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Night sky brightness sensor node appropriate for Citizen Science

IEM Bachelor's thesis

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Abstract

ScienceLinx and Forum Groningen have developed a campaign called Meet-O-Theek (MOT), where interested Dutch Northern citizens are encouraged to contribute in Science and Technology (S&T) by mapping their environment and potentially even cause action to improve their environment, trough Citizen Science. It has been argued that Light Pollution is the best succeeding MOT campaign topic with respect to S&T engagement, cost and potential source of complaint. Light pollution is an underestimated problem in our current environment, considering its serious negative impact on human health, astronomy, eco-systems and economics. With its additional aesthetic loss that most European citizens have already lost the ability to see the Milky Way with the naked eye (Chepesiuk, 2009). The existing night sky brightness (NSB) monitoring devices were analysed and it was found that none of the existing devices fulfilled all defined requirements. Therefore, this research also contributed to the development of a NSB sensor node appropriate for Citizen Science, by selecting components and defining the corresponding assembly.

Contents

Abbreviations

UoG University of Groningen

SLX ScienceLinx

MOT Meet-O-Theek

S&T Science and Technology

ALAN Artificial light at night

NSB Night sky brightness

AHP Analytic hierarchy process

LFT Light to frequency

1 Introduction

Currently ScienceLinx (SLX) feels the need to re-enthuse Dutch Northern citizens in Technology and Science, by launching a 'Meet-O-Theek' (MOT) campaign. Decline in 'interest', 'motivation' or 'attitude' in science and technology (S&T) has been a major concern for educational systems and researchers from all over the world (Potvin Hasni, 2014). SLX is an organization part of the Faculty of Science and Engineering of the University of Groningen (UoG), that tries to build bridges between students, professors and society, through attempting to transferring the spark and passion the UoG has for S&T. Citizen science projects have proven to visualize impacts on various (mostly environmental) matters and most importantly, encourage citizens to contribute and be more involved in S&T (Dickson et al., 2012). Therefore, SLX has launched the MOT based on Citizen Science; projects that engage people to deliver data on a specific topic over broad geographic regions. The main goal of the MOT is to enthuse curious Northern citizens to contribute to S&T, by mapping their own environment and possibly even cause action to improve the environment of the North of the Netherlands (Meet-o-Theek Kick-Off, 2020). After the debut of the first MOT campaign (the air pollution monitoring campaign), which already collected almost 1000 participants in the first week, a succeeding campaign has to be developed in order to maintain its success. Therefore, a new campaign topic has to be selected and consequently selection of a monitoring strategy has to be conducted.

1.1 Stakeholder analysis Meet-O-Theek

A stakeholder analysis is performed in order to define whom the stakeholders are in the MOT campaign. All stakeholders are positioned in proportion to their interest and power in figure 1. As mentioned in section 1.1. the MOT is an initiative from SLX and the Forum. Forum Groningen is a new innovative building in the city center of Groningen and is open for expeditions, films, bibliography, activities and events (Forum, 2020). Forum Groningen also has its own tech area, where it desires to make S&T accessible. Forum Groningen presents the campaign, however it is not participating in the campaign development itself. The head of SLX (Renske de Jonge) is the driving factor behind the MOT, therefor she has highest interest in the MOT. Additionally, she has high power in the project, whereas she decides on all the important end-decisions. While Renske de Jonge is the driving factor, Theo Jurriens is the executive factor called the campaign developer. In consequence, Theo Jurriens can be considered as the problem owner.

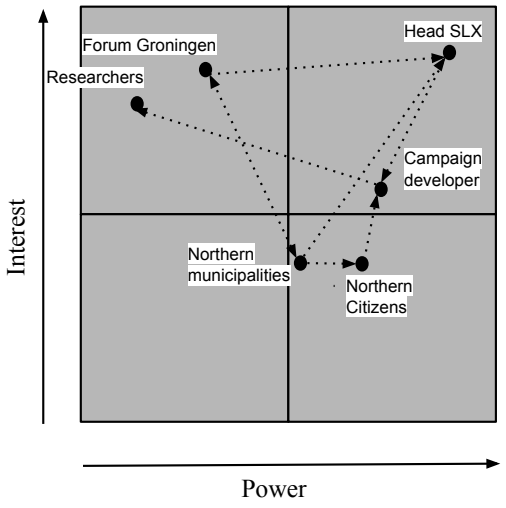

Figure 1: Stakeholder alysis

The campaign developer is influenced by Northern citizens since they will be the participants in the project. In an interview with Theo Jurriens it was argued that participation of municipalities directly results in the participation of citizens of that geographic location, as they promote the MOT campaign on their websites. Most municipalities were interested, however they expressed a fear of citizens basing complaints on the outcomes of the Citizen Science. Therefore, it is important that municipalities participate and their fear is being considered, as missing data of some geographical locations will hamper the quality of the outcomes. Additionally, the data gathered by the MOT Citizen Science projects could contribute to science (researchers).

1.2 MOT requirements according to stakeholders

By examining the stakes of the stakeholders more thoroughly, topic specific requirements could be formulated, which serve as guidance during topic selection. Theo Jurriens maintained close contact with municipalities, Renske de Jonge and Forum Groningen during the development of the previous (air pollution) campaign. Therefore, an interview (Appendix A) was conducted with Theo Jurriens in order to obtain criteria for topic selection. From the interview the most crucial criteria, which is in line with the goal of the MOT, was determined:

1. it should inform, inspire and activate Northern citizens to use Science and Technology (S&T) to be actively involved with the quality and improvement of their own environment.

Secondly, Theo Jurriens's past experience showed that, the participation barrier with respect to cost needs to be low resulting in:

2. the monitoring strategy needs to be low cost.

Thirdly, the importance of the participation of municipalities was addressed in section 1.2, municipalities do don not want to participate when the project may increases the number of complaints on an environmental topic. For example, a too high amount of radioactivity close to citizens houses may cause them to complain about their living environment. Therefore, their requirement should be taken into consideration as well:

3. the outcomes should not be a source to base complaints on.

1.3 System: Meet-o-Theek

In order to understand the problem, the system has to be explored, which is visualized in figure 2. The equipment needed for monitoring is distributed by the Forum, a website and municipalities. Curious Northern citizens buy the product and contribute to the project. In the precursor of the debut

campaign, citizens followed an approximately 1-hour installation workshop and connected the sensor node with their WiFi network. When connected, the device starts uploading data to the network, which is presented on a particular website, visualised in maps. The interested citizens and the self-service channels generate a feedback loop which has generated criteria 1, 2 and 3, explained during the stakeholder analysis in section 1.1.

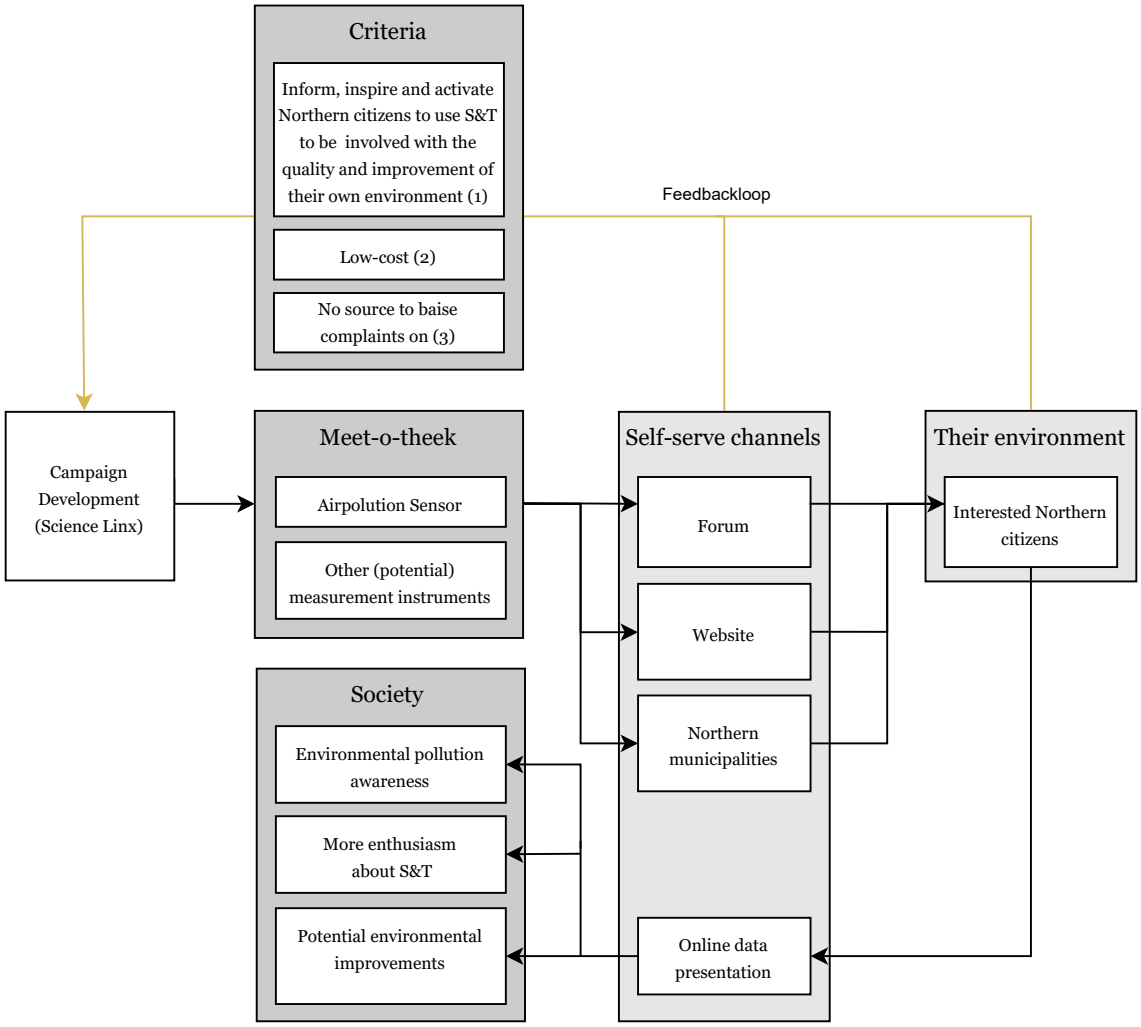

Figure 2: System diagram

1.4 Context: how to engage citizens in S&T

As the main goal of the MOT is engaging citizens into S&T, is was investigated how citizens are best engaged into S&T. “Narrative thinking” and “Romantic Understanding” have been shown adequate methods in engaging people in science (Hadzigeorgiou et al., 2019). Implying, narratives and especially stories used for the communication of the importance of particular Science related issues, engages. “Romantic understanding” is characterized by;

I. creating awareness on the human context of the issue;

II. an association with heroes and heroic qualities (creating confidence, that they too, can deal with the real world);

III. showing limits of environment and extremes of experience (provides security and confidence in dealing with reality);

IV. facing a sense of a wander (i.e., astonishment results in admiration, curiosity, and the awareness that one's knowledge is not complete, and finally;

V. revolt and idealism (i.e., contesting existing ideas).

Combining the aspects of "Romantic understanding" and storytelling results in the best engagement in science (Hadzigeorgiou et al., 2019).

1.5 Citizen Science monitroing equipment requirements

As during the campaigns of the MOT Northern citizens are enthused to contribute to a citizen science project by doing measurements themselves, some restrictions need to analysed considering measurements are being done in nonscientific locations by (mostly) inexperienced researchers. Therefore, a PACT analysis was performed, for further information on PACT, see section 4.3.1. This resulted in equipment specific requirements in figure 3.

SienceLinx	Requirements list for monitoring equipment	20-12-2020
(a) Cost price of ± 50 euro's (b) Regular measurements (c) Sent data (d) Low energy consumption (e) Water resistent (f) Withstand temperatures (g) Withstand temperatures from -10.2 until 40.7 °C (h) Easy to use/easy to install or construct		

Figure 3: Monitoring equipment requirements

1.5.1 People

The target users are interested Northern Citizens with little experience in S&T. According to Theo Jurriens (Appendix A) the first campaign gathered over 1000 participants in only one week, which was far beyond expectations.These participants bought the sensor node for a purchase price of 25 euros, and 25 euros were subsidized. It could therefore be concluded that the entry barrier for participation is low enough for a cost price of 50 euros.

a. Cost price of 50 euro's.

1.5.2 Activities

Data will be gathered by Northern citizens trough monitoring an environmental aspect in their nearby environment. The retrieved data is most valuable if it shows fluctuations geographically or over time according to Martin Stokroos (Appendix A), therefore regular measurements are needed. It is desired that the obtained data can be sent to a database immediately after measuring.

b. Regulatory measurements

c. Sent data

1.5.3 Context

As the monitoring equipment is used outside, it should be water resistant and it should withstand temperatures from -10.2 until 40.7 degree Celsius, as these were the minimum and maximum measured temperatures in 2019 (KNMI, 2019). Additionally, it should be low in energy consumption, so that the sensor node could also function on a portable battery.

d. Low energy consumption

e. Water resistant

f. Withstand temperatures from -10.2 until 40.7 °C

1.5.4 Technology

The technology used for monitoring should be easy to use, to construct and to install, considering participants have little scientific background.

g. Easy to use/install/construct

2 Problem analysis: new MOT Citizen Science campaign

Currently, SLX has not determined what environmental topic is suited for their next MOT campaign. Additionally, they do not possess knowledge on which monitoring equipment is required for the Citizen Science project (referred to as monitoring strategy). Therefore, the following problem statement could be formulated:

"Science Linx currently does not possess a validated upcoming MOT campaign topic nor the monitoring equipment appropriate for Citizen Science"

In figure 4 the why-what model explores what the main obstacles are on solving this problem and the main reasons why there is a need for a new Citizen Science campaign.

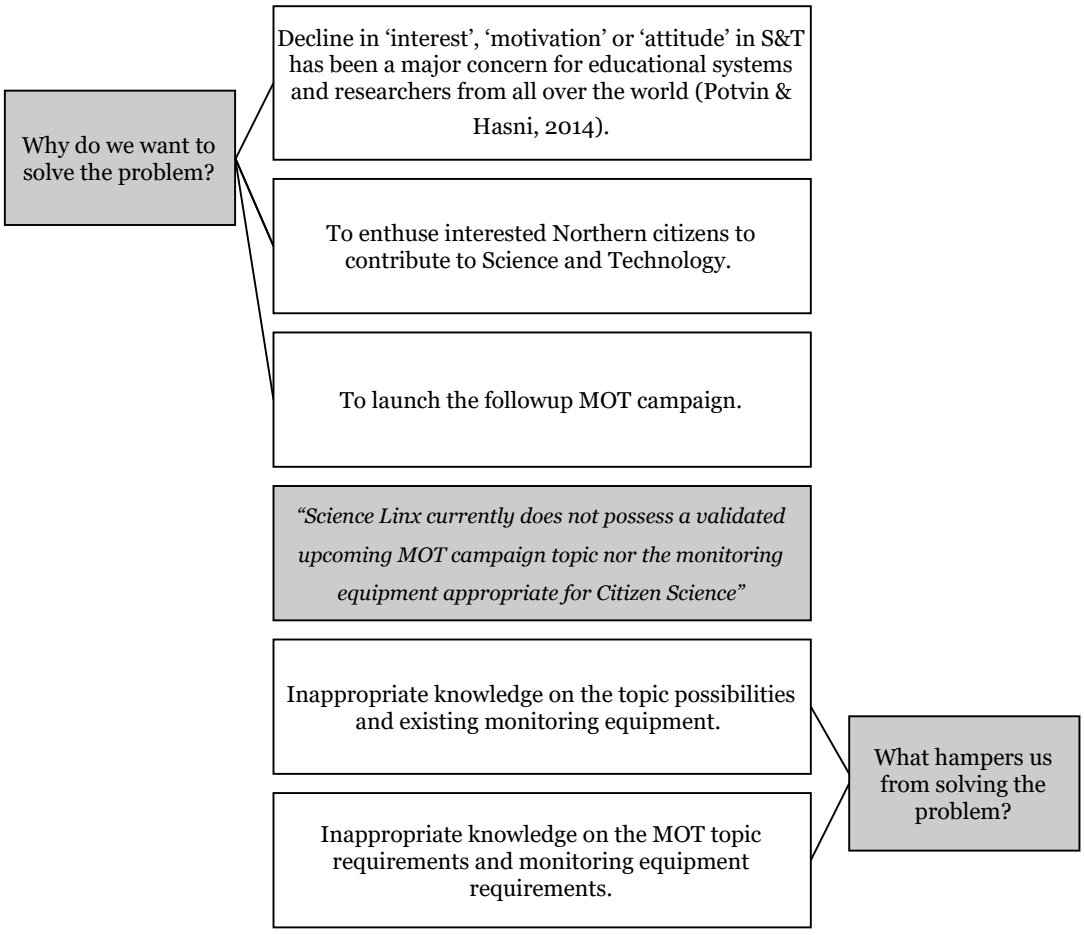

Figure 4: Why-What analysis

3 Goal: contribute to Citizen Science MOT campaign

As in chapter 2 the problem was defined, in chapter 3 the research objective is formulated and the research questions that will form a guidance during achieving the objective were formulated.

3.1 Design: campaign topic and monitoring strategy

The objective of this design is defined according to the S.M.A.R.T. principles of Bjerke and Renger (2016) and is defined as:

"To contribute to the development of the succeeding MOT campaign, ***by selecting a campaign topic and a monitoring strategy****, taking in consideration the 3 MOT requirements and equipment requirements based on literature, sensor experts and existing equipment of the last five years. The duration of the project is limited to a maximum of 2 months."*

3.2 Research Questions

In order to obtain the research objective, central and sub-research questions need to be answered. The central and sub- research questions are obtained by unravelling the key concepts (Verschuren, 2010). The research questions focus on selecting a new MOT campaign topic and selecting/developing monitoring equipment for ScienceLinx.

1. What environmental topic is best suited for the following SLX's Meet-O-Theek Citizen Science campaign?
    (a) What environmental topics could be monitored via Citizen science?
    (b) How are the 3 MOT requirements weighted in relation to each other?
    (c) Which topic has highest potential on fulfilling the requirements?
2. What monitoring equipment is required to monitor the chosen topic?
    (a) What are the monitoring equipment requirements?
    (b) What monitoring equipment does currently exists, do they fulfill all equipment requirements?

It has been argued in section 5 until 8 that Light Pollution is the most appropriate campaign topic and there currently does not exists a monitoring device that fulfills all defined equipment criteria; therefore, new research questions were formulated in order to contribute to the development of a Light Pollution monitoring device that does fulfill all criteria.

3. What features should the monitoring device have?

(a) What development board is most appropriate?

(b) What light sensor is most appropriate?

(c) What lens is most appropriate?

(d) Which filter is most appropriate?

(e) How sensor lock up by bright sunlight be prevented?

(f) How do weather circumstances influence sensor values?

(g) Which water-resistant case is appropriate?

(h) What assembly materials are needed?

4. Which software (code) is needed in order to activate the hardware as required for citizen science?

4 Technical Research Design

In this chapter it will be explained how the research objective formulated in chapter 3 will be achieved, using a research framework, strategy and methods. The followed research planning can be seen in Appendix B.

4.1 Research Framework

The research frameworks visualize the steps that need to be taken in order to obtain the research objective. Considering the research question 1 and 2 needed a different approach than 3 and 4, two research frameworks were developed. Extensive analysis of the key concepts will form requirements that can be compared to the possible MOT topics and monitoring equipment (figure 5).

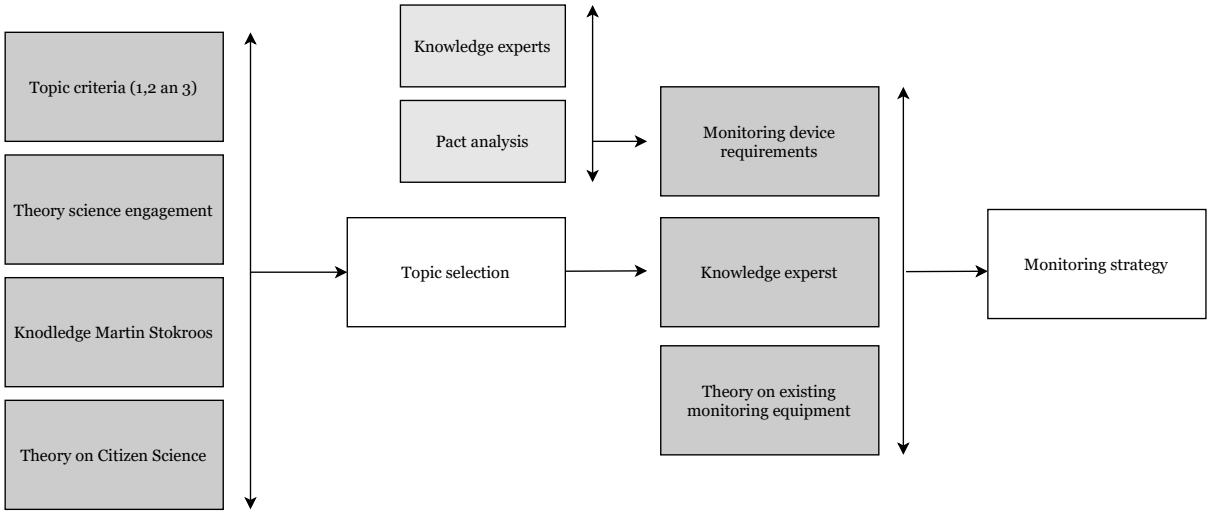

Figure 5: Research framework for research questions 1 and 2

In order to answer research questions 3 and 4, how to develop an appropriate monitoring device, a second research framework was developed, figure 6. Here once again the equipment criteria are being compared with the possible components, which forms the bases of the development of a prototype for the light pollution sensor node.

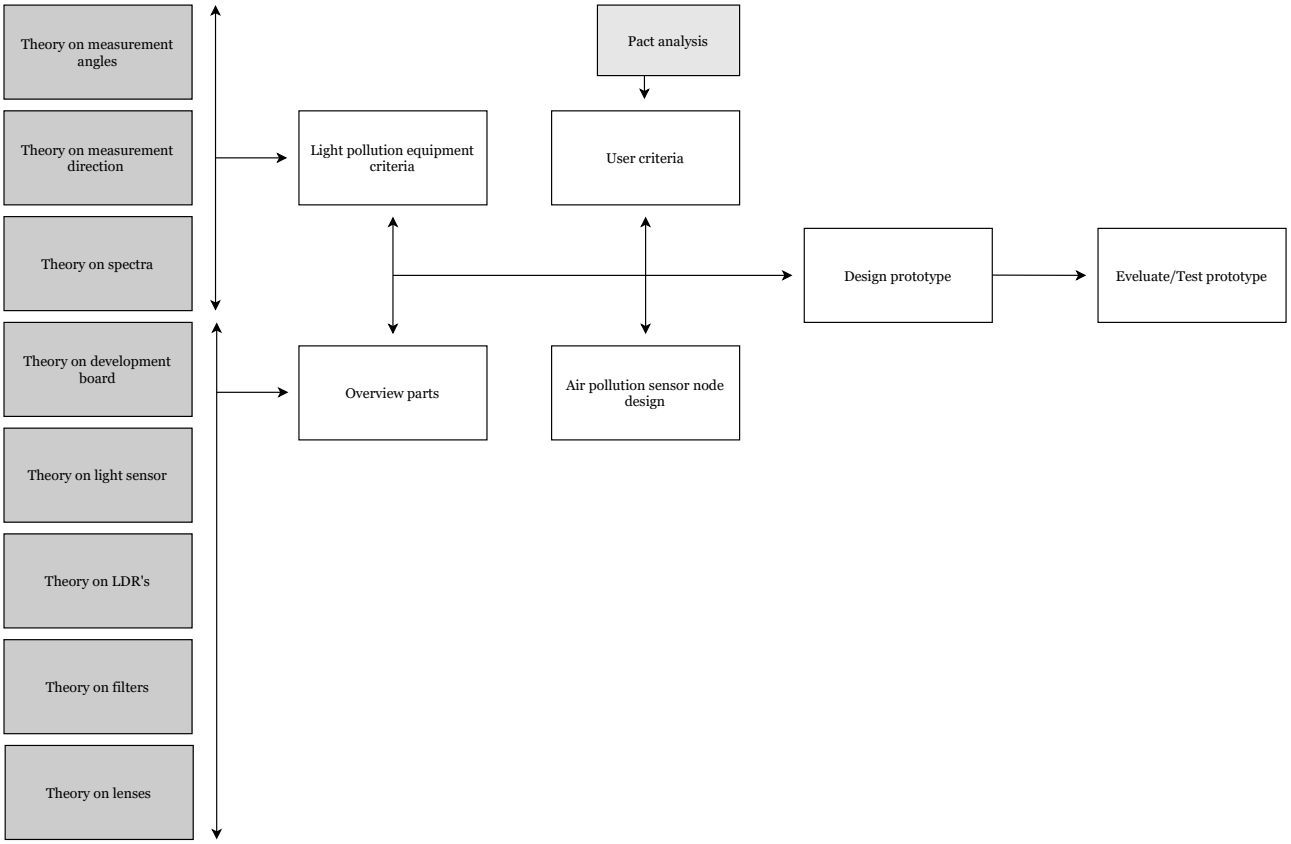

Figure 6: Research framework for research questions 3 and 4

4.2 Research Strategy

It is essential for the research strategy to determine whether the research will be broad or in-depth, qualitative or quantitative and empirical or desk research. An in-depth research will be executed to achieve complexity and elaboration, while minimizing the risk of uncertainties (Verschuren Doorewaard, 2010). The answers to the research questions will be mainly qualitative instead of quantitative since several techniques will be explained and compared. However, the comparison uses scoring matrices which does provides some quantitative results. Lastly, empirical research and desk research will be combined by reason of the combination of the usage of scientific literature and knowledge of experts.

4.3 Research Methods

The research materials and methods chosen to answer the research questions 1, 2, 3 and 4 are presented in table 1.

	Source		**Accessing method**
Question 1	People	Interviews with Campaign developer (Theo) could provide knowledge and data on the user requirements. Interviews with sensor expert M. Stokroos could provide knowledge on interesting monitoring topics.	Questioning: individual face-to-face or online
	Literature	Scientific literature could provide knowledge on existing Citizen Science topics.	Search methods
	Reality	Finding the most appropriate topic	Scoring matrix and AHP
Question 2	People	Interviews with Campaign developer (Theo) could provide knowledge and data on equipment requirements (2.a)	Questioning: individual face-to-face or online
	Reality	Analyzing people, activities, context and technologies to formulate equipment requirements. Done during problem analysis in chapter 1.5. (2.a)	PACT
	Literature	Formulate topic specific equipment requirements (2.a)	Search methods
	Literature	Scientific literature could provide knowledge on the existing monitoring equipment (2.b)	Search methods
	Reality	Comparing requirements with existing equipment	Scoring matrix and AHP
Question 3	Literature	Scientific literature could provide knowledge on all the components	Search methods
	People	Sensor expert Martin Stokroos could provide knowledge on existing techniques and assmblies	Questioning: individual face-to-face or online
Question 4	Literature and Reality	Existing codes can be considered however, will have to be adjusted or combined in order to full fill the sensor node needs.	Content analysis and self-coding

Figure 7: Research sources and methods

SienceLinx	Interviewees	20-12-2020

1. Dhr. T.A. (Theo) Jurriens – Communication adviser SLX
2. Ing. M (Martin) Stokroos – Technician Research and Education
   Specialities: electronics, control, engineering, mechatronics and robotics
3. Dr. M.C.M ((Marijke) Gordijn – Researcher human chronobiology
   Specialities: light effects on humans
4. Dr. ir. K. (Kamiel) Spoelstra – Researcher animal ecology
   Specialties: human disturbance on behavioral ecology

Figure 8: Interviewees information

4.3.1 Interviewees

An elaboration on the interviewees mentioned in figure 7, can be seen in figure 8.

4.3.2 PACT

PACT (People, Activity, Context and Technology) is an applicable approach where people are put first (human-centered) in designing interactive systems. In an enormous amount of settings people are using technologies to undertake certain activities in context. The variety of those 4 elements makes designing such a difficult but fascinating challenge (Benyon et al., 2005). In order to design it is desired to understand and thoroughly analyze the variety inherent in the elements: People, Activity, Context and Technology. As can be seen in figure 9, activities establish requirements for technologies, which will ultimately change the nature of activities.

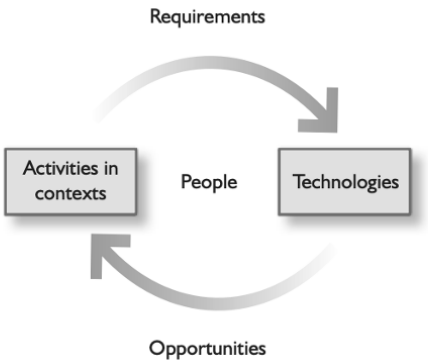

Figure 9: PACT cycle

4.3.3 Scoring matrix and AHP

During a decision-making process, the most creative task is to define the factors that are important in making that decision. Those factors are arranged in a hierarchy during the Analytic Hierarchy Process (AHP). Thereafter priority to the criteria is determined, by pairwise comparison, resulting in weighting factors. Thereafter, pairwise comparison for the “options” per criteria is performed,

resulting in priority vectors (Saaty, 1990). Combining weighting factors and priority vectors results in the weighted scoring matrix.

5 Topic selection: Light Pollution

Several potential campaign topics were formulated during brainstorm sessions with Martin Stokroos and Theo Jurriens (Appendix A), by applying a weighted scoring matrix (using the Analytic Hierarchy Process) to the potential topics and topic requirements (1,2 and 3), light pollution was determined to be the most suitable campaign topic. In this chapter the selection of light pollution is substantiated.

5.1 Hierarchy in topic requirements and candidate topics

The problem was decomposed into a hierarchy in figure 10. In the top level the overall goal is presented: "satisfaction with MOT topic" indicating that the aim is finding the topic that generates the highest satisfaction towards all stakeholders. In the middle level the criteria's formulated during the stakeholder analysis in section 1.1 are presented, which contribute to the goal. The candidate topics, formulated during interviews with Martin Stokroos and Theo Jurriens on 2nd and 3rd of October 2020 (Appendix A), which are presented in the bottom level. The MOT topic campaign requirements are once more cited underneath.

(1) S&T engagement; it should inform, inspire and activate Northern citizens to use Science and Technology (S&T) to be actively involved with the quality and improvement of their own environment

(2) Low cost; since participants need to pay for the monitoring equipment the price should be as low as possible, in order to maintain a low entry barrier.

(3) No source of complaints; municipalities do not want to participate when citizens could base serious complaints related to the citizen science project.

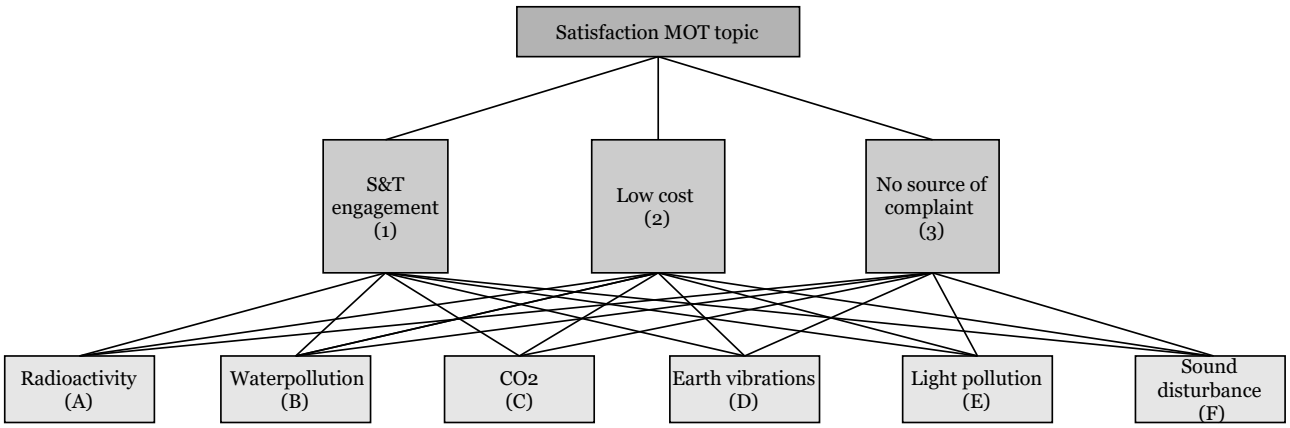

Figure 10: Hierarchy topic selection

5.2 Weighted scoring matrix results in Light Pollution

As can be seen in table 1, light pollution obtained the highest priority vector with a score of 26/100, therefore light pollution was selected to be the best suited topic for the upcoming MOT campaign. The weighted scoring matrix was obtained by pairwise comparison of the requirements and the pairwise comparison of the potential topics per requirement.

S&T	*1: S&T Engagement (0.5)*	*2: low cost (0.25)*	*3: complaint (0.25)*	*Priority vector*
A: Radioactivity	0.10	0.3177	0.0403	14%
B: Water pollution	0.30	0.1113	0.0996	20%
C: CO2 pollution	0.10	0.0308	0.0996	8%
D: Earth vibration	0.10	0.3177	0.0115	16%
E: Light pollution	0.30	0.1113	0.3227	26%
F: Sound disturbance	0.10	0.1113	0.3227	16%

Table 1: Weighted scoring matrix requirements versus candidate topics

5.3 Weighting factors

The weighting factors shown in table 2, are based on the interview with Theo Jurriens (Appendix A) and the MOT website that both highly address the importance of criteria 1. The weighting factors for the requirements were generated by pairwise comparison judgement, all pairwise comparisons done in this chapter are done according to the scale (Appendix B) developed by (Saaty &Katz, 1990).

	1: S&T engagement	*2: Low cost*	*3: Complaint*	*Weighting factors*
1: S&T engagement	1	2	2	0.5
2: Low cost	1/2	1	1	0.25
3: Complaint	1/2	1	1	0.25

Table 2: Spairwise comparison for the middle level (weighting factors)

5.4 Potential to engage in S&T

To determine to which degree the topics will cause engagement into S&T the theory on "Narrative thinking" and "Romantic Understanding" as explained in section 1.5 is being used(Buytaert et al., 2014). A checklist on the aspects of the theory versus the topics (table 3) substantiates the pairwise comparison in table 4.

S&T	*a: human context*	*b: heroic qualities*	*c: limits environment*	*d: wander*	*e: revolt & idealism*	*f: story telling*	*Total*
A: Radioactivity	x		x			x	3
B: Waterp-	x		x	x		x	4
C: CO2	x	x	x				3
D: Earth v-	x		x			x	3
E: Light p-	x		x	x		x	4
F: Sound d-	x			x	x	x	3

Table 3: Checklist on degree of fulfilling Narrative thinking and Romantic understanding.

S&T	*A: Radio-activity*	*B: Water pollution*	*C: CO2*	*D: Earth vibrations*	*E: Light pollution*	*F: Sound disturbance*	*Priority vector*
A: Radioactivity	1	1/3	1	1	1/3	1	10%
B: Waterp-	3	1	3	3	1	3	30%
C: CO2	1	1/3	1	1	1/3	1	10%
D: Earth v-	1	1/3	1	1	1/3	1	10%
E: Light p-	3	1	3	3	1	3	30%
F: Sound d-	1	1/3	1	1	1/3	1	10%

Table 4: Pairwise comparison matrix of S&T engagement

5.5 Potential to be low cost

To develop the cost matrix in table 5 a quick literature analysis had to be performed. Since it is relatively hard to develop exact cost prices an estimation was being made based on the most prevailing Citizen Science projects per topic, stated in the sections 5.5.1 – 5.5.5.

Cost	*A: Radioactivity*	*B: Water pollution*	*C: CO2*	*D: Earth vibrations*	*E: Light pollution*	*F: Sound disturbance*	*Priority vector*
A: Radioactivity	1	3	9	1	3	3	31.77%
B: Waterp-	1/3	1	4	1/3	1	1	11.13%
C: CO2	1/9	1/4	1	1/9	1/4	1/4	3.08%
D: Earth v-	1	3	9	1	3	3	31.77%
E: Light p-	1/3	1	4	1/3	1	1	11.13%
F: Sound d-	1/3	1	4	1/3	1	1	11.13%

Table 5: Pairwise Comparison matrix of costs

5.5.1 Radioactivity (A)

Most radioactivity Citizen Science project are performed by participants collections samples from their environment. Participants prepare samples and perform preliminary analyses. Thereafter, research institutes do further compilation and analysis, like in Sweden during the autumn of 2018 (Andersson-Sundén et al., 2019).

5.5.2 Water pollution (B)

The advent of cheap and low maintenance water quality sensing equipment, provides valuable opportunities for Citizen Science projects (Buytaert et al., 2014).

5.5.3 CO2 pollution (C)

Several research institutes have difficulty finding a balance between low-costs and appropriate reliability for CO2 sensors (theconversation., 2015). The existing commercial CO2 sensors are approximately priced around 100 euro's (Dataloggers.Shop, 2020).

5.5.4 Earth vibrations (D)

Recently it has been shown that seismograms converted to audible frequencies can be used in detecting earthquakes, which enables earth vibrations monitoring without every citizen needing a seisometer (an instrument that responds to ground motions) (Huihsuan Chen et al., 2020).

5.5.5 Light pollution (E)

Contrary, light pollution monitoring has high potential to be low cost. Considering the existence of an award winning 2 euro night sky brightness monitoring app (Grove, 2001), an attempt (Zamorano et al., 2017) to decrease the price of the only exiting commercial night sky brightness monitoring device; The Sky Quality Meter (SQM) (Hänel et al., 2017) and UoG student N.Visser whom designed a darkness monitoring method using a toilet paper roll.

5.5.6 Noise pollution (F)

Noise pollution can be easily monitored by inexpensive smartphone apps or noise sensors (Maisonneuve et al., 2009).

5.6 Potential to cause no complaints

The comparison matrix in table 6, is based on three categories; topics already receiving complaints, having influence on citizens direct environment, having no direct or sever influence on citizens direct environment, resulted in Light Pollution and Sound Disturbance to have the least chances on complaints. Firstly, the topics that are already known for receiving complaints are assumed to have the highest risk of again receiving complaints in response to the Citizen Science outcomes. Thereafter, the topics having severe negative influence on citizen's environment are ranked. Leaving the topics having little impact on the citizens environment as the best option.

5.6.1 Topics already receiving complaints

In the North of the Netherlands there exist over 15.000 complaints about damage caused by earthquakes (Trouw, 2019). Also, there is a rising number of complaints about transmission towers and WiFi since, people strongly believe the radiation caused by it has terrific influence on their health (van Rees, 2018).

5.6.2 Topics influencing citizens direct environment

Water pollution and CO2 exposure negatively influence citizens environment. Since, water pollution in ditches and lakes causes garden plants get ill or even die (Deltawerken, 2004) and the large variation

Complaint	*A: Radioactivity*	*B: Water pollution*	*C: CO2*	*D: Earth vibrations*	*E: Light pollution*	*F: Sound disturbance*	*Priority vector*
A: Radioactivity	1	1/3	1/3	1	1/7	1/7	4.03%
B: Waterp-	3	1	1	3	1/4	1/4	9.96%
C: CO2	3	1	1	3	1/4	1/4	9.96%
D: Earth v-	1	1/3	9	1	1/7	1/7	11.50%
E: Light p-	7	4	4	7	1	1	32,27%
F: Sound d-	7	4	4	7	1	1	32,27%

Table 6: Pairwise comparison matrix of potential of complaint

of CO2 exposure human health effects, elaborately explained in scientific and medical literature (Rice, 2003).

5.6.3 Topics not having a severe influence on environment

This results in light pollution and sound disturbance being the best option in terms of complaint potential. The topic sound dissturbance was namely focused on the decrease of train noise and would therefore only benefit citizens environment. Aditionally, light pollution has effects on human's health but not severe (Coogan et al., 2020).

6 Introduction to Light Pollution

In this chapter background information on the selected topic, light pollution, will be provided in order to ensure proper knowledge for understanding the rest of the paper.

6.1 Light Pollution

Along with the massive industrialization during the past decade, an unintended, unwanted and obtrusive issue arose, namely: "light pollution". This is a result of the ever-increasing artificial light and bad light design (Olsen et al., n.d.). This does not implies that Artificial Light at Night (ALAN) is inherently bad. ALAN has brought many benefits to society, for instance, possibility to extend working times, not just offering more time for working but also more time for recreational activities. However, when the ALAN becomes annoying, inefficient and unnecessary, it is defined as light pollution. According to Amanda Gormley of the International Dark-Sky Association is the disappearance of the night sky tied up in our ever more fast-paced world (Drake, 2019). While, 83% of worlds populations is living under light-polluted skies (Drake, 2019), there is very little awareness on the negative impacts of light pollution.

Light pollution can take different forms, including the most common "sky glow" and "glare". The bright halo appearing over urban areas at night is called sky glow, caused by light being scattered by particles and water droplets in the air (Chepesiuk, 2009). Glare is created by horizontally shining light.

6.2 Light Pollution effects for engagement

This section elaborates on how light pollution is harming today's environment and how this campaign topic will create environmental pollution awareness. Citizen Science is known to be a valuable method to create awareness on a specific topic (Turrini et al., 2018). However, apart from the generated data, additional information will have to be provided during the campaign, to create the desired awareness and engagement. By creating awareness, the potential of improvement arises. For instance, when Natuur Milieufederatie Nederland confronted large offices in Amsterdam with the effects of their generated ALAN, they were all shocked and said to be open to change (Meijer, 2020). A cross-sectional survey in the United States showed that motivation for voluntary mitigation is mostly based on personal perspective, for example health threats (Semenza et al., 2011). Explaining the human context creates engagement into S&T as explained in section 1.5 (Hadzigeorgiou et al., 2019). Apart from the aesthetic loss Europeans not being able to see the Milky Way with the naked eye (Chepesiuk, 2009), the improper and imprudent shielding of lighting also has negative effects on humans, animals and ecosystems (Longcore Rich, 2004). Additionally, it burdens society with unnecessary costs of wasted energy.

6.2.1 Ecological

According to Longcore & Rich (2004), light pollution has two main effects on ecology: animals are repulsed or attracted by glare and experience increased disorientation or orientation from the generated light, which affects communication, reproduction, foraging and other critical behaviors. Interspecific interactions involved in natural patterns of dark and light are disrupted, which has serious impact on ecosystems. For example, night butterflies are attracted by glare and thereby become too visible for their predator's. As a result, the night butterfly almost extinct in the Netherlands (Meijer, 2020). From the 50 million migratory birds that fly across the North Sea, 6 million birds get lost because of the ALAN generated by drilling platforms (Meijer, 2020). Additionally, sea turtles have returned for decades to the beaches where they were born, to lay their own eggs. It often occurs that those beaches are brightly lit at night, which causes females to get disoriented and wander onto roadways; or they are even discouraged from nesting. Whenever the turtles do nest, their hatchlings navigate towards the artificial light source, instead of the sea (Chepesiuk, 2009).

6.2.2 Human

For humans the effects of light pollution at night are associated with, reduction in sleep quality, decreased sleep times, obesity, impaired daytime functioning and excessive sleepiness. Caused by the changes in light regimes away from the circadian rhythm (biological clock) (Chepesiuk, 2009). Due to the disruption, the melatonin production is hampered. Since melatonin is an anti-oxidant capable of removing radicals, the disruption may increase the risk of prostate and breast cancer (Deharo et al., 2014). Additionally, the impact of light pollution on sleep patterns causes people who carry a genetic risk of bipolar disorders to potentially be at greater risk of full-blown bipolar disorders (Carta et al., 2018).

6.2.3 Astronomy

Darkness is disappearing because of the artificial light that is either reflected or directed upward (Piselli, 2006). When the night sky is not dark enough, stars and other celestial bodies can not be seen by the naked eye nor by the most expensive telescope.

6.2.4 Energy

The United states wastes billions of dollars annually on energy of lamps with poorly directed lighting. Many photons shine directly upwards and do not contribute to improving, visibility, security, or safety (Scott Kardel, 2012). On Texel an experiment was performed with streetlights containing moving sensors, which resulted in up to 70% of energy savings (VVV Texel., 2016). Energy savings can be generated when better designing lightning, having less useless photons shining upward (figure 11). Additionally, many ALAN is generated to create a "safe" image for instance, at offices. It is being

estimated that annually 536 million kWh (energy consumption of 150.000 households) of electricity can be saved when Dutch offices shut down their lights after office hours. (Natuur en Milieufederaties, 2020).

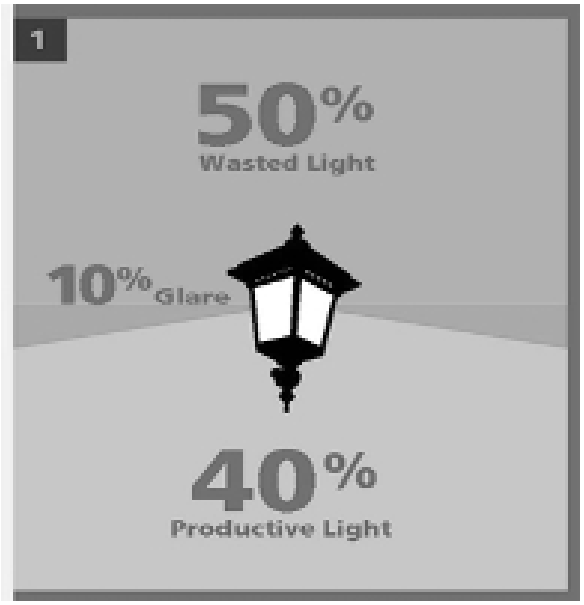

Figure 11: Lighting design

7 Requirements for the Light Pollution monitoring device

Succeeding the PACT analysis performed during the problem analysis, the monitoring device requirements need to be further specified while focusing on the selected MOT topic: light pollution. Therefore, the variable, unit, spectrum, dimension, direction and angle to be measured should be defined. Resulting in an updated monitoring device requirement list.

7.1 Monitoring variable and unit selection

Light pollution can be monitored by measuring night sky brightness/luminance. Night Sky Brightness is the best indicator of sky glow, as it takes in consideration both ALAN and starlight (Cinzano et al., 2001). Therefore, NSB will be measured by the sensor node which needs to be designed. Sky brightness can be measured by two parameters: radiance; how bright an area in the view appears and irradiance; the total amount of electromagnetic radiation falling on a surface. The radiance per unit wavelength is called spectral radiance. The spectral response from a photometric instrument can vary from the human visual system, meaning it measures more than can be seen by the human eye. When the spectral response perfectly matches the human vision, radiance is called luminance in popular terms 'brightness' and irradiance is called illuminance. Astronomers measure brightness in the astronomical magnitude system mag/arcsec^2 (Hänel et al., 2017). This is a complex unit of measurement; it takes into account the absolute magnitude of one star measured in a small square area a side of one arcsecond. These magnitudes vary from -7 of bright day light, to 22-23 on the darkest place on earth (Studi et al., 2013). So:

h. The sensor has to measure NSB in mag/arcsec^2.

7.2 Spectrum selection

Astronomers measure light in different wavelength, called spectra (Bessell & Bessell, 2005). The effects of light pollution as mentioned in section 6.2, are based on behavioral changes caused by the visible light pollution. Although, there are animals that are effected by UV or IR light, like bats (Straka et al., 2019), choosing a too wide measuring band hampers accuracy (de Miguel et al., 2017). Therefore de Miguel et al., (2017) recommends measuring within the visible spectrum. Additionally almost all tools existing for NSB monitoring do measurements on visible wavelengths (Hänel et al., 2017) Therefore:

i. the sensor has to measure in the visible spectrum.

7.3 One dimensional or two-dimensional measurements

In the spectrum of night sky brightness measurement methods, one dimensional and two-dimensional measuring instruments do exist. One dimensional instruments measure the sum of both the sky

background-brightness and the stars within the viewing field. Contrary, two dimensional instruments are capable of measuring sky luminance and background luminance by analyzing wide angle images (Hänel et al., 2017). Two dimensional instruments are generally bigger and more expensive instruments (Hänel et al., 2017), which does not suit Citizen Science. Concluding:

j. the sensor has to do one dimensional measurements

7.4 NSB Measuring direction

The disruption in measurements is the least when measuring from zenith (Birriel & Adkins, 2010); measuring the imaginary point directly above the observer on the celestial sphere, illustrated in figure 12. So:

k. the sensor has to measure from Zenith

7.5 NSB Measuring angle

When a too wide measuring angle is used scattered light from nearby sources can dominate over the sky brightness (Hänel et al., 2017). Research has been done in the relation of the night sky brightness and the distance to zenith for instance, Birriel & Adkins (2010) and Green Stein & Observatory (1937) both experimented and generated a graph where the night sky brightness in mag/arcsec^2 was plotted as a function of the zenith angle. It could be concluded that the brightness increased significantly from wider angles than 30 degrees, because then it starts measuring artificial light (mostly in suburban area's) sources directly, like streetlights and buildings. During this research the darkness of the sky is desired to be measured, therefore disruptive light sources need to be ommited. To conclude:

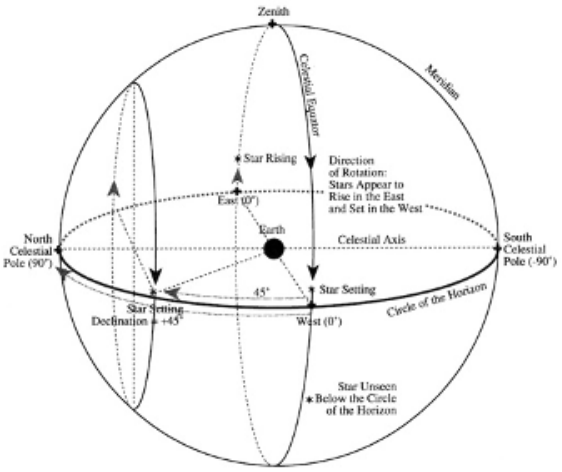

Figure 12: Celestial sphere, Zenith visualized

l. a measuring angle 40 degrees from Zenith.

7.6 Accuracy

During a follow-up interview with Theo Jurriens (Appendix A) after topic selection, it was specifically mentioned that accuracy is of great importance, in order to make the Citizen Science project academically relevant. Also, in chapter 12 (validation), it shows that an accurate light sensitive low-cost sensor node would contribute to research in Light Pollution. So:

m. an accuracy of ±0.1 mag/arcsec^2; equal to the only other commercial NSB sensor available on the market the SQM (Hänel et al., 2017).

7.7 Accurate under dark circumstances

As the goal is measuring the brightness of the night sky, the measurements will have to be performed during times when the sun is set. Therefore, the sensor monitoring the brightness will have to be very accurate under dark circumstances.A range in which accurate measuring needs to be done was set. According to table 7 mag/arcsec^2 values for night sky lie between 12.9-21.8.

n. Be so light sensitive to measure accurate between 12.9-21.8 mag/arcsec^2

Condition	Surface illuminance	Zenith sky luminance (mcd/m^2)	Zenith radiance (mag$_{SQM}$/arcsec^2)
Overcast natural night	< 0.6 mlux	< 0.2	> 21.8
Natural starlit night	0.6–0.9 mlux	0.2–0.3	21.4–21.9
Bulge of the Milky Way	N/A	2.71	20.5–21.0
Maximum value of 50% moon at zenith	25 mlux	N/A	N/A
Typical summer full moon	50–100 mlux	N/A	N/A
Maximum value of full moon at zenith	320 mlux	N/A	N/A
Rural night sky (clear, no moon)	0.7–3 mlux	0.25–0.8	20.3–21.6
Rural night sky (overcast)	0.7–9 mlux	0.25–2.7	19.0–21.6
Suburban night sky (clear)	2–45 mlux	0.75–14	17.2–20.4
Suburban night sky (overcast)	6–140 mlux	2.1–43	16–19.3
Urban night sky (clear)	7–65 mlux	2.3–21	16.8–19.2
Urban night sky (overcast)	30–550 mlux	9–170	14.5–17.7
End of nautical twilight (clear)	8.1 mlux	1.9*	19.4
End of civil twilight (clear)	3.4 lux	450*	12.9
DIN or CIE suggested street values	2–30 lux	0.3–2 cd/m^2	N/A
Extremely overlit street	70–150 lux	10 cd/m^2	N/A
Overcast day	100–2000 lux	32–640 cd/m^2	5.6–8.8
Direct sunlight	129,000 lux	N/A	N/A

Table 7: Typical brightness values (Hänel et al., 2017)

7.8 Continuous measurements

In addition to the previous requirement Theo Jurriens (Appendix A) brought up the need for continuous measurements instead of manual measurements. In line with the quotation from Martin Stokroos (Appendix A); “data is most valuable when it is being measured consistently from a high variation of geographic locations, because then fluctuations can be monitored and from fluctuations we learn”. Substantiated by the dependence of continuous collection of accurate data on commitment and motivation of participants (Shinbrot et al., 2020). In water-monitoring programs it was found maintaining

group motivation is hard, resulting in participation dropouts (Njue et al., 2019). Therefore requirement b is changed to:

b. continuous instead of manual measurements

7.9 Summarization: updated requirement list

The requirements for a Citizen Science sensor node are analyzed in section 1.5, after a summary and addition of the NSB sensor node specific requirements, the requirement-list has been updated and visualized in figure 13.

SienceLinx	Requirements list for light pollution monitoring equipment	20-12-2020

a. Cost price of ± 50 euro's
b. Continuous measurements
c. Sent data
d. Low energy consumption
e. Water resistent
f. Withstand temperatures from -10.2 until 40.7 degree Celsius
g. Easy to use/easy to install or construct
h. Measure NSB in mag/arcsec2.
i. Measure in the Visible spectrum.
j. Do one dimensional measurement
k. Measure from Zenith
l. Have a measuring of angle 40 degrees
m. Accuracy of at least ±0.1 mag/arcsec 2 (equal to SQM)
n. Measure accurate between 12.9-21.8 mag/arcsec2

Figure 13: Requirements list for NSB monitoring equipment

8 Existing monitoring devices vs requirements

Using a checklist (table 8), it was found that there does not exist a monitoring device that fulfills all NSB monitoring requirements, especially focused on Citizen Science. Therefore there is a need for a new sensor node. The existing methods and tools available for NSB monitoring will be examined with respect to the formulated NSB requirements in figure 13.

	a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*	*m*	*n*	*Total*
Satellite		x	x		x	x		x	x					x	7
Toilet roll	x			x			x	x	x	x	x			x	8
Sky meter app	x			x		x	x	x	x	x	x			x	9
Solar-cell-based				x					x	x	x		x		5
SQM		x		x		x	x	x	x	x	x	x	x	x	11
Lux meter				x	x	x	x	x	x	x	x				8

Table 8: Checklist of monitoring equipment requirements and monitoring methods

8.1 Satellite

Satellites have contributed significantly to the understanding of the distribution and amount of light pollution around the globe. However, there has not yet been found a solution for the saturation of the detectors because of the sensing of very bright light coming in from cities (Barentine, 2020). Additionally, satellites are not capable of measuring sky glow (light reflected by aerosols).

8.2 Toilet paper roll

N. Visser (2020), an astronomy student from the UoG, has developed a method where the brightness in mag/arcsec^2 can be determined by the usage of a toilet paper roll. However, those visual based observations do not allow accurate measurements. Visual observations on average lower the measuring precision with ±1.2 mag/arcsec^2 (Kyba et al., 2013).

8.3 Sky meter app

An iPhone app that uses the back camera of the iPhone to determine the brightness of the sky by taking two pictures. The data obtained is immediately submitted to the globe at night database (Hänel et al.,

2017). This method is based on the fact that every camera has a ccd or cmos sensor, that response linearly with respect to the light that falls on the sensor surface. All phones that can download the app, may have different technologies and sensors each with a different sensitivity. Generalization is practically impossible because of this heterogeneity (Studi et al., 2013).

8.4 Solar-cell-based light meter

Normally a solar-cell is used to convert light into electrical energy. There exists a current flow because of the caught light. This flow is measurable and linearly proportional to the light that is caught by the surface of the panels (Hänel et al., 2017). However, this method entails the same problem as the app, the normalization process is complex to achieve (Studi et al., 2013).

8.5 Sky Quality Meter (SQM)

SQM was developed to measure NSB for amateur astronomers. However, major drawbacks are the unavailability of doing measurements continuously and the relatively high prices starting from 150 euro's. Also, it is only capable of showing the results on a display instead of sending the data to a database. Despite, that it is the most used NSB sensor used for several NSB studies (Hänel et al., 2017). The manufacturer claims the SQM to have an accuracy of ±10% corresponding to ±0.1 mag/arcsec

8.6 Lux meters

Lux meters are widely used during light-regulation and photography, they measure the light that falls on the sensor (Studi et al., 2013). Normally these Lux meters achieve the highest accuracy under high amount of light circumstances and therefore lack accuracy in darker circumstances (Studi et al., 2013). Although there are lux meters capable of measuring accurate under low light circumstances, they are still very expensive (Hänel et al., 2017).

8.7 Conclusion: need for new NSB sensor node

When analyzing the existing methods for NSB monitoring and combining the outcomes with the requirements for a Citizen Science sensor node, it can be concluded that there does not yet exist a monitor which could do continuous measurements, is low cost and has a sufficient accuracy. Therefore, the following sections will elaborate on the development on a prototype NSB sensor node that does fulfill all requirements. The SQM scores best in table 8 and is therefore considered as best alternative.

9 Component selection prototype

Since in chapter 8 it has been argued that currently there does not exist a low cost NSB sensor node appropriate for Citizen Sience, in this chapter the components needed for the development of a NSB sensor node prototype are selected. The prototype has been developed based on a Sky Quality Meter Arduino Do It Yourself project named mySQM (Brown, 2017), however adapted to fulfill the needs of a NSB Citizen Science sensor node. Figures of all selected components can be found in Appendix D and a purchase list can be found in Appendix B.

The AHP scoring matrix method explained in section 4.3.2 and used for the topic selection was also used for the component selection.

9.1 Hierarchy component selection

The hierarchy of the requirements and the components, is visualized in figure 14. Not all requirements are applicable to all components, therefore scoring matrices are developed with the applicable requirements per component. In figure 14 it has been visualised which requirements are applicable to which components.

9.2 Weighting factor requirements

All requirements are equally important except for a: cost and n & m: accuracy (table 9). Whenever a component is being chosen because it is a lot more inexpensive, while it results in inaccuracies, the sensor will be hampered in its main goal of measuring NSB. N and m are merged together, since it is not a strict prerequisite to be as accurate as the SQM, however it should be accurate in the same order of magnitude and in dark circumstances.

	a: cost	*n&m: accuracy*	*Weighting factors*
a: cost	1	1/7	0.13
n&m: accuracy	7	1	0.87

Table 9: Hierarchy for component decision making

9.3 Chip

In electrical engineering there exist two “computers” that can be used to run a program and include multiple components, like a brightness sensor. Firstly, Arduino, a micro-controller motherboard,

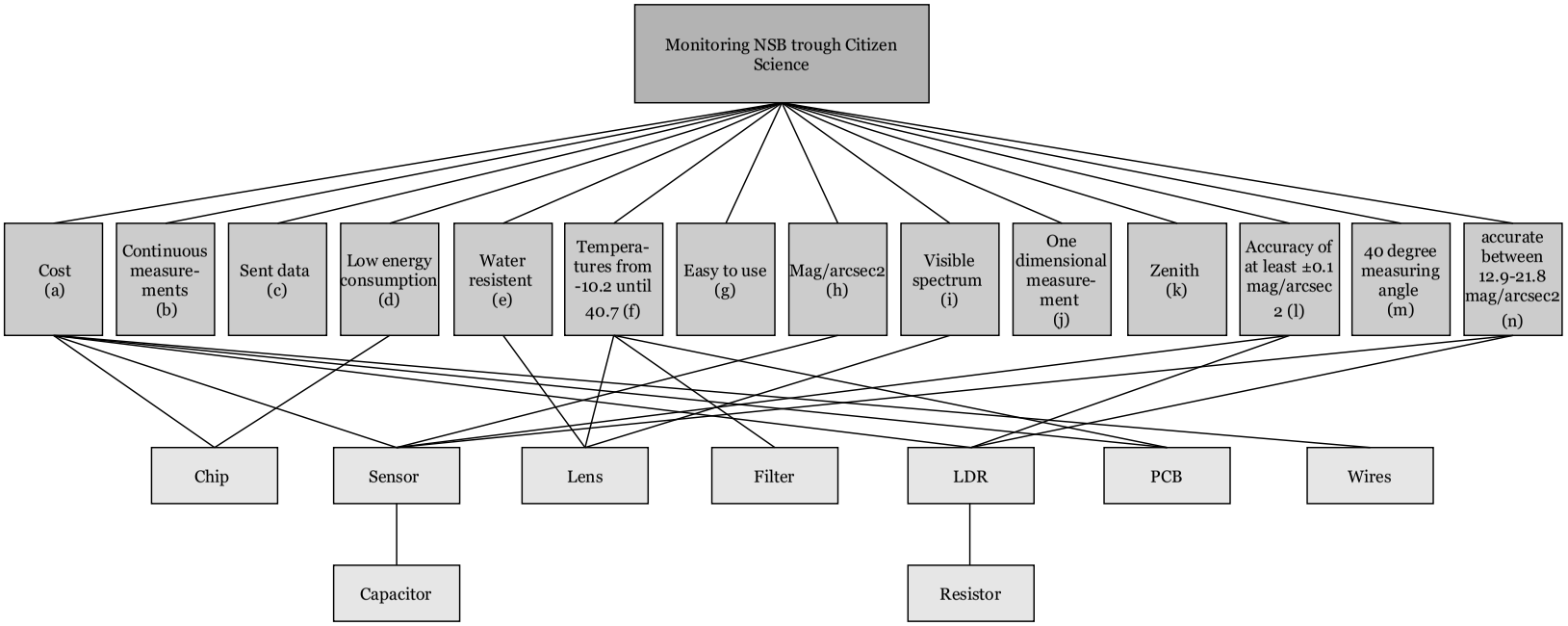

Figure 14: Hierarchy for component decision making

a simple computer that could run one program at the time repeatedly. A Rapsberry Pi is a more general computer, usually used in combination with a Linux operation system, it has the ability to run multiple programs at the same time (Di Justo, 2015). In the weighted scoring matrix in table 10 Arduino is having priority over Raspberry pi, in order to see the pairwise comparison for cost and energy consumption see Appendix C.

	a: low cost (0.5)	*d: low energy consumption (0.5)*	*Priority vector*
Arduino	0.9	0.9	0.9
Raspberry pi	0.1	0.1	0.1

Table 10: Chip decision based on cost and energy consumption

9.4 Sensor

The scoring matrix in table 11 shows that the TSL237 best suits cost and accuracy requirements, for the pairwise comparison used for the development of the scoring matrix can be found in Appendix C.

There exists tree light-to-frequency (LFT) sensors on the market: TSL253R, TSL237, and TSL238T from which TSL237 is best suited for the citizen science sensor node. Frequency can be transferred to mag/arcsec^2 using the following formula (Brandl, 2012):

$$NSB(mag/arcsec^2) = (NSB.\ddot{limit} - (2.5 * log10(frequency)) \quad (1)$$

A LFT sensor converts the analogue measurements of the brightness to a digital form (square wave or frequency) for direct interfacing with a motherboard (AMS, 2017). The TSL237 has according to its corresponding data-sheet the lowest dark frequency of 0.1 Hz. Which means it is the most sensitive of the three in dark circumstances (AMS, 2017). Also a TSL2561 was examined, which detects light ranges up to 0.1-40,000+ lux. According to table 7 "overall natural night sky" until "urban night sky"(0.6-30 miliLux) will not be accurately measured using this sensor.

	a: low cost (0.13)	*n&m: accuracy (0.87)*	*Priority vector*
TSL237	0.25	0.6	0.55
TSL253R	0.25	0.08	0.11
TSL238T	0.25	0.12	0.14
TSL2561	0.25	0.20	0.20

Table 11: weighted scoring matrix light sensors

9.5 Lens

A lens is needed to protect the sensor from the outside weather circumstances (so in order to fulfill criteria 10) and will be placed over the sensor. A low-cost lens with the largest measuring angle on the market is 19-34 degrees. As only a wider measuring angle negatively affects the measured outcomes, a smaller measuring angle fits within the requirement. As there is no real competition, no scoring matrix was applied.

9.6 Filter selection

An UV/IR filter is needed, in order to cut the UV and IR spectra. To ensure measurements only within the visible spectra. Which is required to meet requirement i. In figure 15 the responsivity (black line) of the TSL237 sensor can be seen as a function of the wavelength. The responsivity is compared to the visible spectrum, which ranges from wavelengths of 380-700 nm (NASA Science, 2010). As can be seen in Appendix B smaller wavelengths than 380 fall in the infrared (IR) spectrum and wavelengths bigger than 700 nm in ultraviolet (UV) spectrum (Volchko, 2019). Since the responsivity of the TSL237 sensor also includes wavelengths of 300-380 nm (IR) and 700-1100 nm (UV), it does not only measure the visible spectrum (NASA Science, 2010). In order to abandon the IR and UV spectrum an astronomic filter can be used. Which blocks light of certain wavelengths. The responsivity of the SQM is also plotted, as it is currently the best alternative on the market. It can be seen that the filter used in the

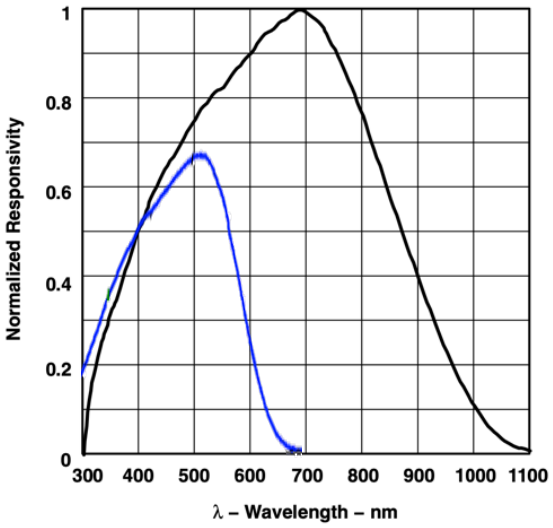

Figure 15: SQM (blue) (Zamorano et al., 2017) and TSL237 responsivity (black)(ams AG, 2017)

SQM (HOYA CM-500) omits too much of the visible red spectrum (NASA Science, 2010). Also, for the filter there do not exist many different options, therefore selection was only based on price. See appendix B for the supplier of UV/IR block 9.5 mm lens.

9.7 LDR

In the weighted scoring matrix in table 12 it can be seen that the NSL-5510 Light Dependent Resistor (LDR) was selected based on cost and accuracy. The TSL237 is a sensor sensitive under dark circumstances, however the sensor node will be exposed to daylight as well. When the sensor is exposed to high amounts of light for a too long time period the frequency counters within light sensor would overflow and lock up in bright sunlight or provide false results during dark nights. Sun light can reach values up to 1366 W/m^2 and the sensor only responds until 0.1 W/m^2 (figure 16). By first measuring the amount of light via a LDR, the frequency of measuring can be determined (Brown, 2017). When it is dark one measurement will take 2 sec, while when the sun is shining bright one measurement will take 100 milliseconds, which prevents an overflow.

There exist several options for LDR's, more accurate LDR's result in being able to show a wider resistance range however, are associated with higher cost. Therefore, a decision on a cheaper and less accurate or more expensive and more accurate LDR had to be made.

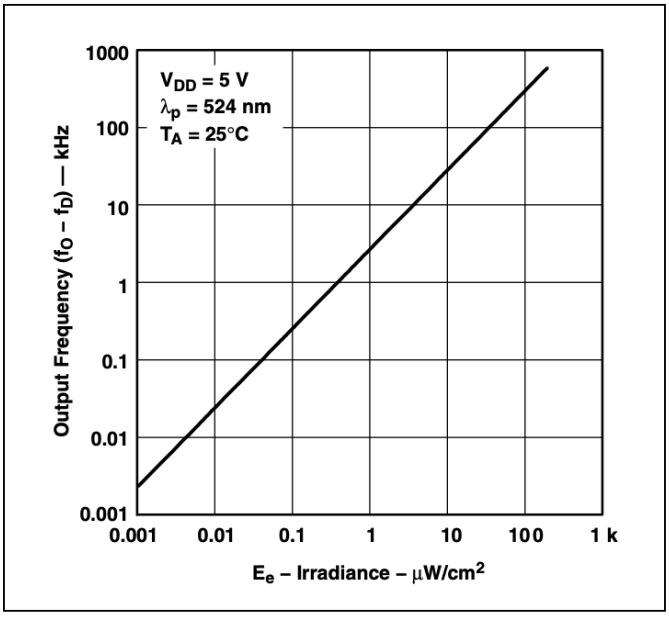

Figure 16: Frequency vs irradiance

	a: cost (0.13)	*n&m: accuracy (0.87)*	*Weighting factors*
GL5528	0.75	0.13	0.21
NSL-5510	0.25	0.87	0.79

Table 12: Weighted scoring matrix LDR

9.8 Rain sensor

A new requirement was formulated during the component selection, as it has been found that raindrops, snow and dew covering the lens window could incorrectly define the sky as very dark (Ścieżor, 2020). Therefore, a last requirement was formulated:

o. Should measure rain

There exists only one rain sensor usable for Arduino projects named: "rain drop sensor", selection was also only based on price.

9.9 Board

In order to connect all components mentioned in section 9.1-9.6 a PCB board could be used or a stripboard. PCB boards are customized made per project where stripboards are universal, which makes PCB boards more expensive. However, stripboards require soldering skills and have a higher risk of making mistakes. Therefore, a scoring matrix is made based on criteria a: low cost and g: easy to use/install/construct. When buyin the PCB outside of Europe it will cost 3 euro's (JLCPCB, 2020) and a stripboard 1,39 (Conrad, 2020).

	a: cost (0.5)	*g: easy to use (0.5)*	*Priority vector*
PCB	0.33	0.9	0.62
Stripboard	0.67	0.1	0.38

Table 13: Weighted scoring matrix board

For ordering for a PCB, a PCB design in specific documentation, called Gerber files is required. Since, the researcher has no experience in designing such files and due to COVID-19, Martin Stokroos was

not able to help design a new PCB over this research time period. Therefore, the Gerber files of the mySQM (Brown, 2017) were used. Resulting in some unnecessary options on the board.

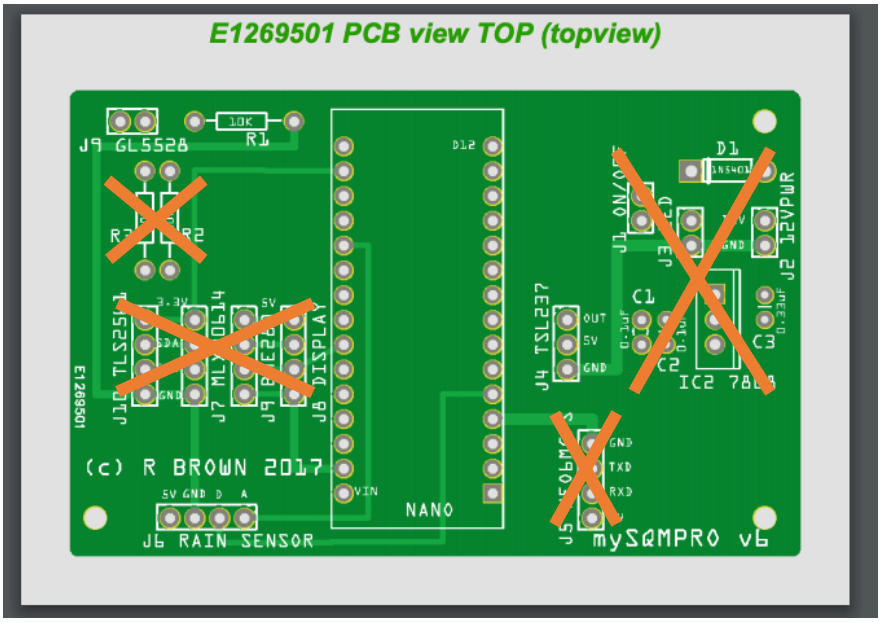

Figure 17: PCB, in orange indicated what is not needed for this project

9.10 Capacitor

A capacitor is placed between the Voltage pin and the Ground pin of the TSL237 to ensure a consequent voltage supply. A 0.01μF to 0.1μF is suggested in the fact sheet of the TSL237 (AMS, 2017). As the price differences only a few cents per capacitor no scoring matrix is being applied.

9.11 Resistor

When a LDR is used, also a resistor is needed because the LDR provides a varying resistance for different brightness values, however Arduino can only measure differences in voltages. Therefore, the varying resistance needs to be converted to a varying voltage by using a 10kΩ resisor. (How to Use a Light Dependent Resistor (LDR): 3 Steps - Instructables, n.d.).

9.12 Wires and Headerpins

To connect the components to the motherboard female to female jumper wires and headerpins are needed, this is a solder-less method to connect components. This is such a universal method, that here also no comparison is required.

9.13 Wire case

The developed electric circuit has to be protected from water, stated in requirement e. The circuit is placed in a wartel wirecase since this is a universal case and therefore cheap. A customized case, for example produced by a 3d printer, could be an option however not within the scope of this research. A design will have to be made and an analysis of the cost has to be performed.

10 Assmebly prototype

The assembly of the prototype consisted out of two parts, the assembly of the PCB and the assembly of the components to the PCB. In figure 18 the result of the hardware assembly is showed and in figure 19 the full assembly is presented. In figure 18 the numbers indicate:

1. lens, filter, sensor and capacitor
2. LDR
3. rain sensor
4. PCB and Arduino NANO

In figure 19 the rain sensor and the lens are present on the same side of the case, the LDR is located on the side right from the lens and rain sensor. The idea was to drill a small hole for the LDR next to the wartel containing the lens, as it should be pointing in the same direction as the brightness sensor. Since, the LDR, rainsensor and TSL237 should all measure from Zenith. However, being shackled at home, drilling was currently not possible.

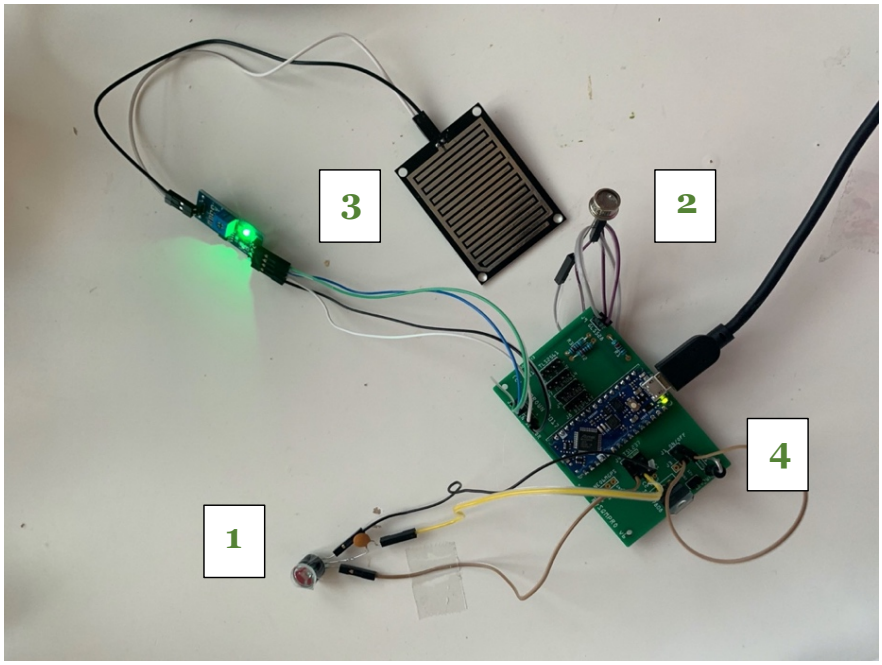

Figure 18: Prototype NSB sensor node without case

Figure 19: Prototype NSB sensor node with case

10.1 PCB assembly

As mentioned in section 9.8, several options on this PCB board will not be used, since these are not required according to the equipment requirements. However, in order to use the PCB, header pins need to be soldered trough the round holes on the PCB (figure 17). Which provides the possibility to connect jumping wires to the PCB trough header pins (figure 20).

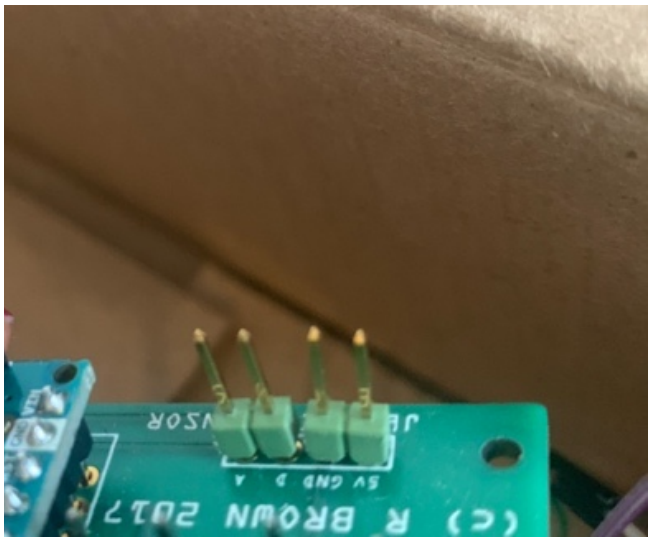

Figure 20: Example header pin soldered to PCB

10.2 Components to PCB assembly

In figure 21 the connection type and connection place of the components to the PCB is visualized in a figure. The GND to GND, V5 to V5, Digital to Digital or Analog to Analog pins are connected via

a Female to Female jumper wires. As the Filter has the same diameter as the lens it can be placed on the lens by using a small tape, thereafter the lens is glued on the TSL237 sensor. Additionally, the capacitor needs to be soldered onto the legs of the TSL237 and the resistor and need to be soldered on the PCB.

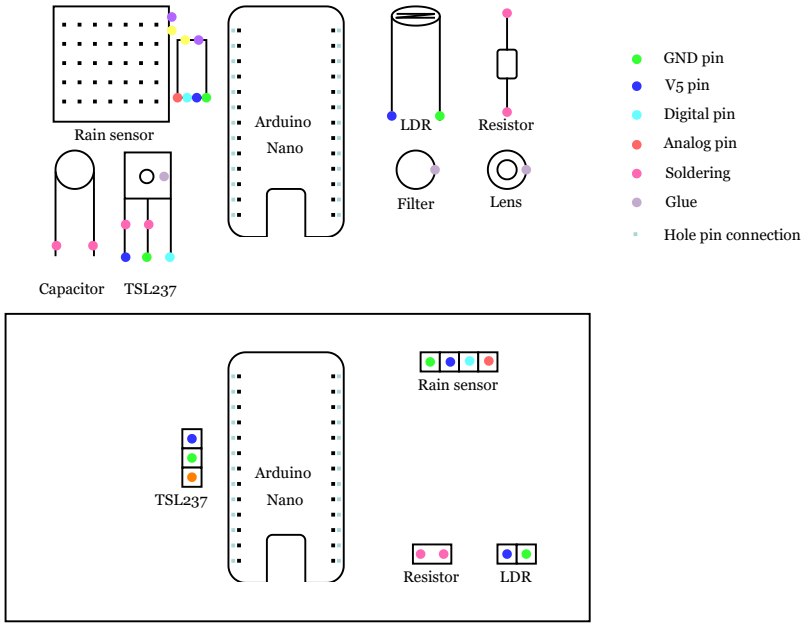

Figure 21: Connection between components

11 Code prototype

Since mySQM (Brown, 2017) forms the basis of the prototype it's code also has been used. It contains a code which can be loaded on the Arduino chip and thereafter will continue operating as stated in the code. The code was designed for doing a high variety of sky measurements, which are not needed for the NSB Citizen Science sensor node. Therefore, several functions of the code had to be put off in the code. This was done using the controllerconfig.h, the TSL2561, GPSNEO, MLX906114, BME280, LCD and OLED were disabled. The full code can be examined in Appendix E, however the code is quite extensive, therefore Appendix E is provided in a separate file.

Additionally, a decision on how to transform the sensor output Hz into Mag/arcsec^2 had to be made accourind to the code. The code offers 4 options, from which 2 use formula (1) of section 9.2. However, (Brown, 2017) found a correction for the TSL237 of 0.973. Therefore, the corrected formula was selected:

$$NSB(mag/arcsec2) = (NSB.limit \ddot{-} (2.5 * log10(frequency)) * 0.973) \quad (2)$$

12 Validation

As the research was composed out of two sections, the validation will also be done separately for the topic selection/equipment analyses and the contribution to a NSB sensor node development.

12.1 Validation light pollution and need for NSB sensor

Validation is being done by validation interviews with people in the scientific light field and Theo Jurriens the campaing developer of SLX. Interviews with Marijke Gordijn (2020) and Kamiel Spoelstra (2020) confirmed the results of a need for a very sensitive affordable light sensor. M. Gordijn is a scientist specialized in sleep and light and a member of the Goodlight Group. She confirmed that a sensitive cheap light sensor would be valuable for her as researcher as well as for the Goodlight Group, whom also desire to start a global Citizen Science light monitoring campaign. However, Kamiel Spoelstra, one of the precursors in researching the effects of light, unfortunately dd not respond yet, on the request for an interview. Kamiel Spoelstra (email communication, 2020) did confirm that a there is a need for a sensitive light sensor.
Additionally a validation interview is being conducted with Theo Jurriens (Appendix A). He confirmed that light pollution is a perfectly suited campaign topic and that there does not exists a low cost, continuous measuring and capable of sending NSB sensor node. Additionally he stated that it was adequate that water pollution and sound disturbance obtained a third and second place, as these topics are also national Citizen Science campaigns organised by the RIVM.

12.2 Validation NSB sensor node

Validation of the NSB sensor node prototype will be done on the basis of the earlier formulated monitoring equipment requirements. In figure 22 it is shown which requirements are met and validated, explanation is provided in the following sections.

12.2.1 Cost validation

One of the initial requirements was that the monitoring equipment should not be more expensive then approximately 50 euros. In Figure 23 it is shown that indeed the requirement is met because the total cost of components is 39.12 euros. Which will even become less when the order amounts increase. For a list including suppliers of the components see Appendix B.

12.2.2 Continuous measurements

The NSB sensor node does continuous measurements and with the introduction of a LDR it is also capable of determining its own measuring frequency.

SienceLinx	Requirements list for light pollution monitoring equipment	20-12-2020	
a) Cost price of ± 50 euro's			✓
b) Continuous measurements			✓
c) Sent data			
d) Low energy consumption			✓
e) Water resistent			✓
f) Withstand temperatures from -10.2 until 40.7 degree Celsius			✓
g) Easy to use/easy to install or construct			
h) Measure NSB in mag/arcsec2.			✓
i) Measure in the Visible spectrum.			✓
j) Do one dimensional measurement			✓
k) Measure from Zenith			✓
l) Have a measuring of angle 40 degrees			✓
m) Accuracy of at least ±0.1 mag/arcsec 2 (equal to SQM)			
n) Measure accurate between 12.9-21.8 mag/arcsec2			✓

Figure 22: Requirements list NSB sensor node

SienceLinx	Component list + price	20-12-2020
	1. Arduino Nano.	8.99
	2. TLS 237.	3.69
	3. Rain sensor.	2.4
	4. Lens 12-24 degree	3.1
	5. UV/IR filter 9.5 mm	2.2
	6. PCB board	3
	7. LDR 10k	4.4
	8. Resistor 10KΩ	1.25
	9. ceramic capacitor 0.1 uf	0.9
	10. Arduino header pins 2.54mm spacing	0.93
	11. Jumper wire	1.6
	12. Wire case	3.13
	13. USB mini	2.0
	14. USB charger	1.53
		39.12

Figure 23: Requirements list NSB sensor node

12.2.3 Sent data

Unfortunately, the sensor node is not jet capable of sending data via WiFi. An Arduino code in combination with a Arduino WiFi component will enable data via Wi-Fi sending. However, also a web address needs to be opened in order to send the data. This is of such high complexity that help from a professional is needed, however that did not fit in this research's time constraint and in the current COVID-19 circumstances.

12.2.4 Low energy consumption

Arduino can operate from a power bank (Powering the Arduino with a 5V Power Supply, 2014). Therefore, criteria e has been fullfilled.

12.2.5 Wire case

In the previous MOT campaign, the wire case also had been used and showed its capability of protecting the electric circuit form its outside exposures (Appendix A).

12.2.6 Withstand temperatures from -10.2 until 40.7 degree Celsius

The LDR has an operating temperature from -60 until 75 degrees (Sampieri, 2014). The rain sensor is functional within a temperature range from -30 until 70 degrees (Andivi, 2012). Additionally, the TSL237 has a operating temperature of -40 until 85 degrees (Andivi, 2012). Also, an Arduino Nano withstands temperatures between -40 and 85 degrees. Therefore, requirement f is also met.

12.2.7 Easy to use/construct

The sensor node is easy to use, the only thing citizens have to arrange is (preferably) finding a high location with no light sources in the nearby surrounding, connect it to an energy supply and point the NSB sensor to Zenith. As the citizens will construct their sensor node themselves, soldering might be too complex. However, in the previous MOT campaign construction workshops were being held. It should be examined if the sensor node can be constructed during workshops, where soldering is possible.

12.2.8 Accuracy of at least ±0.1 mag/arcsec 2 (equal to SQM)

A proper calibration with an existing light meter as for example SQM, has not yet been performed. Therefore, the accuracy is currently not yet validated.

12.2.9 Measure accurate between 12.9-21.8 mag/arcsec2

The use of the LDR makes sure the TSL237 will not be oversaturated, A test was performed to set two LDR setpoints, LDRCutoff1 and LDRCutoff2. LDRCutoff1 to indicate the value between black and dark and LDRCutoff2 the barrier between dark and light. Based on the cutoffs the measuring period is determined as can be seen in the code underneath.

By doing simulations where, curtains were open, curtains were closed while a slight amount of light was entering the room (dark) and during night when curtains were closed, LDRcutoff1 and LDRcutoff2 were obtained (figure 24-26). The pre-measurement of the LDR ensures accurate measurements 12.9-21.8 mag/arcsec^2 because it prevents over saturation from bright day light.

```
1
2     case State_sqm:
3       // refresh sqm readings
4       LDRval = analogRead( LDRpin );              // read LDR to
           determine background light level
5       if ( LDRval < LDRCutoff1 )                  // and use this to
           set the Gate Time (duration) for this samples frequency
           measurement
6       {
7         period = blackperiod;                     // its very dark
8       }
9       else if ( LDRval < LDRCutoff2 )
10      {
11        period = darkperiod;                      // its dark
12      }
13      else
14      {
15        period = lightperiod;                     // its light
16      }
17      light();                                    // read frequency
           from sensor
```

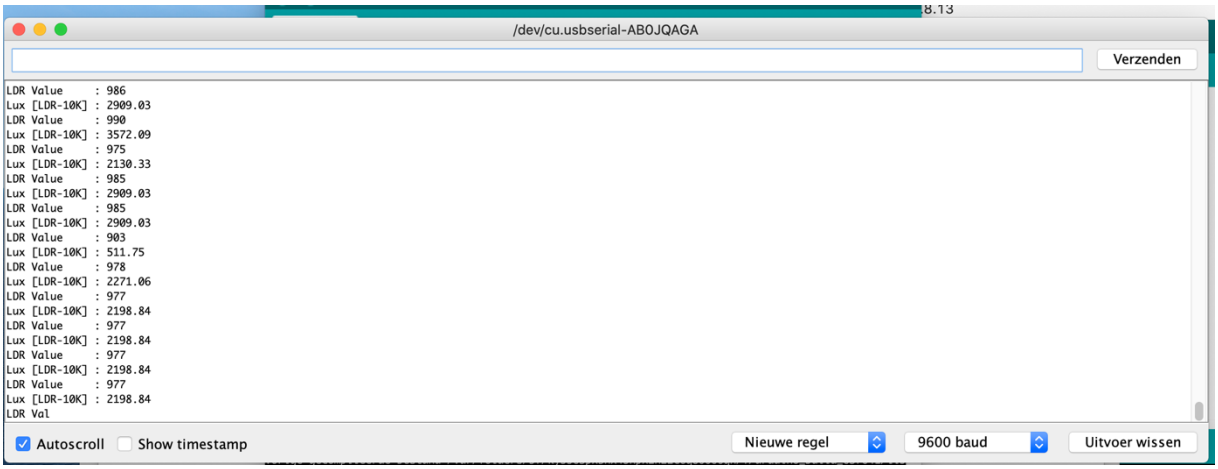

Figure 24: LDR value day light (980)

The pre-measurement of the LDR ensures accurate measurements 12.9-21.8 mag/arcsec2 because it prevents oversaturation from bright day light.

Figure 25: LDR value dark (580)

Figure 26: LDR value black (220)

12.2.10 Should measure rain

By the introduction of a rain sensor, inaccurate measurements by the coverage of the lens is prevented. In a simulation, the rain sensor was tested, by placing a wet finger on the rain sensor. In figure 27 it is shown that the controller then accurately indicates raining.

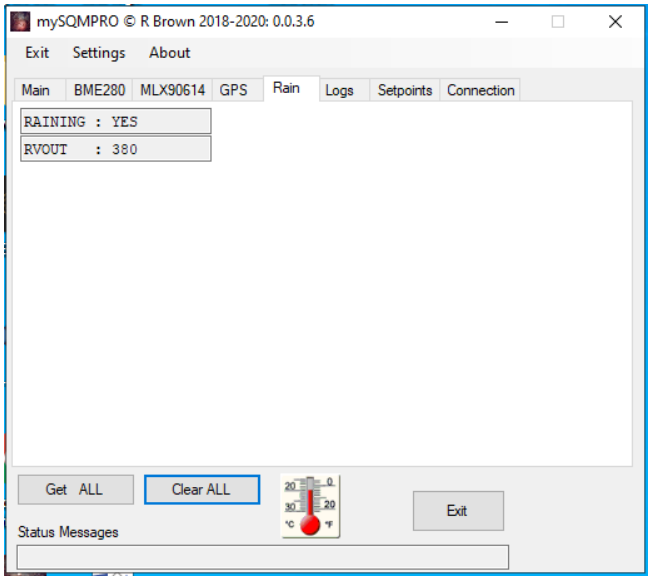

Figure 27: Controller indicating rain)

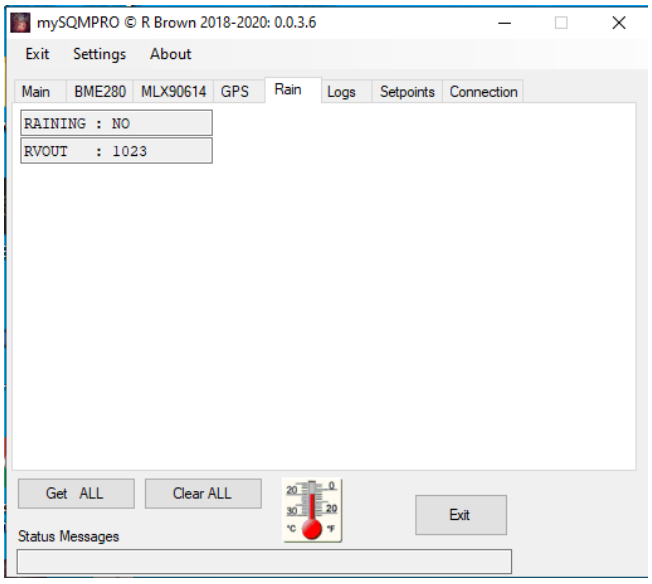

Figure 28: Controller indicating no rain

13 Recommendations

Further research is needed in order to full fill all defined NSB equipment requirements. Three requirements have not yet been met namely; Sent data; Easy to use/construct/install; Measure accurate between 12.9-21.8 mag/arcsec^2.

In order to sent data the prototype has needs further development on a WiFi component and adjustment of the code. The only drawback in the fulfilment of the requirement Easy to use/construct/install, is the fact that a connection mechanism "soldering" has been used. There exist several methods to avoid soldering, here could be looked into or into the possibility of soldering on campus. Additionally, the calibration of the sensor fell out of this research time constrain, however calibration and testing of the accuracy would be a valuable next step in the development of a low cost NSB sensor node.

Additionally, a strong correlation between the night sky brightness and the concentration of atmospheric aerosol particles has been found (Ścieżor & Czaplicka, 2020). It scatters artificial light shining upward. Therefore it could be really interesting to combine the outcomes of the debute MOT campaign on particle matter in the air with this Light Pollution upcoming campaign.

14 Conclusion

In order to obtain ScienceLinx's goal of enthusing curious citizens of the North of the Netherlands to contribute to Science and Technology by mapping their environment and possibly even cause action to improve the Northern environment, light pollution is the best suited succeeding campaign topic. Since, the human context of the problem can be explained elaborately, it shows the limits of environment, is provides a sense of a wander and narrative thinking can be applied. Additionally, the campaign topic provides low cost campaign opportunities and it will not be a source for citizens to base complaints on. Based on a literature analysis and formulation of monitoring equipment requirements for measuring NSB via Citizen Science it was concluded there does not exist a NSB monitoring device, that is low cost, does continuous measurements and sent data. Therefore, a prototype of a low cost NSB sensor node appropriate for Citizen Science projects has been developed, in order to fulfill all set monitoring equipment requirements further research needs to be done on; sending data; avoiding soldering and accuracy.

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Appendices

A Interviews

Interviewee: Theo Jurriens (T)
Interviewer: Geertje Motzelt (G)
Date: 3-10-2020
Location: Online Google meet

G: Hoi Theo, dank voor je snelle antwoord.

T: Geen probleem!

G: Naar aanleiding van ons eerste gesprek ben ik gaan nadenken, het lijkt mij het leukst om bij te dragen aan het opvolgende Citizen Science project aan het fijnstof project. Maar om een onderbouwde keuze te kunnen maken, lijkt het mij handig om de voorwaarde aan het project samen te vatten.

T: Nou ja, de voorwaarde zijn eigenlijk vrij simpel.

G: Ja volgens mij heb ik de meeste al wel op papier.

T: Het mag niet te veel kosten, ik heb een subsidie van 25 per persoon, onze fijnstof meter ligt rond een prijs van 50 euro. Dus mensen betalen nu zo'n 25 euro per deelname. Zo blijft de instap drempel overzichtelijk.

G: ja check, die heb ik.

T: Natuurlijk is het achterliggende doel, mensen enthousiasmeren en betrekken bij techniek en de wetenschap. En daarnaast het "awereness" creëren over problemen in het Noordelijke milieu en daardoor misschien wel bijdragen aan verbeteringen van het milieu.

G: Ja duidelijk, dat had ik eigenlijk zelf ook al. Dank Theo!

T: Spreek je wel weer

Approved by T. Jurriens on 6th of Januari:

Figure 1: Interview Theo Jurrens

Interviewee: Martin Stokroos (M)
Interviewer: Geertje Motzelt (G)
Date : 2-10-2020
Location : Online Google meet

G: Wat fijn dat je even tijd had om met mij te bellen!

M: Geen probleem, leuk dat je me benadert.

M: Je wil dus iets gaan monitoren voor je scriptie?

G: Ja, het zit eigenlijk zo. Theo Jurriens mijn stakeholder bij SLX, heeft net een campagne opgezet genaamd Meet-o-Theek gericht op Citizen Science met als eerste project; fijnstof in de lucht gemeten. Dit project is vooral opgezet om geïnteresseerde Noorderlingen te enthousiasmeren meer betrokken te zijn bij Science en Techniek, door hun eigen environment in kaart te brengen en het potentieel ook te verbeteren. Nu wil ik een nieuw onderwerp kiezen wat interessant zou kunnen zijn voor Citizen Science en wat gemonitord zou kunnen worden. Nu weet jij volgens mij goed wat je allemaal zou kunnen monitoren, en zou je me op weg kunnen helpen met wat interessant zou kunnen zijn voor zo'n project

M: Dat klinkt wel als een interessant project, en ik heb er ook al even over na gedacht. Iets wat mensen veelal interesseert is het kunnen zien van verschillen, daar kun je namelijk oorzaken achter zoeken of gevolgen. Iets wat veel fluctueert en een actueel onderwerp is, is natuurlijk aardtrilling in het Noorden.

G: Oja, dat is inderdaad interessant. Daar had ik nog niet eens aan gedacht. Ik had zelf inderdaad ook al bedacht dat iets waar veel fluctuatie in zit interessant zou kunnen zijn. Zodat daar verbanden uit getrokken zouden kunnen worden. Zo dacht ik zelf aan watervervuiling of geluid verschil bij bewoners langs trein rails (er gaat namelijk een geluidloze trein geproduceerd worden).

M: Is inderdaad interessant maar zoveel fluctueert dat ook weer niet, alleen als iemand net toevallig wat in de sloot gedumpt heeft. Geluid zou wel een interessant project kunnen zijn, maar dan draagt de sensor zelf misschien niet heel veel bij aan de verbetering van de environment.

M: Je zou nog kunnen denken aan radioactiviteit.

Figure 2: Interview Martin Stokroos

G: Ja dat is dus een moeilijk onderwerp want uit de interviews met Theo Jurriens bleek dat de Gemeentes die tot nu toe mee doen, erg bang zijn dat mensen klachten gaan indienen als bepaalde metingen heel hoog zijn dicht bij hun huis. Dat zou natuurlijk gemakkelijk het geval kunnen zijn bij radioactiviteit.

M: Ja dat klinkt logisch ja. Maar we hebben zo wel een stel potentiele onderwerpen die goed mogelijk te meten zijn aar mijn mening. Leuk project hoor! Kan je hier een beetje wat mee?

G: Jazeker, heel erg fijn dat je even met me mee hebt willen denken.

M: Je kan me altijd nog vragen stellen als je verder in het proces bent van het ontwikkelen van een sensor, ik help je graag!

G: Wat fijn, nogmaals heel erg bedankt! Fijne dag!

Stokroos, M. 10:17 AM (4 hours ago)
to me

Hallo Geertje,

Ik wens jou ook een gelukkig nieuwjaar!
De transcriptie is niet helemaal letterlijk geciteerd, maar ik herinner mij dat deze onderwerpen zijn besproken. Wat mij betreft akkoord.

Groeten,
Martin

Figure 3: Interview Martin Stokroos

M: Ja, en de goodlight group focust zich eigenlijk vooral op genoeg licht krijgen overdag. Maar als chronobioloog stop ik er ook altijd in, en niet te veel ‘s avonds en ‘s nachts. Wat misschien ook wel interessant is voor jou: ik heb ook een onderzoek gedaan naar dat je je ook aanpast aan de licht intensiteit waaraan je wordt blootgesteld. Dus als je overdag aan meer licht wordt blootgesteld dat je ‘s avonds minder gevoelig bent voor licht intensiteit. Dat is ook wel een belangrijk punt. Want we worden verstoord door het avond licht. Maar het komt ook doordat wij overdag aan zo weinig licht worden blootgesteld, daardoor heeft de licht intensiteit meer impact. Dus in die zin zijn wij ook bezig geweest met licht meten. Je mobieltje kan het ook he?

G: Ja inderdaad, maar dat is niet zo best zag ik.

M: Precies, die zijn niet goed, vooral omdat het ook nogal uitmaakt welke mobiel je hebt.

G: Dat is inderdaad ook mijn onderbouwing geweest, al die verschillende camera’s vallen niet te generaliseren.

M: Ja al helemaal op jouw niveau zou dat niet werken, maar voor ons eigenlijk ook al niet. Dus wij hebben nu de opdracht gegeven aan een app bouwer om te kijken of ze dat zouden kunnen verbeteren. Of dat dat gekalibreerd kan worden. Met een Android is dat eigenlijk wel redelijk te doen maar met een iPhone helemaal niet. Dus mobieltjes voor jou is inderdaad echt niet reel.

G: nee nee oké

M: Er is dus wel een andere licht sensor maar die is meer op gezondheid gericht genaamd de Lys.

G: A maar die zal dan misschien niet gevoelig genoeg?

M: Nou dat weet ik niet, het probleem met de lys is, is dat het echt een consumentenproduct. Als researcher krijg je niet echt de data, je krijgt alleen advies over je licht gebruik. Dus toen heb ik het eigenlijk aan de kant geschoven. Maar ik ken iemand uit Eindhoven die heeft geprobeerd de data er uit de krijgen. Volgens mij was hij is rond de 100 euro. Het is een soort button.

Figure 4: Interview Marijke Gordijn

G: A ja dat is dan wel leuk, want ik ben dus daadwerkelijk een lichtgevoelige sensor aan het bouwen. Die eigenlijk in een elektrisch circuitje is geplaatst en wordt aangestuurd door een chip. Maar daar zou je wellicht ook wel gemakkelijk een iets minder gevoelige licht sensor in kunnen zetten.

M: Oh dat is wel heel interessant, dat zou voor ons ook zeker handig zijn. En jij bouwt hem zelf en jij test hem dan ook?

G: Nou dat is nog even de vraag, qua tijd.

M: En heb jij een goede meter waarmee je hem kan kalibreren.

G: Ja wij hebben een SQM op de universiteit waarmee ik het dan zou kalibreren denk ik. Maar daar ben ik dus eigenlijk nog niet echt.

M: Ja wij hebben namelijk wel een goed gekalibreerde licht sensor namelijk een Yeti, maar ik weet even niet meer wat de ondergrens is van waar hij accuraat meet.

G: Maar wat leuk dat jullie eigenlijk een soort gelijk project zouden willen doen

M: Ja daarom vond ik het ook zo leuk dat je contact op nam, want wij lopen nu een beetje vast met die mobiel en want het gaat ons vooral om de awareness. Dus dan vraag je je af hoe belangrijk is de accuracy dan.

M: We hebben ook wel eens proberen te bekijken of je iets op je camera zou kunnen zetten ofzo. Dat soort ideen hebben we ook gedaan.

G: Ja dat is eigenlijk voor mij allemaal heel waardevol, want ik probeerde er eigenlijk achter

Figure 5: Interview Marijke Gordijn

G: eigenlijk achter te komen of mijn sensor naast dit citizen science project dan ook zou kunnen bijdragen in andere licht onderzoeken

M: Ja zeker, je mag zeker noemen dat voor zowel the goodlicht group als ik zelf als wetenschapper het zeer relevant zou zijn om een zeer gevoelige licht sensor te hebben.

G: Ik ben heel blij omdat te horen.

M: Nou fijn, bedankt voor het gesprek. Ik blijf graag in contact om de voorderingen van je project te horen. Misschien is het wel een hele mooie uitkomst voor ons.

Voor interview Geertje Motzelt M.C.M. Gordijn

Figure 6: Interview Marijke Gordijn

Interviewee: Theo Jurriens (T)
Interviewer: Geertje Motzelt (G)
Date : 20-01-2021
Location : Rijksuniveristeit Groningen Zernike Complex

G: Hey Theo, goedemiddag

T: Geertje, goedemiddag

G: Nou ik moet dus even mijn resultaten met je bespreken, en kijken of je erkent wat er gevonden is.

T: Ja heel goed.

G: Uhm, ik was dus een tijdje geleden tot een soort inzicht gekomen, dat ik nu eindelijk snap wat mijn supervisors me volgens mij al eerder probeerde duidelijk te maken.

T: Ja

G: Dat was dat mijn goal/probleem stelling eigenlijk anders was dan ik op dat moment had. Ik zat al heel specifiek of die sensor, terwijl het vraagstuk eigenlijk begon bij: er is een volgende campagne en het is nog niet duidelijk wat daar het onderwerp van moet zijn en hoe er gemeten moet worden. En in feite had ik dat wel ook al onderzocht, ik onderbouwde mijn keuze voor lichtvervuiling en waarom er een sensor moest komen maar dat stond allemaal voor mijn resultaten. Dus ik heb alles een beetje omgegooid, waardoor mijn eerste twee onderzoekvragen over topic een meetmethoden zou gaan. Waardoor mijn analyse van meetmethoden en topic keuze ook al resultaten zijn. En dan vervolgens komt daaruit dat er nog geen goedkope licht gevoelige sensor bestaat bruikbaar voor Citizen Science. Dat koste even veel tijd en daardoor ben ik wel wat tijd verloren voor de ontwikkeling van de sensor. Dus ik ga je nu even mijn onderbouwing voor de topic keuze en uitkomst van de need voor een nieuwe sensor laten zien.

T: Ja heel goed.

G: Wat ik dus heb gedaan, ik moest meer visualiseren waarom licht vervuiling het beste nieuwe campagne onderwerp is. Ik heb daarin drie voorwaarden opgesteld, de S&T-engagement, dus dat het moet enthousiasmeren voor techniek, het moet goedkoop zijn en op de uitkomsten mogen geen klachten gebaseerd worden.

Figure 7: Interview validation Theo Jurriens

G: Het verhogen van enthousiasme voor S&T is natuurlijk de belangrijkste en krijgt daarom een zwaardere weging. Ben je het eens met deze requirements? Ook al hebben we die natuurlijk enigszins samen opgesteld haha.

T: Ja, ja correct

G: Nou dan heb ik dus een paar opties gedefinieerd en dan zie je dus dat aan de hand van deze matrixen en voorwaarden light vervuiling als beste optie naar voren komt. Ben je het er mee eens dat licht vervuiling een goede optie is voor de volgende MOT-campagne?

T: Ja, dat is dan wel grappig dat je dit zo doet. Want het RIVM doet nog twee Citizen Science meet campagnes dat is namelijk: geluid en water. En dat zijn bij jou de tweede en de derde plek.

G: Nou kijk eens, als dat geen mooie validatie is.

T: Ja, ja en het grappige is ik ben ook heel voorzichtig met de waterschappen in overleg of we in de toekomst een meet campagne water kunnen doen.

G: Ja, die sloot eigenlijk ook heel mooi aan.

T: Ja heel goed.

G: Toen vervolgens heb ik een lijst opgesteld met voorwaarden hoe je dan light vervuiling gaat meten. Hier is de lijst ervan, in mijn scriptie staat natuurlijk een uitleg van hoe ik aan deze ben gekomen. Die heb ik toen afgezet tegen de bestaande methodes en gekeken hoe die deze voorwaarden vervulden.

G: Nou dan komt het er op neer dat de SQM het dichts in de buurt komt maar qua kosten te duur is voor een Citizen Science project, niet continue metingen kan doen en geen data kan versturen.

T: Dat heb je wel mooi gedaan zo

G: Dus de vraag daarover, ben je het er mee eens dat er nog geen goedkope sensor is die continue met en data kan versturen?

T: Absoluut

Figure 8: Interview validation Theo Jurriens

G: Ja dat heb ik dus eigenlijk ook al gevalideerd door een leuk interview dat ik had met Marijke Gordijn die inderdaad ook aangaf dat een goedkope lichtgevoelige sensor nog niet bestaat. Zij heeft kort bij de RUG gewerkt en doet veel met licht.

T: Ah ja en slaap onderzoek enzo.

G: Ja precies ja.

T: Ik zal je nog even het linkje sturen komende zondag is er een college over lichtvervuiling en de biologie erachter.

G: Ja nou dat was eigenlijk wat ik even moest valideren, zullen we dan die sensor even bekijken?

T: Wat ook heel grappig is, ik ben in contact met een oud PhD student van ons, ook een oud wielrenster en die heeft bijna privé een soort slaaponderzoek gedaan en dat afgezet tegen licht. Zij wil heel graag een licht meter van mij hebben.

G: Kijk eens nog meer vraag.

T: Hier deze niet vergeten he *geeft een wire wartel case*.

G: Oh ja daar over, kunnen we concluderen dat deze waterdicht zijn geweest in het lucht verontreiniging onderzoek?

T: Absoluut.

Approved by Theo Jurriens on 21th of January:

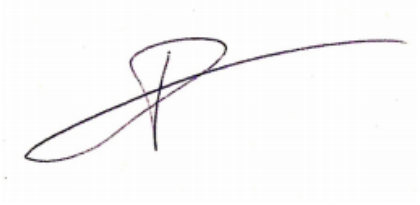

Figure 9: Interview validation Theo Jurriens

B Theory and purchase list

Components	Price	Supplier
1. Arduino Nano.	8.99	https://www.bol.com/nl/p/nano-v3-0-atmega328p-compatible-met-mini-usb-kabel/9300000008059094/?Referrer=ADVNLGOOoo
2. TLS 237.	3.69	https://www.digikey.nl/products/nl?keywords=%20TSL237-S-LF-ND
3. Rain sensor.	2.4	https://opencircuit.nl/Product/Regen-sensor-module
4. Lens 12-24 degree	3.1	https://www.digikey.nl/products/nl?keywords=711-1105-ND
5. UV/IR filter 9.5 mm	1.1	https://www.digikey.nl/products/nl?keywords=711-1105-ND
6. PCB board	3	https://cart.jlcpcb.com/quote
7. LDR 10k	4.4	https://www.digikey.nl/products/nl?keywords=NSL-5510-ND
8. Resistor 10KΩ	1.25	https://www.sossolutions.nl/10-x-weerstand-10-ohm-0-25-watt?gclid=CjwKCAiAouD_BRBIEiwALhJH6HbfcGvvx-yiEi2yWmloEVzPl
9. ceramic capacitor 0.1 uf	0.17	https://www.conrad.nl/p/tru-components-tc-k100nf5-keramische-condensator-tht-100-nf-50-v-20-1-stuks-1589524
10. Arduino header pins 2.54mm sp	0.93	https://www.conrad.nl/p/te-connectivity-male-header-standaard-mta-156-totaal-aantal-polen-9-640383-9-1-stuks-1278440
11. USB mini cable	1.99	https://www.allekabels.nl/usb-mini-kabel/176/1239035/mini-usb-naar-usb-a-kabel-2.0.html?gclid=Cj0KCQiAjKqABhDLARIsABbJrGkawMLUYJ_UY
17. Jumper wire	1.6	https://www.digikey.nl/product-detail/en/sparkfun-electronics/PRT-12796/1568-1513-ND/5993861

Figure 10: Purchase list and suppliers

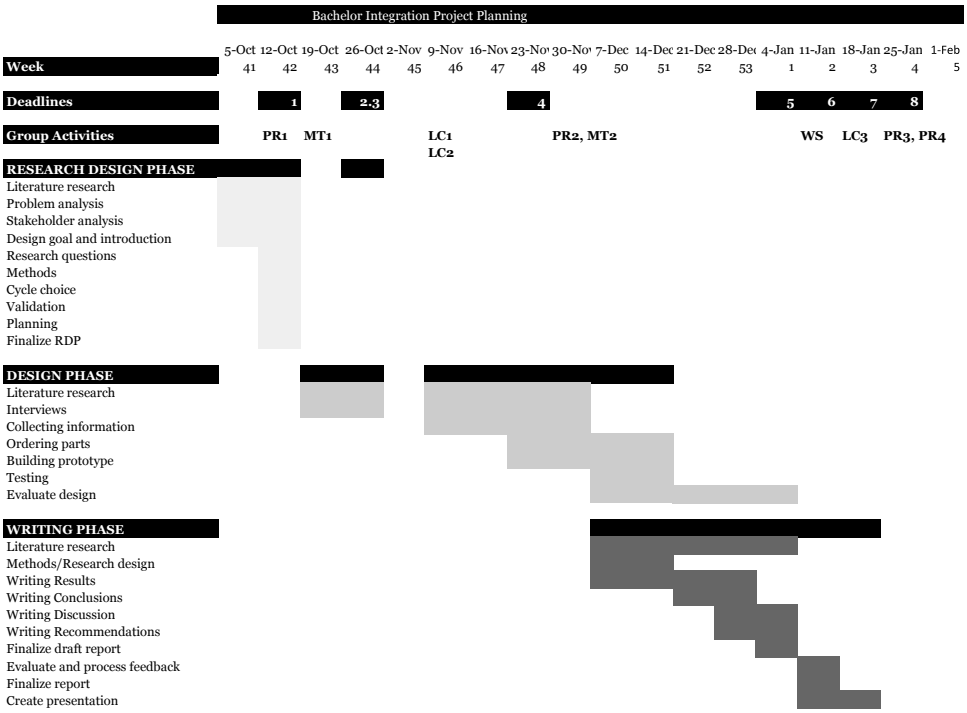

Figure 11: Research planning

Deadlines		
1	Reserach and Desing Plan (RDP)	Friday 16-10-2020, 17:00
2	RDP repair	TBD (week 40)
3	Upload corrected RDP version	Thursday 29-10-2020
4	Intermediate Report (IR)	Friday 27-11-2020 at 17:00
5	Preliminary Report (PR)	Friday 08-01-2021 at 17:00
6	Image and Summary for Symposium Booklet	Friday 15-01-2021 at 17:00
7	Final Report (FR)	Tue 26-01-2021 at 17:00
8	Poster	

Course/Group Activities		
PR2	Week 42	RDP practice presentation
MT1	Week 42/43	Meeting 1: Online RDP meeting
MT2	Week 49	Meeting 2: Intermediate meeting (10, min pres)
PR4	Week 4	10 min FR
PR5	Week 4	15 min online symposium

Figure 12: Deadlines

Table 1
The fundamental scale

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgement strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals	If activity i has one of the above numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

Figure 13: Pairwise comparison scale (Saaty & Katz, 1990)

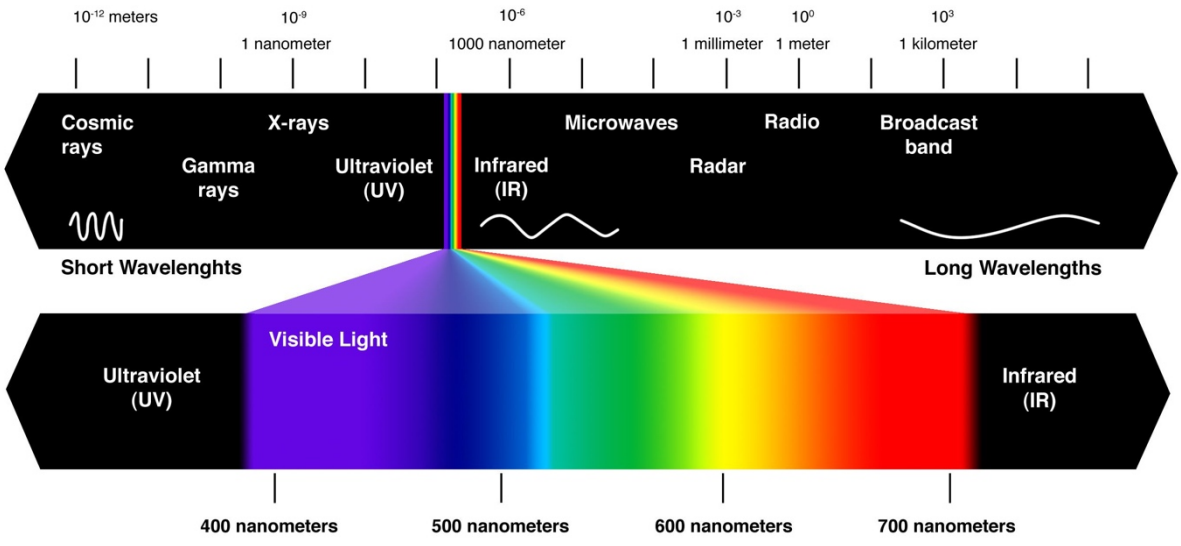

Figure 14: Different light spectra's and it's wavelengths (Volchko, 2019)

C Pairwise comparison

8: Low cost	*Arduino*	*Raspberry pi*	*Priority vector*
Arduino	1	9	0.9
Raspberry pi	1/9	1	0.1

Figure 15: pairwise comparison with respect to costs for chip

9: Low energy consumption	*Arduino*	*Raspberry pi*	*Priority vector*
Arduino	1	9	0.9
Raspberry pi	1/9	1	0.1

Figure 16: Pairwise comparison with respect to energy consumption for chip

7: Accurate under dark circumstances	*TSL237*	*TSL253R*	*TSL238T*	*TSL2561*	*Priority vector*
TSL237	1	6	5	4	0.60
TSL253R	1/6	1	1/2	1/3	0.08
TSL238T	1/5	2	1	1/2	0.12
TSL2561	1/4	3	2	1	0.20

Figure 17: Pairwise comparison with respect to accuracy for light sensor)

a: Cost	*GL5528*	NSL-5510	*Weighting factors*
GL5528	1	3	0.75
NSL-5510	1/3	1	0.25

Figure 18: Pairwise comparison with respect to cost for LDR

n&m: Accuracy	*GL5528*	NSL-5510	*Weighting factors*
GL5528	1	1/7	0.13
NSL-5510	7	1	0.87

Figure 19: Pairwise comparison for assembly board with respect accuracy for LDR)

a: Low cost	*PCB*	*Stripboard*	*Priority vector*
PCB	1	1/3	1/3
Stripboard	3	1	2/3

Figure 20: Pairwise comparison for assembly board with respect to cost for board)

a: Easy to use	*PCB*	*Stripboard*	*Priority vector*
PCB	1	9	0.9
Stripboard	1/9	1	0.1

Figure 21: Pairwise comparison for assembly board with respect usability for board

D Component images

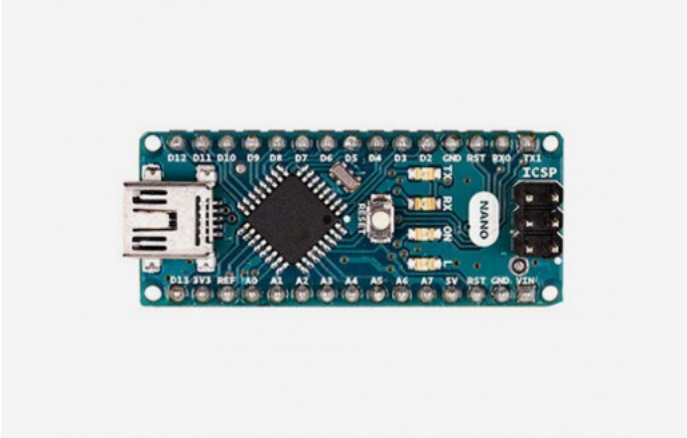

Figure 22: Pairwise comparison for assembly board with respect to easy to use

Figure 23: TSL237 light sensor (Arduino, 2020)

Figure 25: IV/IR block filter 9.5mm (Ebay., 2020)

Figure 24: FP10995 lens (LEDIL., 2019)

Figure 26: LDR NSL-5510 (Sampirie., 2014))

Figure 27: Rainsensor (Elektrokit., 2020))

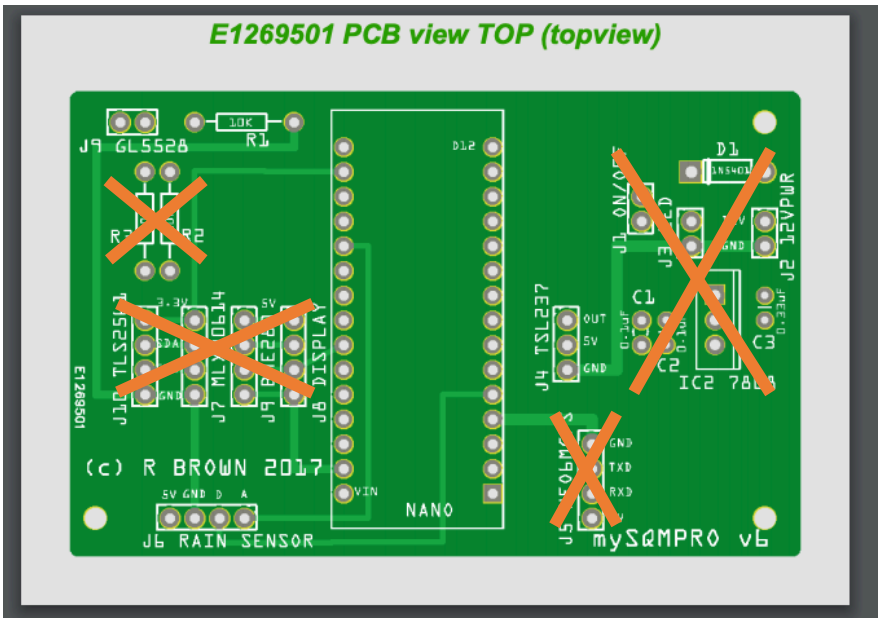

Figure 28: PCB (JLPCB., 2020)

Figure 29: Capacitor TC-K100NF5 (conrad., 2020)

Figure 30: Resistor 10kΩ 0.25W (Addicore., 2020)

Figure 31: F to F jumper wires (Adafruit., 2017))

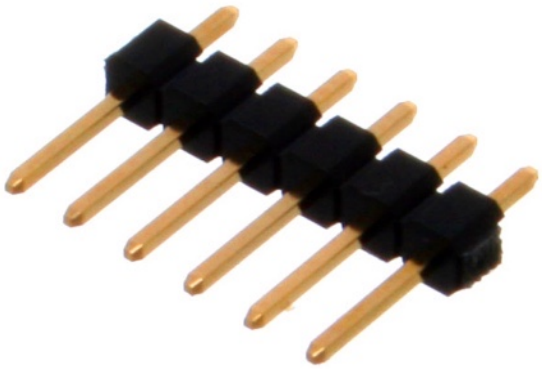

Figure 32: Headerpins (Digikey., 2020)

Figure 33: Resistor 10kΩ 0.25W (Addicore., 2020)