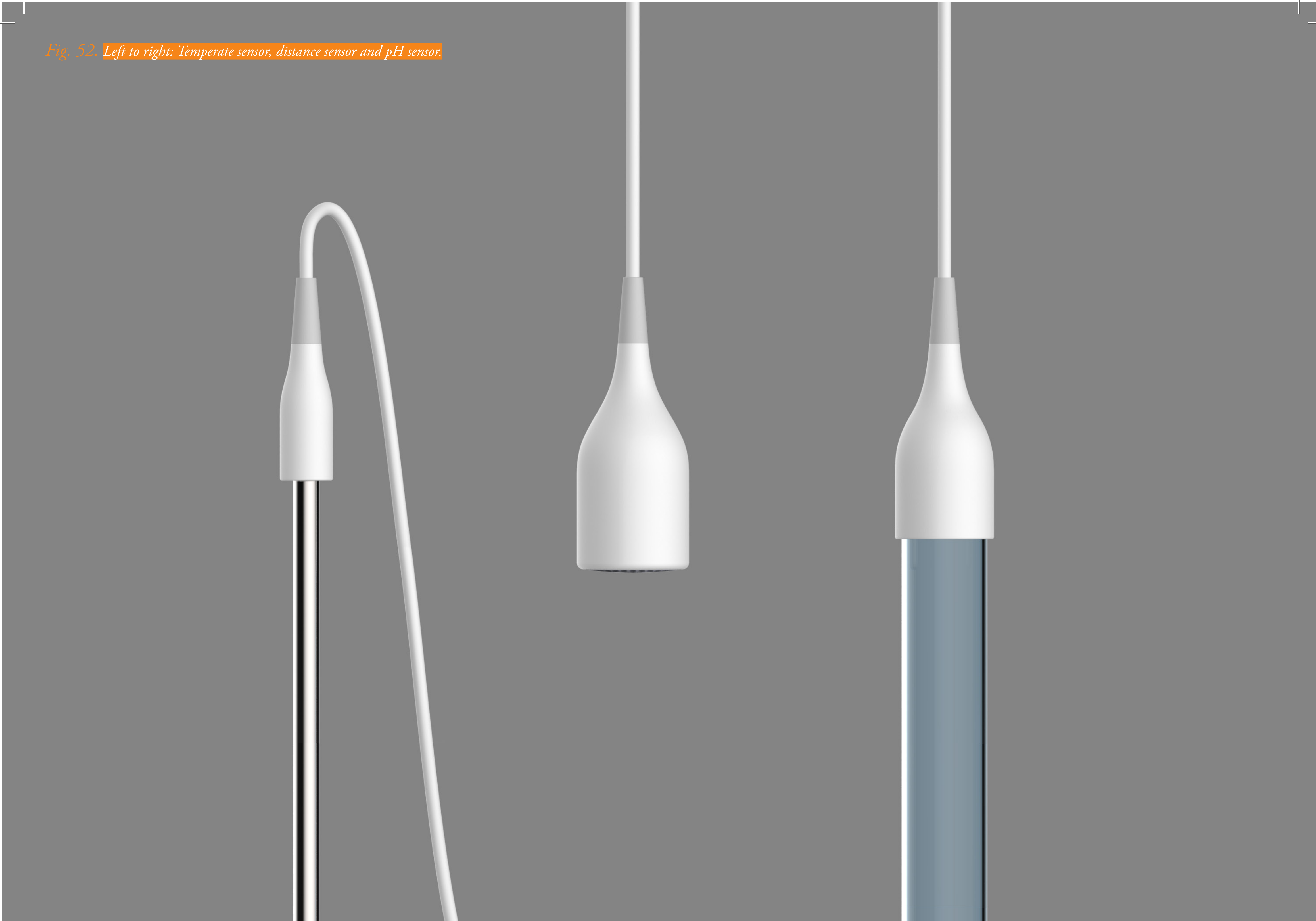


*Fig. 52.* *Left to right: Temperate sensor, distance sensor and pH sensor.*

*Fig. 53.* *Mounting solution.*
*The mounting solution is able to rotate in order to position the sensor accurate, specific angle if that is needed in an experiment. The screw will let the 'jaws' come closer and thereby secure the probe.*
*The probe end of all sensors should have a straight cylinder shape at on part of the form, this would enable the sensor to fit into the mounting solution.*

## Introduction user interface development

The development of the user interface (UI) will start with an analysis of how the current product work from Pasco. Then the whole service of Sense is described and discussed, and finally the UI is designed based on the analysis and the services around Sense.

## User interface for Pasco Pasport Probeware

To get the data from a sensor to the iPad with the Pasco Pasport Probeware system, it is required to set up a wireless connection over bluetooth with an Airink.

The first problem by connecting a wireless product is that the product itself needs to be charged in order to work, and this could be a problem in a school where students should have responsibility of charging the devices, this might not be done and thereby there is a potential problem that the students enter the lab and none of the hub devices is charged. The app does not have permission to set up the bluetooth connection to external hardware, this is something which should be done in system preferences on the iPad, because Apple think it should be that way. This can create some feeling of disconnection to the hardware because it is not supposed to be setup inside the application where it is supposed to be used. When the bluetooth connection is established and the SPARKvue application is launched the first screen looks like Fig. 46.

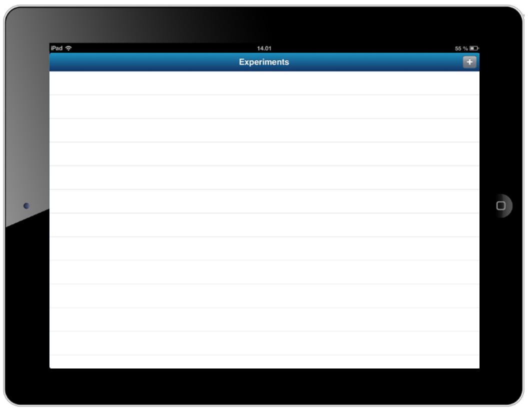



*Fig. 54. First screen of the SPARKvue.*

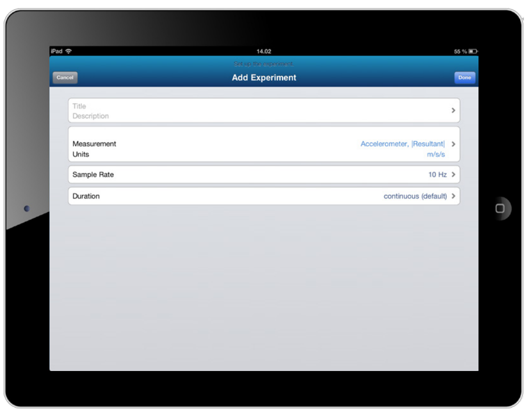



*Fig. 55. The setup screen in the SPARKvue.*

The SPARKvue application forces the user to use the 'Waterfall method' where the previous step it supposed to be completely configured before going to the next step. So when the experiment is setup (Fig. 55), the user needs to specify which kind of sensors to collect data from, the rate in which the data should be collected and the total duration of the experiment (i.e the duration can be set to infinitive or a predefined time).

When the student is ready to collect the data the icon 'Play' is pressed (Fig. ) and the data is collected. When the 'Play' button is press again the data collection stops. If the 'Play' button is pressed a third time, a new set of data is collected (Fig. 56). This is useful if the experiment is supposed to be performed more than once to ensure higher accuracy.


*Fig. 56. Play button is placed at the bottom of the application, the data collection starts when that is pressed.*

On the Pasco product it is possible to change some of the settings from the initial setup within the data collection screen. If the user presses the labels for each axis, it is possible to choose what to display on the axis (Fig. 57). It is not possible to change the setting of the data collection period.

In terms of navigation, the graph on the display is not intuitive. The primary thing which is for the most users is to pan around the graph area, but if one finger is used the application will swipe to another view where it is possible to see the data as a speedometer, this can be seen on Fig. 58. If it is desired to pan the graph the finger should be held down for a second to 'grab' the graph.


*Fig. 57.* *Setup screen within a measuring*


*Fig. 58.* *Speedometer view is entered when the user try to pan around the graph.*

### Exporting data

When the user has finished the data collection, the different series can be exported as individual CSV documents. A challenge with this is that if the user wants to use a graph from the application, they will either need to take a screenshot or generate the graph again using Excel or a similar piece software.

On the enclosed CD it is possible to see a video demonstration of both Pasco and Veniers solution. They are placed in cd/videos/pasco_ui.mov and cd/videos/vernier.mov.

## Additional analysis

## The System Around the Product

Before this project will go into further detail about how the user interface is designed, the whole system of how the Sense is working is explored, in order to be able to incorporate all these features into the user interface in an intelligent and integrated way.

### The cloud

The iPad is well know for people to viewing content, youtube, pictures, documents and the Internet through a browser, but one things which many people see as a problem when using the iPad for generating con- tent is getting it off the iPad. Apple have made their own solution called iCloud which have the capability of saving documents and opening on other devices and synchronizing contacts, pictures, calendar ect. This solution is elegant because it works without the user needing to actually do anything to have the data available through their different devices.

The cloud is a key feature in Sense because it is in the cloud where all the users data is stored and can be accessed from other devices such as a desktop computer or a mobile phone.

The data should continuously flow to the cloud while collecting the data from the sensors, and it should even be possible to view the data of an ongoing experiment. So that an experiment can be observed without be- ing present in the lab.

The data should continuously flow to the iCloud while collecting the data from the sensors. It should also be possible to view the data of an on-going experiment on another device. This would mean that it would be possible to observe an experiment performed in the laboratory without being present in the laboratory.

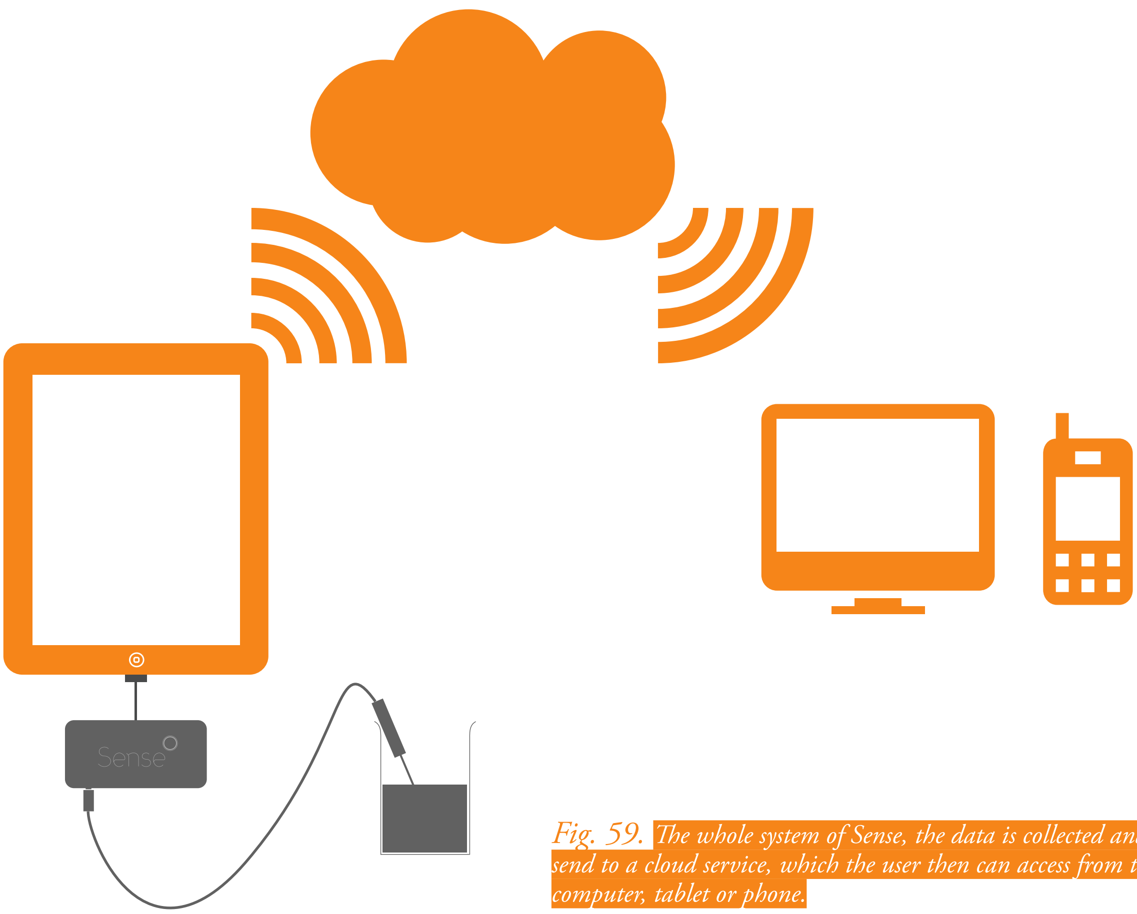



*Fig. 59. The whole system of Sense, the data is collected and send to a cloud service, which the user then can access from their computer, tablet or phone.*

### Getting Data in the Cloud

To get the data into the cloud it would require a web service that application running on the iPad to communicate, but before that service is established it is interesting to discuss what data that service should be able to get.

The other systems of data loggers does not have any opportunity for

the user to take their data off the iPad and do additional data analysis

on a desktop computer. The problem with this is that the iPad would be good for initial data analysis, but the whole report would be written on a desktop computer anyway, so to do all the work and generating all the graphics on the iPad is not desired for this project. It should be possible to gather the data on the iPad make some data analysis which would be.

Adding custom graphs

Finding fitting graphs

Mark points of interest or regions of a graph

After the data is collected it should be possible to export them as .*CSV and generate pictures of the graphs directly from the iPad, but the web service is an important tool for getting the data from the iPad to a desktop computer just by downloading an image of the graph, or simply be able to copy/paste the data from a web application to excel or other programs.

With using the cloud for synchronizing between devices, this would re- quire users to have an account in the Sense service, there are many aspects of designing such a web application, such as integration with other services (Google Docs, Facebook, Dropbox...) The ability for different users to organize themselves in groups. All these aspects are not considered within the scope of this project.

With an web application there is a possibility to make a public API, this would allow producer of existing and new software in science to integrate the Sense in to their product and thereby generate money.

By letting third party developers use the API of Sense the new applications may generate more attention around the product. Depending on the new application a better and more full experience could also be generated for the users, it they had specific needs that the Sense software did not support.

# User interface development

## Introduction

The knowledge from the analysis of the Venier and Pascos solution to iPad software, and the development of the services around sense is the foundation for the development of the user interface.

In the development of the UI it quickly became clear that it was very hard to design the experience without being able to program the actual software, and test it with the users. The user experience of the product exstends way beyond the user interface, because it also includes what kind of feedback a user gets when he attach a sensor or attach the hub to the iPad. Therefore it was chosen to give an example of how the experience with the product should be by producing a movie that showed the process of data logging, this video is shown on the webpage that is on the enclosed cd.

In addition to that in this chapter I will show what style the user interface is supposed to have. This is done by producing some screen shots of the interface in different situations.

*Fig. 62.* *Start and stop collection of data.*

*Fig. 61.* *This area will also provide general information from Sense software to the user. This would display things such as time elapsed and time left.*

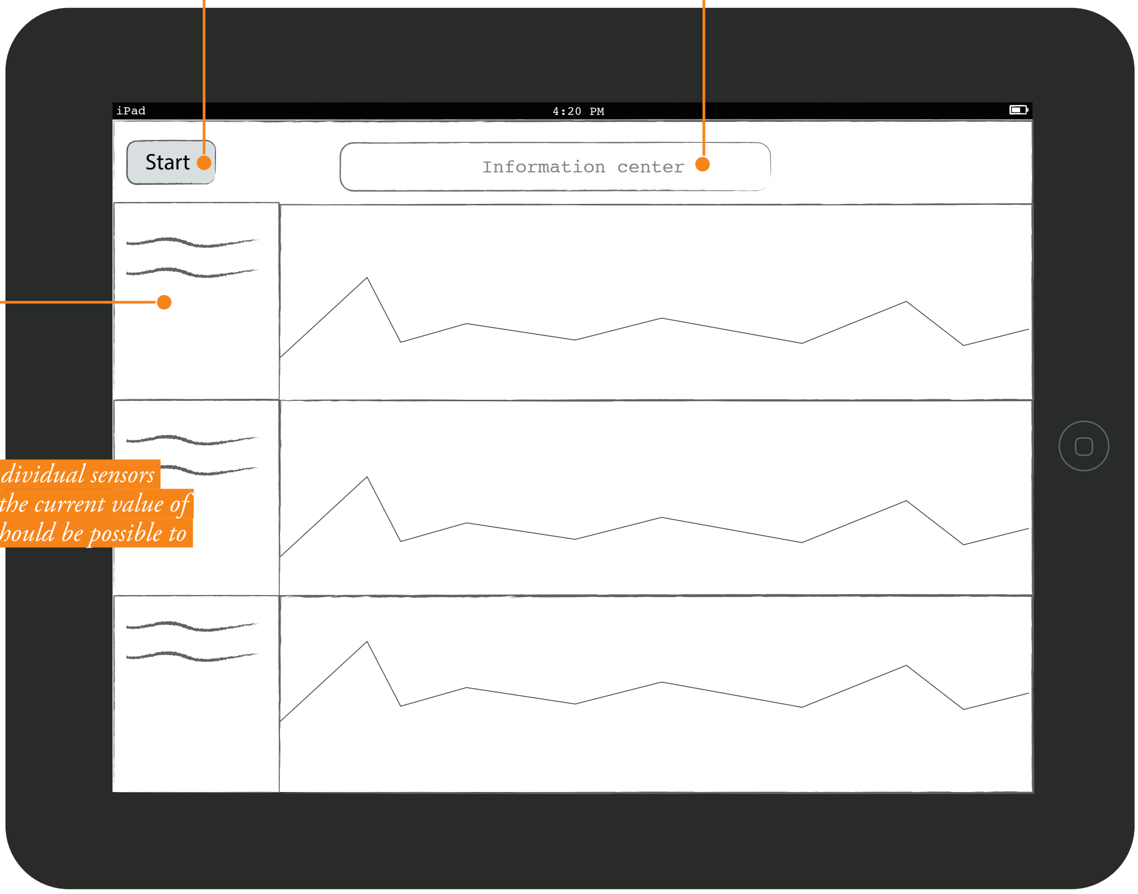
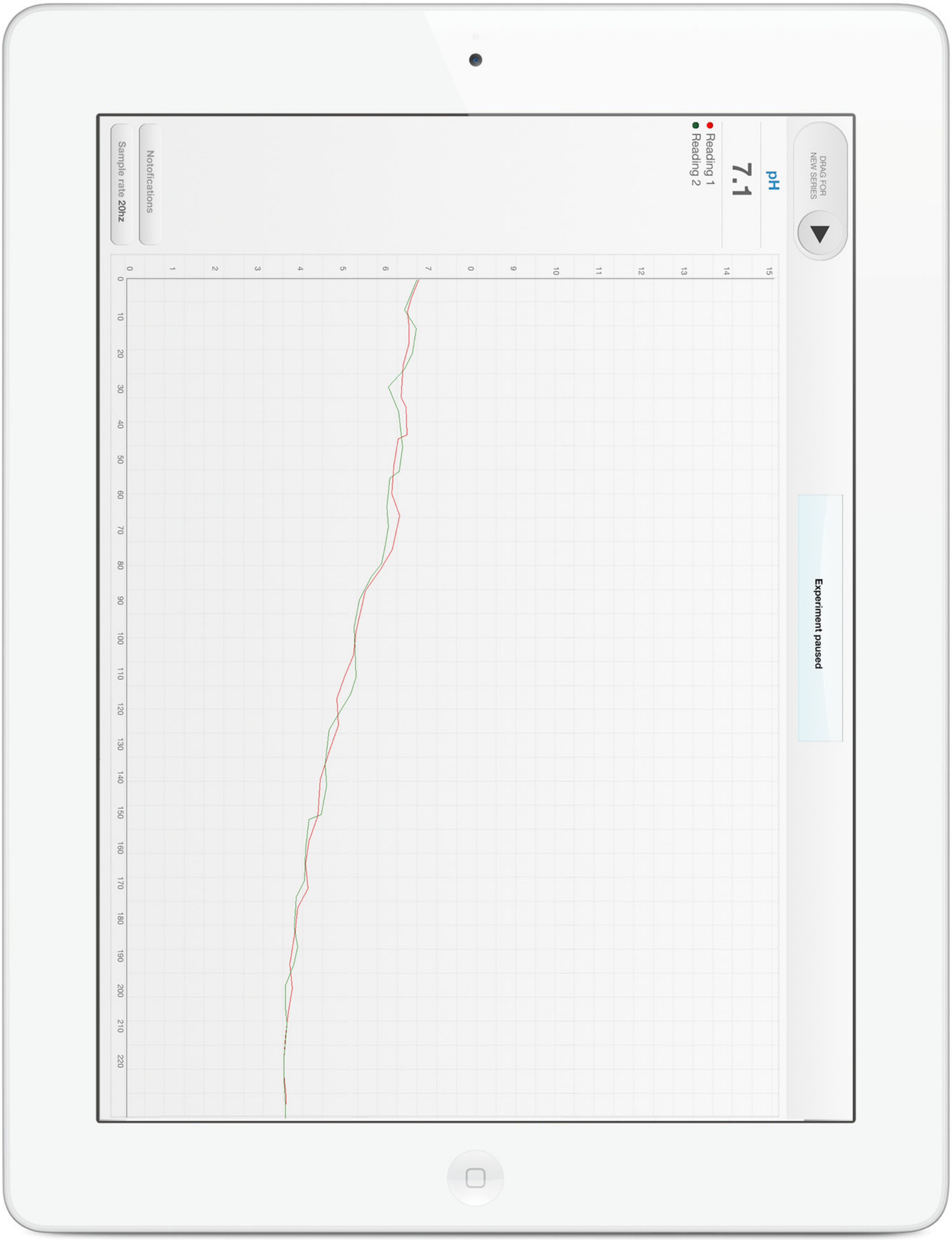



*Fig. 60.* *Information about individual sensors attached, countinuesly showing the current value of the sensor. This is also where it should be possible to calibrate the individual sensors.*


Sense
Logged into Dana's account
Log out
Experiments
Thermodynamics Experiemnt
pH measuring
Acceleration Experiment
Lecture 1
Conductivity


DRAG FOR
NEW SERIES
pH
7.1
Reading 1
Reading 2
Notofications
Sample rate 20hz
Experiment paused

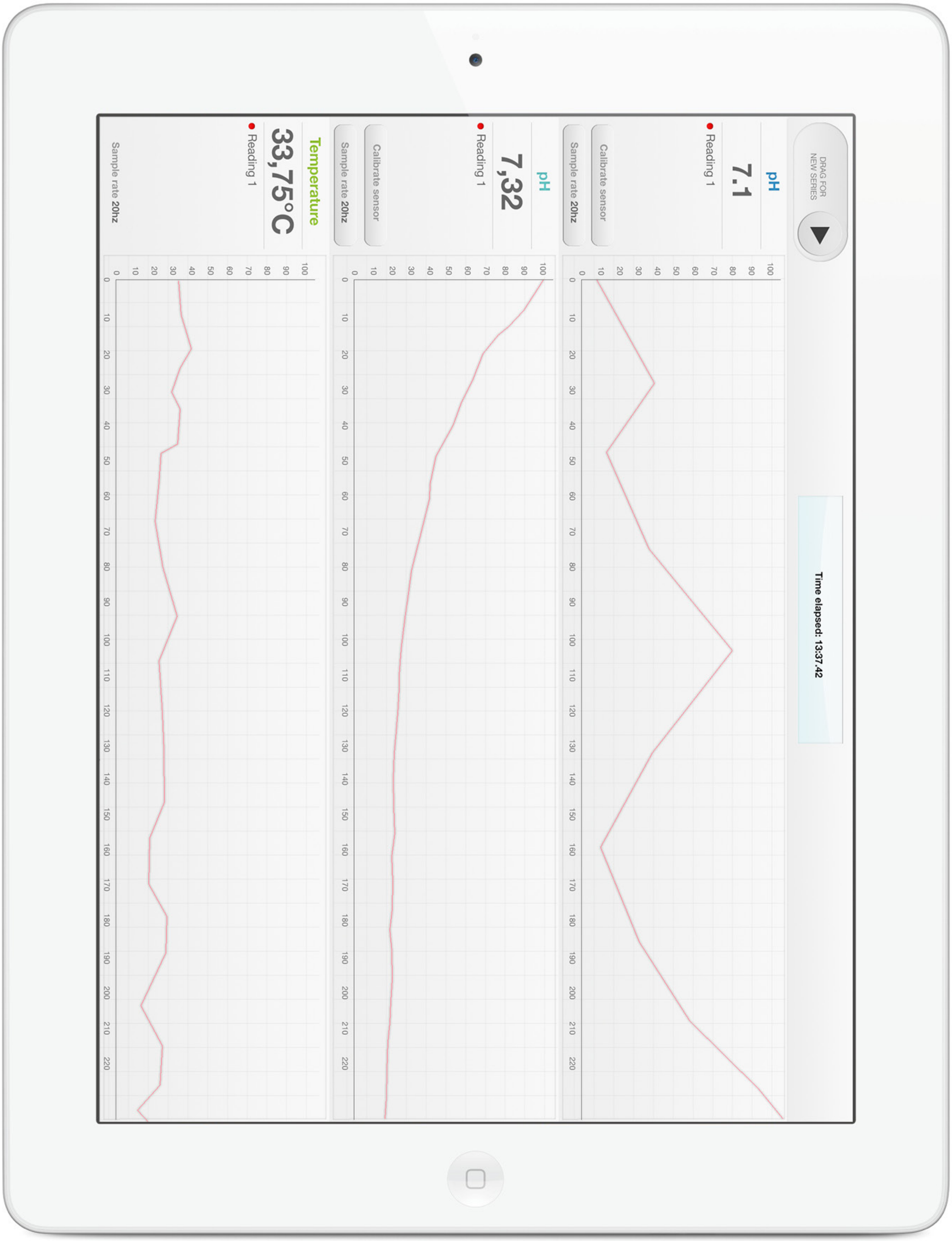
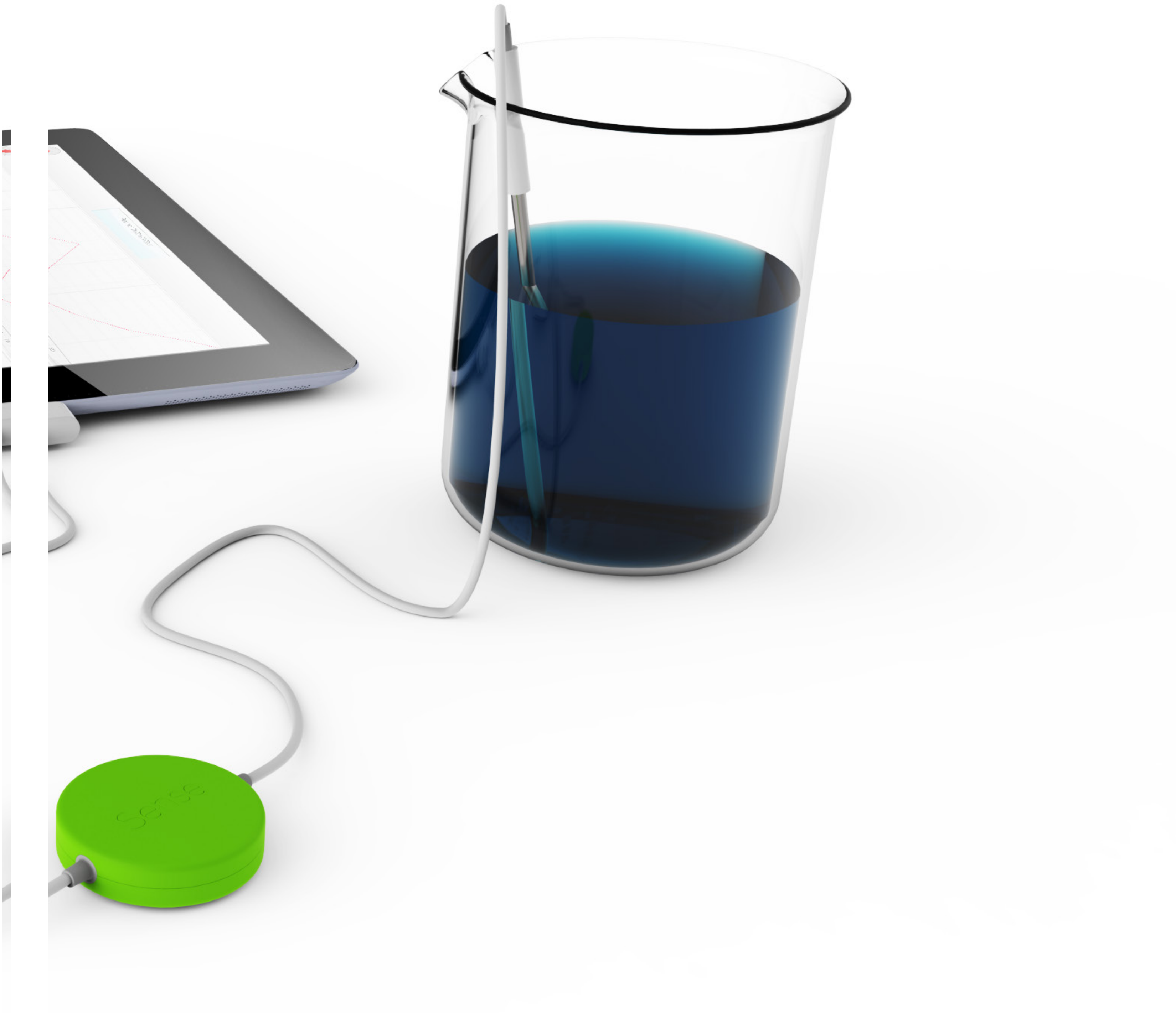

DRAG FOR NEW SERIES
pH
7.1
Reading 1
Calibrate sensor
Sample rate 20hz
pH
7,32
Reading 1
Calibrate sensor
Sample rate 20hz
Temperature
33,75°C
Reading 1
Sample rate 20hz
Time elapsed: 13:37.42

*Fig. 64.* *Now it should finally make Sense*



# Conclusion

## Process reflection

The overall concept of this project started out with an urge to learn something new, and that new should be electronics and programming for the iOS platform (Objective-C). I would like to build a product which integrated both hardware and software in order to get an understanding of how these things interconnect in a product. I focused on having a pragmatic approach learning this theory because I believe that the ‘handcraft’ should come first in order to be able to integrate the softer values in a product. Just like a carpenter gradually refine his joints to be more elegant and integrated along with being better with his tools. Ambition and result simply goes up with skill, and I believe this to be true in any situation. I believe that the best way to be better at designing products is to acquire new skills and for this project I chose to increase my skill in programming and electronics.

The problem with learning new skills is that they can be intimidating, hard, and take a very long time to even get a grasp of, which was definitely true for the learning curve on objective-c in this project. I spend a lot of time just learning objective-c without actually developing my product much further in the process. Some could say that it was a bad choice based on the fact that I probably had been able to develop my solution further if I had not tried to learn something new. But I believe that being able learning something new is just as important for an engineer as being able to utilize the knowledge which is already present.

The final product is of course more a concept than an actual product, the reason for this is that the main focus of this project never was to develop a finished product, but to learn. I have utilized all the skills within my field of study, but I have also tried to seek new grounds which is highly relevant for an industrial designer / engineer.

## Product evaluation

When working with a project it can be hard to evaluate the product when being the developer, because there is so much information on how the product should work that is just embedded in the developer, and thereby the understanding is bigger.

But what I think is a good measure of how good a concept is how other people react when the are shown and told about the product. This concept focused on the use of the product in high schools, but at written earlier it might as well just be embedded in primary schools. And that has been the reaction I got when ever I have told about the product to people. Almost anybody I have shown it too could actually see themselves using the product, no matter if they were a photographer, a chef, or a terrarium enthusiast. And I think that makes a good measure of how good the concept is, that people can see themselves use a product like this.

I order to give this project an extra push forward to production, first of all it would require professional people to evaluate the choices which have been made throughout the project. Because people that have been told about the project seem to have their own use of the project. The place to start is to make a broader analysis of to whom a product like this could make sense. Then come all the more technical decisions like electronics and the form of the final physical hardware.

## Conclusion

From the first analysis and just by being present in the society it is not possible to doubt that the iPad and other tablets are influencing peoples lives more and more. At lot a people is replacing their PCs with tablets, and this gives different businesses an opportunity to rethink their products and services, and form new businesses to evolve. In this project I have tried to design a product entirely focused on the iPad (or tablets) which is a relatively new paradigm in product development, because the tablet is such a new thing. The final solution is really a solution that is integrated with the iPad, it would not be possible to do this kind of product 5 years ago when the tablet was not as embedded as it is today, and that is a positive thing.

Even though the product is far from a production ready state, the concept is explored far enough for an investor to evaluate it, and that is from my point of view one of the main objectives in designing a product concept.

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## Illustration list

Datalogger

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3. http://eduspiral.files.wordpress.com/2012/06/lab.jpg

4-12. Own illustration

Fig. 12 http://www.fysikkemifaget.dk/uploads/tx_cliopolaroidphotoflex/ASSrenFrederiksen._07.jpg

Fig. 14: Own illustration

Fig. 15: http://dayintheclassroom.edublogs.org/files/2010/08/First-Friday_17.JPG

Fig. 16 Withings Press

Fig. 17 WeMo Press

Fig. 18 Square Press

Fig. 19 http://static2.businessinsider.com/image/4df7b6fdcadcbbf33a120000-400-300/this-unityremote-by-gear-4-will-help-your-father-keep-his-gadgets-in-check.jpg

Fig. 20 https://dlnmh9ip6v2uc.cloudfront.net/images/products/9/3/7/5/09375-1.jpg; http://thesensorconnection.com/sites/default/files/imagecache/product_full/product_files/product_images/EGT%20Probe%20EP%20Series%20Exposed%20Tip%203-16%20Probe%20Photo_Compression%20Fitting_2.jpg; http://www.phidgets.com/images/3522_0_Big.jpg;

Fig. 21 http://www.schoolsavers.com/images/Vernier_Gas_Pressure_sensor-det.jpg

Fig. 22 http://www.ibotz.com/media/catalog/product/cache/1/image/9df78eab33525d08d6e5fb-8d27136e95/l/a/labquest2-copy.jpg

Fig. 23 Own illustration

Fig. 24 http://en.wikipedia.org/wiki/File:MiniDIN-9_Diagram.svg

Fig. 25 Own illustration

Fig. 26-30 Pasco Press

Fig. 31 http://www.redpark.com/images/C2TTL-RGB-S.jpg

Fig. 32 Own illustration

Fig. 33-34 Own illustration

Fig. 35 http://2.bp.blogspot.com/-vl1tm715jBo/UB1vXl_KukI/AAAAAAAABCw/PS-Tog4sT0s/s1600/arduino_uno.png

Fig. 36 Own illustration

Fig. 37 http://www.icenternet.net/STORE/images/computer%20cables.jpg

Fig. 38 http://www.resistors-and-diodes-and-picchips-oh-my.co.uk/wp-content/uploads/2011/03/ics.jpg

Fig. 39 iRig Press

Fig. 40 http://webhydro.com/media/catalog/product/cache/1/image/9df78eab33525d08d6e5fb-8d27136e95/p/h/ph_probe_1.jpg

Fig. 41 - 64 own illustrations

Sense