Aquaponics in the Classroom

The Potentials of Implementing an Aquaponics System in Elementary Schools in Order to Forward STEM Education

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Aquaponics in the Classroom: The Potentials of Implementing an Aquaponics System in Elementary Schools in Order to Forward STEM Education

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Abstract

This research investigates whether aquaponics could serve as a teaching tool and contribute to STEM education in an elementary school. The aim is to integrate food literacy, and more specifically its sustainable agriculture aspect. STEM education usually centers around a problem that has the capability to connect students to the real world. Aquaponics can deal with all of these issues, therefore, it could provide a discussion of topics such as diminishing food-mile, dealing with water and soil scarcity, and providing food safety.

An aquaponics unit was set up in Herstedlund Skole, Albertslund in order to conduct a 6 weeks intervention. The 8th-grade students have been using the aquaponics in a biology class setting and learned about sustainable food production. During the classes, the students were measuring water quality of the aquaponics system with digital sensors. For data collection four observations have been conducted during the classes. After the six weeks, a focus group interview with the children and an interview with the teacher were organized to help to evaluate the intervention.

Three theories are used to conceptualize the results. First, Piaget's constructivism was applied as the main teaching theory to understand the student's developmental level and how aquaponics and the sensors could be implied in their age. Second, the co-creational theory is applied. Following the characteristics of the SEWDM model, the certain elements were identified and analyzed. Third, the attributes of an outreach activity for STEM education is examined for this specific case.

The intervention has run successfully for six weeks. This digital component highly contributed to the STEM disciplines, therefore the aquaponics system for teaching purposes could be advanced this way. The 8th grade seemed to be the right age to learn about aquaponics and food literacy, especially the sustainable aspect. Furthermore, it also fit into STEM education and by following the implications of constructivism and co-creation, the students' engagement in scientific subjects could be highly enhanced with a hands-on project such as aquaponics.

Keywords: STEM education, aquaponics, food literacy, sustainable agriculture

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1. Introduction

1.1. Background

The term STEM education, STEM disciplines has been established in the 1990's. The acronym stands for *Science, Technology, Engineering,* and *Mathematics* and it is an educational framework. The four disciplines of the model are combined together and it is applied in scientific branches. It aims to integrate these elements into one concept in a cross-disciplinary way, and in the center, there is often a complex problem that incorporates all the units of the STEM. When speaking of it, people often refer to it as science or mathematics but tend to forget the engineering and technology part, although these are equally as important of the concept (Bybee, 2010). The STEM concept origins from graduate programs, however, in the last decade it caught the attention of elementary and secondary schools. There have been attempts to start STEM in an earlier age, so more students would choose this branch of education as their university studies and work in the field of STEM later on (Wu-Rorrer, 2017).

The world's population is constantly growing according to the United Nations' Human Development Report 2016, and by 2050, it will reach 9.7 billion (UNDP, 2016). Feeding more than 9.7 billion people with conventional farming is challenging due to several occurring issues. The world is facing problems like soil-degradation, water-scarcity, different kinds of crop diseases and climate change. The arid regions are rising, and the availability of fresh water is highly limited (Haley, 2013). Decreasing food-mile would also be a vast contributor to a sustainable food production, the length of the journey of the food supply chain. These food supply challenges potentially call for innovative solutions, emphasizing new ways of producing food. In the next 20 years, controlled environment agriculture, genetically modified organisms, and urban farming can play a big role in modernizing current food systems. Growing food in the cities can highly contribute to the development of them and it opens up for alternative farming techniques (Haley, 2013). One of these alternatives is an *aquaponics system*; one can grow plants and fish at the same time in a controlled

environment (Haley, 2013). The system can run without using fertilizers, thus it can be considered as an organic food production. It can be set up in arid areas, where it is especially important to have a water-efficient system. In fact, it reuses irrigation water in a very big percentage (95-99%), as opposed to conventional farming, where changing water is unavoidable. The minerals that are essential for plants, for example, potassium, phosphorus, are recycled in an aquaponics system. These, being non-renewable resources, are very important for the future of agriculture to keep in recirculation. Therefore, it could contribute handling both ecological and social challenges (Goddek et al., 2015). The background studies used for this research suggest aquaponics as a tool for education in primary and secondary schools. As it already turned out it is excellent for teaching food literacy, system thinking and science in general (Junge et al., 2014; Bosire, Sikora, 2017). However, there has been a little research on how an aquaponics can be the part of the STEM model. For this paper, an aquaponics system is used to incorporate STEM, thus the context is sustainable agriculture and how is that part of food literacy.

1.2. Overall research problem

Different kinds of research, both quantitative and qualitative, have already been conducted on teaching food literacy and promote system thinking, and how an aquaponics system can serve as a tool for that. This paper will build on previous studies summarized in the state of the art chapter. The missing part from these studies is the digital component, which is necessary for monitoring an aquaponics system and keep it operating. The utility of measuring with sensors in order to enhance STEM-based learning is still an unexplored territory, and the actual potentials of it are unknown. A few studies have already tried to unfold the potentials of an aquaponics system to teach food literacy (Bosire, Sikora, 2017; Clayborn et al., 2017) although very little has been done on the sensors part and including it in STEM-based learning. Aquaponics has been used to engage students with STEM education (Wu-Rorrer, 2017), although there is not much focus on which grade it should be implemented in and in which aspects of food literacy it can be used.

1.3. Research question and sub-questions

Research question:

> How will the integration of an aquaponics system with sensors possibly influence students' engagement of food literacy and contribute to STEM education in a primary school biology class?

Sub-questions:

- *How can the sensors contribute to STEM education in a primary school?*
- *What is food literacy?*
- *Does STEM belong to elementary school?*
- *Why is it important to teach food literacy with an aquaponics?*
- *What does it take to integrate a simple aquaponics system for STEM education?*

The aim of the sub-questions is to fold out the research question, the issue that this research places its fundaments on. It aims to clarify what this research focuses on, so these questions can be answered in the following pages.

1.4. Aims of the research

This master thesis is sought to explore the potentials and effectiveness of aquaponics in an elementary school in order to incorporate the STEM disciplines. It will allocate aquaponics and food literacy in the central context of the STEM, since the aquaponics system considered to be the manifestation of food literacy. The unit used by Bosire, Sikora (2017) will be replicated in a different elementary school, and it will be built and used by 8th-grade students in Herstedlund Skole, Albertslund. Furthermore, the utility of sensors for the aquaponics project will be analyzed, and its potentials will be examined with regards to STEM education. The factors of water quality such as temperature, pH, ammonia and nitrate content will be measured with sensors by the students. The aim is that the students learn about food systems and sustainable agriculture, in the classroom where the aquaponics unit is set up thus they can enhance their food literacy. The students will maintain the system and they can learn about the basic disciplines of STEM education along with sustainable

farming. Additionally, children will work in groups, and organizing their work will be able to provide cooperative skills. As a result, the outcomes of the intervention will be evaluated.

1.5. Delimitations on the research

The sensors were a necessity for the research, this being the gap in the literature review and because this component serves as a fundament for STEM education. However, tools like these can be rather expensive. The chosen primary school is very well equipped, they have received a funding for new materials to use in biology and chemistry classes. The school has bought sensors to measure dissolved oxygen, carbon dioxide, nitrate and ammonia, pH and temperature, and an interface that collects data. It has to be mentioned for future reference that these sensors are rather expensive, although for this project it did not mean a financial problem. Furthermore, the testing period will be relatively short-term, thus there is not enough time to try it with every subject that could be relevant with regards to aquaponics. As a specification, it is implemented in biology class, although as it will be presented in the state of the art it can be used for various other subjects. Due to the nature of qualitative research, there will not be any pre-test, after-test that the students have to take in order to measure what they have learned. Instead, the investigation will focus on their attitude towards the system, which the observations and focus group interview will provide data for.

1.6. Background studies: aquaponics in schools

This master thesis attempted to investigate the most recent studies conducted on aquaponics as a teaching tool in elementary and secondary schools, by examining its potentials for teaching purposes (Junge, 2015, Bosire, Sikora 2017). These are going to be used for this master thesis as background studies. The scholars have investigated how can one build an aquaponics model and install it in a classroom. Bosire and Sikora (2017) aimed to use it to enhance food literacy among elementary school. Junge (2015) tested whether it contributes to students' system-thinking to enhance their competencies of knowledge. These studies have already provided suggestions on how to build a unit and how to operate it. This paper, however, will allocate an already existing and simplified version of aquaponics unit in a classroom, the place that it was designed for. The same system from the research of Bosire, Sikora (2017) will be used, with one difference from the technological point of view;

in the study conducted the aquaponics system will operate with sensors, so the students can measure certain variables and collect data to improve the ecosystem.

1.7. Definitions

Accommodation: *"The difference made to one's mind or concepts by the process of assimilation. Note that assimiliation and accommodation go together: you cannot have one without the other."* (Joubish, Khurram, 2011:1261)

Aquaponics: *"Aquaponics is a potential sustainable food production system that integrates aquaculture with hydroponics in which nitrogen-rich effluent from the fish production is utilized for plant growth."* (Wongkiew et al., 2017:9)

Assimilation: *"The process by which a person takes material into their mind from the environment, which may mean changing the evidence of their senses to make it fit."* (Joubish, Khurram, 2011:1261)

Food miles: *"roughly a measure of how far food travels between its production and the final consumer"* (Weber, Matthews, 2008:3508)

Food supply*: "Supply Chain as a sequence of (decision making and execution) processes and (material, information and money) flows that aim to meet final customer requirements, that take place within and between different stages along the continuum, from production to final consumption. The Supply Chain not only includes the producer and its suppliers but also, depending on the logistic flows, transporters, warehouses, retailers and consumers themselves."* (Vorst et al., 2007:7)

pH: *power of hydrogen*

RAS: *recirculating aquaculture system*

SEWDM: *Student Engagement Work Design Model* (Wardly et al., 2016)

STEM: *The acronym that stands for science, technology, engineering, mathematics. A type of education, that focuses on these realms of science in a holistic approach.* (Bybee, 2010)

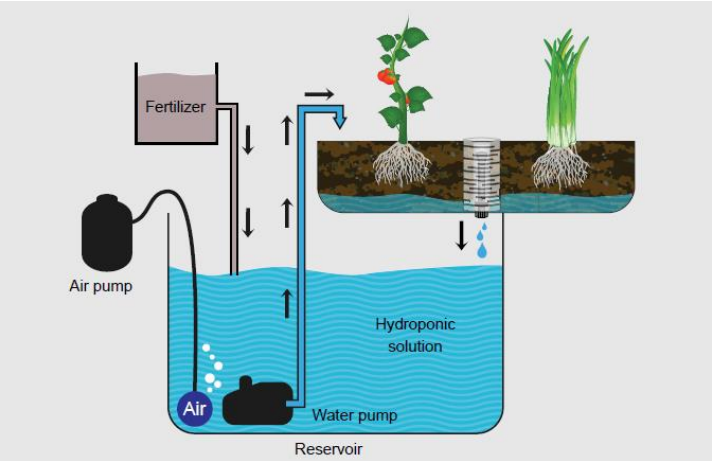
Sustainable agriculture: *'Sustainable agriculture consists of agricultural processes involving biological activities of growth and reproduction intended to produce crops, which do not*

undermine the future capacity to successfully practice agriculture…. sustainable agriculture consists of agricultural processes that do not exhaust any irreplaceable resources which are essential to agriculture.' (Lehman et al., 1993:139)

2. Aquaponics

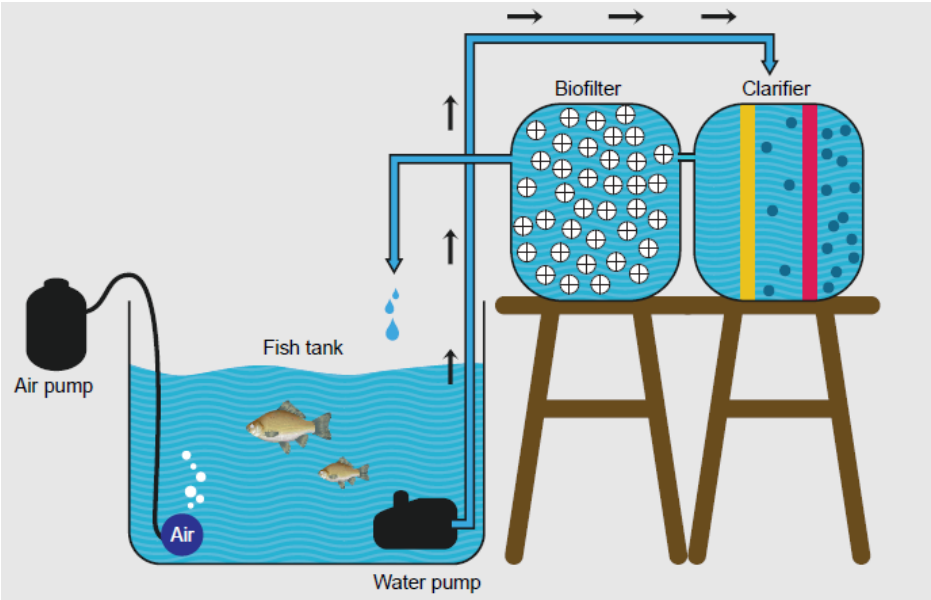
This chapter aims to explain the facts and figures of a basic aquaponics system. It is a technological part preluding the state of the art, thus the reader can understand *what* an aquaponics system is precisely and how it works. The focus is on small-scale production since a simplified model will be applied for conducting this study.

Aquaponics is a food production system that is considered to be sustainable for many reasons. An aquaponics system can be set up almost anywhere and it can bring socio-environmental changes (Goddek et al., 2015). It integrates two alternative farming systems: a hydroponics unit and an aquaculture. A hydroponics system is the most commonly used soil-less culture, which means the growing plants are standing in some kind of media such as rocks or plastic instead of soil. This media provides water retention and holds the plants steady. There is an irrigation system built into this media, and the irrigating water is full of added nutrients, therefore the plants are able to absorb everything they need from this solution. Hydroponics has many advantages, for example, due to lack of soil the soil-borne diseases are eliminated because there is no substrate for these bacteria. This way the use of chemical fertilizers can be spared. Hydroponics can overcome the problem of soil-degradation, and it can be set up in regions, where the soil is not arable. This means it can supply food in such areas and provide a step closer to food security. The produced food and the consumed food take place in the same area, which means the food-miles can be reduced to almost zero. Moreover, it has a higher efficiency in terms of water and fertilizer usage. In the limitations, the need for electricity and high initial installation cost has to be highlighted (Somerville et al., 2014).



2. Figure 1. A simple hydroponic system in work (Somerville et al., 2014)

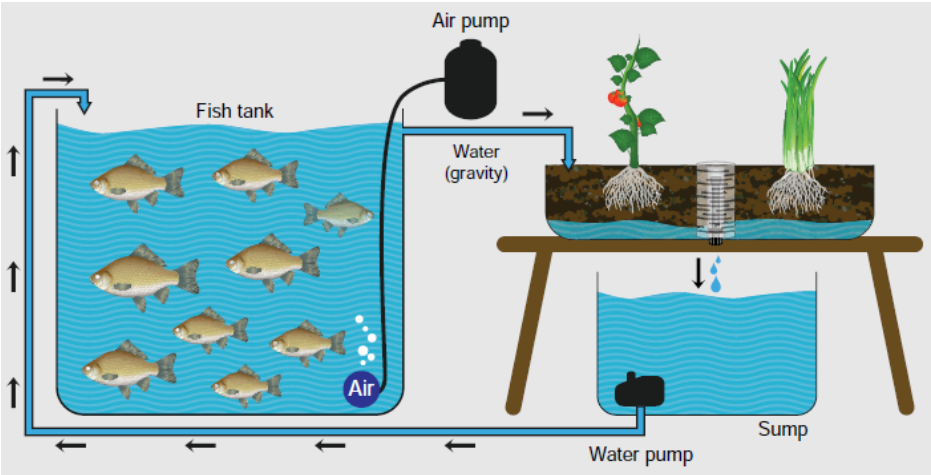
The second part of an aquaponics system is an aquaculture; producing fish and other aquatic animals in a controlled environment. There are four types of aquacultures: open water systems, flow-through raceways, pond culture and recirculating aquaculture systems (RAS). The last one recirculates the water through a biofilter, which cleans the water from the fish waste (Somerville et al., 2014). It is highly water-efficient because a RAS can reuse up to 95-99% of the operating water. Due to overfishing, the world's oceans are over-exploited, although the demand is still increasing for fish consumption. This is how producing fish in aquacultures have become the fastest expanding food sector (Goddek et al., 2015).



2. Figure 2. A simple recirculating aquaculture system (RAS)

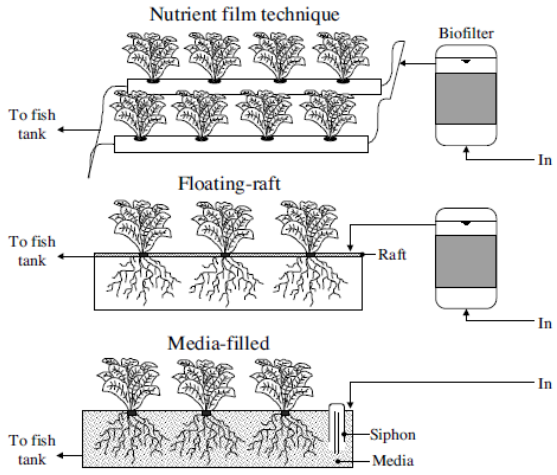
(Somerville et al., 2014)

In an aquaponics system, the biofilter (2. Figure 2.) is technically some kind of plant that the placed in the hydroponics system. The water, which is polluted with fish waste, is toxic for the fish, but rich in nutrients for the plants (Goddek et al., 2015). This synergy is a mutualistic relationship, that both living systems benefit from by eliminating disadvantages and turning their weaknesses into strengths. This means the cost of cleaning the aquaculture can be saved, and the plants get a nutrient rich solution.



2. Figure 3. A simple aquaponics system (Somerville et al., 2014)

There are three types of aquaponics system based on the formation of the grow bed: nutrient film technique, floating-raft and media-filled. The most commonly used is the floating raft (deep water culture) where the plant's roots are always in water, so they can absorb the nutrients directly. However the simplest version is the media-filled, the grow bed contains clay beads or stones. There is no need for biofilter because the rocks are providing a surface for the bacteria, it is a microbial substrate in the nitrification process (Goddek et al., 2015). A mechanical solution called siphon-bell is built in the middle, which controls flooding and draining the grow bed in a very simple way. It only uses the vacuum force thanks to its structure. Accordingly, it is also known as flood and drain system (Wongkiew et al., 2017). Another advantage of this type of aquaponics is that the rocks are helping in the mineralization process. Keeping the unit simple as possible and easy to handle was a major contributing factor for this project, therefore for this type will be implemented.



2. Figure 4. The 3 different kinds of AP system (Wongkiew et al., 2017)

There are macro- (C, H, O, N, P, K, Ca, S, Mg) and micronutrients (Fe, Zn, Mo, Cl etc.) that are essential for plants. They are able to use it for assimilation in mostly in ionic form, except for C, O, and H which are absorbed from water and the air. In case of an aquaponics system the abovementioned ions are solubilized in the water from the fish waste, thus the plants are able to utilize them. Nitrogen is one of the most important elements for the plants; it is a building block of DNA, proteins and other cell components. Usually, the plant absorbs it from the soil in ionized form, or in case of an aquaponics system from the water of the aquaculture (Somerville et al., 2014). The initial source of nitrogen is coming from the fish feed that the fish excretes in ammonia form after digesting it. Then the ammonia goes through a process called nitrification when it oxidized to nitrites by nitroso-bacteria (for example Nitrosomonas sp.). This is followed by the nitrites transforming to nitrates (NO_3^-) by nitro-bacteria (Nitrospira sp, Nitrobacter sp.) (Goddek et al., 2015). The latter one, alongside ammonium (NH_4^+), can be absorbed by plants, so it can start assimilating it (Wongkiew et al., 2017). These processes are a part of the nitrogen cycle, the bigger picture of how nitrogen circulates in nature. Phosphorus is another macronutrient that is essential for plant growth, both vegetative and flowering stages. Research on aquaponics shows that the phosphorus level is often not sufficient and this element has to be added to the system occasionally (Goddek et al., 2015).

There are several variables that are crucial to monitor in order to keep an aquaponics system working. These are as follows:

1. Total nitrogen (ammonia, nitrite, nitrate)
2. Temperature
3. pH
4. Dissolved oxygen
5. Water hardness (Somerville, 2015)

There are different ways of measuring nitrogen because this element can be present in three different ionized forms. Either in nitrite form (NO_2^-), which oxidates to nitrate form (NO_3^-) or in ammonium ion form (NH_4^+). These contents in the water in high quantity are toxic for the fish, especially the nitrite form. It has a very high affinity to bond with the red blood cells, blocking the space for oxygen (Somerville, 2014).

However, by measuring nitrites the content of nitrate can be derived as well, as the former will transform into the latter. Therefore as the nitrite content decreases the nitrate content will increase. Measuring and stabilizing pH is also very crucial. In the system, there are three different organisms, plants, fish and bacteria and all of them require variant pH optimums. These are enlisted in 2. Table 1.

organism		**pH**
plants		6.0 - 6.5
fish		7.0 - 9.0
bacteria	*Nitrobacter*	7.5
	Nitrosomonas	7.0 - 7.5
	Nitrospira	8.0 - 8.3

2. Table 1. pH optimum for living organisms in an aquaponics system (visualization after Goddek et al., 2015)

Each bacteria has different optimums (e.g. temperature and pH), which means under certain conditions they grow the fastest. The most important bacteria with regards to nitrification process are *Nitrosomonas sp*., *Nitrobacter sp*. and *Nitrospiras sp*. The optimal pH for each bacteria is also shown in 2. Table 1. For the overall nitrification process, the optimum is approximately 7.8 (Goddek et al., 2015).

3. Literature Review and State of the Art

In this chapter, a systematic literature review will be presented that aims to provide basic understanding of the topic. The first theme is about STEM education in general, its current role and future plans. The second is about food literacy and sustainable agriculture, to show its relevance in today's world. Lastly, it will give a comprehensible review of studies that have already used aquaponics for teaching purposes.

Searching terms were: *STEM, food literacy, sustainable agriculture, aquaponics and education*

Searching platforms were: AAU EBSCOhost, ScienceDirect, Google Scholar

3.1. STEM education

The acronym of STEM stands for *science, technology, engineering,* and *mathematics*. It is a concept that originates from the National Science Foundation, from the 1990s, and has been applied in many contexts, teaching among others. This educational framework is very often used in relation to graduate and post-graduate courses seldom it concerned with elementary or secondary school settings. However, it would be very important to implement it as a program in earlier ages, as it can enhance the value of the contemporary education (Bybee, 2010).

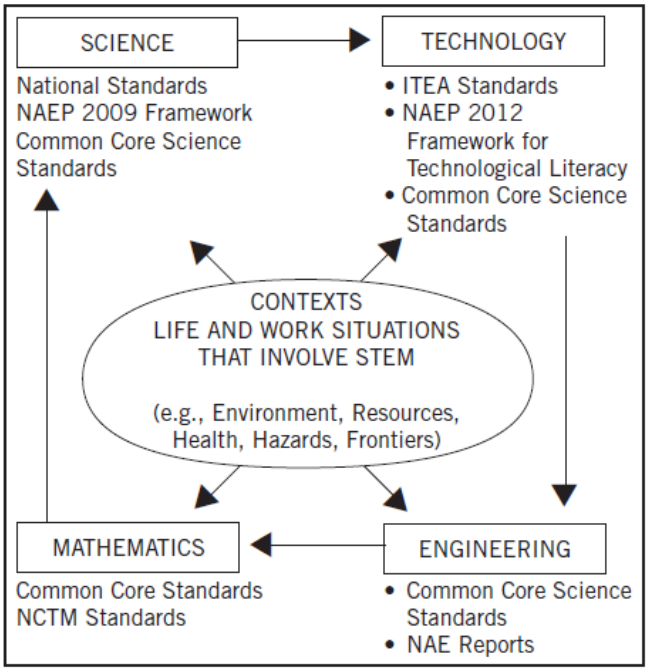
There is already evidence that it is important to start applying STEM disciplines in an earlier state than graduate programs; it can be highly advantageous to imply it in elementary and high schools as well (Schneller, 2015, Wu-Rorrer, 2017). First and foremost STEM education provides scientific, technological, engineering and mathematical knowledge, and it also includes how to apply this knowledge on real-life issues (for example health, climate changes or frontiers of science). Therefore students can be engaged to deal with these problems, and they can learn and figure out solutions as citizens as well. Another purpose of this kind of education is that students gain certain abilities and skills along the way, and they learn how to coop with a problem on the individual, social and global levels (Bybee, 2010).

According to Vennix et al. (2017), students are more likely to pick a STEM-based university course, if they engage in these branches of studies at an earlier age. According to other studies, it is also important to improve procedural skills at an earlier age that are useful and necessary to learn in order to coop with certain issues in the world. These are called the 21st-century skills, for example, are problem-solving, system-thinking, communication, which are strongly incorporated in the STEM disciplines. It may look self-evident that these skills are usually the characteristics of engineering courses and applied sciences, which are also elements of the STEM (Vennix et al., 2017, Junge et al., 2014, Bybee, 2010).

Bybee (2010) shows us the disciplines of STEM presented in a simple model (3. Figure 1.). The model has four units, (*science, technology, engineering,* and *mathematics*), and these are integrated into one meta-discipline (Bybee, 2010; Wu-Rorrer, 2017). It also shows what different kinds of standards they have to live up to. What is more important, however, to point out that every bit of the model is placed in a certain *context*. This central problem or theme addresses a real-life situation, an issue that requires a solution and a problem-solving method from the STEM-based learning tools (Bybee, 2010). It is also important to incorporate a contextual problem if the aim is to build an interdisciplinary curriculum (Wu-Rorrer, 2017).

This context that is in the center of the elements, is the key to understand how context-based STEM education is built up. It can be broken down into three levels: personal (individual plus family, peer groups), social and global. Bybee (2010) stresses that there are 6 main groups of discussion that can be used as a context: health, energy efficiency, natural resources, hazard reduction, environmental concerns and frontiers of science. Given the fact that aquaponics entails natural resources as a context, let's see an example for that with regards to how that manifests on different levels. The personal or individual level starts with the very end, the consumer of food. The social level is how the food is produced and distributed, how food security can be ensured in our community, and what energy sources are used for the production. On a global level, certain problems can be addressed, such as over-population of the globe, how the sustainable version of production can be applied all over the world, and distinguishing renewable from non-renewable natural resources (Bybee,

2010). The disciplines of STEM can help understand and deal with these issues that the students will also face as regular citizens later on.



3. Figure 1. Framework for modeling STEM units (Bybee, 2010)

The study of Wu-Rorrer, (2017) aims to investigate how an aquaponics system can contribute to STEM education in elementary schools in order to get children engaged in such topics. The STEM model formulates a concept that provides a holistic view of its elements, instead of focusing on single subjects. The context is usually a problem that our world is currently facing, and this issue is in the center of STEM disciplines. This context can be, for instance, in the realm of health, environmental quality or energy efficiency (Bybee, 2010). This paper aims to allocate aquaponics and sustainable farming in the context, addressing issues such as scarce natural resources, production of food with high food mile. When it comes to defining STEM disciplines, people often only conceptualize the science and mathematics bids of it (Bybee, 2010). It is not easy to implement the abovementioned goals of the STEM, so it effects students positively in elementary and high schools. Special programs have to be developed and the schools have to take technological or engineering courses. It requires well-organized programs which are designed for reaching the required learning outcomes (Bybee, 2010).

Indicating that active learning is in strong relation with STEM education, Freeman et al. (2014) conducted a study to investigate whether there is a correlation between active learning and student performance in STEM-based learnings. Their hypothesis was formulated by opposing lecture-based teaching to the preferred interactive classes. They defined active learning as a method that *'engages students in a process of learning through activities and/or discussion in class, as opposed to passively listening to an expert. It emphasizes high order thinking and group work'* (Freeman et al., 2014).

In this quantitative research, 225 different studies were meta-analyzed, targeting students' performance in undergraduate STEM courses. The results clearly show that students taking traditional lectures fail 1.5 times more likely, and it steps down in favor of active learning (Freeman et al., 2014).

3.2. Food literacy

Food literacy is not easy to define. It is a relatively new term that includes various things; for example, where the food comes from, what is a healthy diet, what are the nutrients the human body needs, how to prepare food, etc. The term most often comes along with health literacy, which by Nutbeam's definition: *"The cognitive and social skills which determine the motivation and ability of individuals to gain access to, understand and use information in ways which promote and maintain good health."* (Nutbeam, in Ronto et al. 2016: 824). In the research of Ronto et al., (2016) one of the teachers who promote food literacy in schools defined it as: *"having the knowledge, skills and the capacity to source, prepare, cook and share food in a sustainable manner to promote a healthy and balanced lifestyle" (*Ronto et al., 2016:824).

Another paper tried to investigate, what other aspects the term could include. Truman et al., (2017) found and presented 22 definitions for the emerging term in their study. After making a scoping review, the identified definitions were analyzed and the main objectives were divided into six themes. Therefore they tried to conceptualize the term and capture it in a broader sense. These themes are the followings: culture, food and health choices, emotions, food systems, knowledge about food, skills and behaviors (Truman et al., 2017).

In the paper of Ronto et al. (2016) the views of secondary school teachers were investigated about food literacy. This research aimed to find an answer for how to promote healthy food choices and cognitive skills of making food. The teachers wished to include food literacy under the subject of Home Economics. This paper also found it important to stress that food literacy has many aspects, just like in the paper of Truman et al. (2017). Healthy dietary intakes, food safety, environmental sustainability, food chain are all part of the term just to highlight some. Ronto et al. (2016) concluded that secondary schools seemed to be a good choice for the place of such interventions in order to teach food literacy.

One of the recently conducted studies, Nanayakkara et al. (2017) focuses on the importance of food literacy in Australia in order to strengthen the connection between citizens and the food system. They argue, that not only adolescents, but citizens in general, lack knowledge on how the food is produced, where it comes from, and every other step of the food supply process. The wider and more complex our food system becomes, the more difficult it is the get a full grasp of it. Nanayakkara et al. (2017) investigated food system professionals' opinions on the importance of teaching it in secondary schools. According to this paper, food literacy in a broader sense also includes knowledge about food production and avoiding food-waste. Instead of searching for a definition, the answers of the respondents were divided into four different themes: food systems; health and well-being; socio-economic, cultural and environmental aspects; skills to manage, prepare and eat food. In the previous years, there was a high emphasis on the latter, how to teach cooking in schools and under which subject. Some of the experts interviewed for this study stated, that teaching food literacy should start in primary schools (Nanayakkara et al., 2017). The same paper shows how teaching food literacy in a broader sense can become part of the curricula. The local authorities initiated a project in order to incorporate it in secondary schools. The new subject was called Food Studies, and it included knowledge about accessing food, food production and the cultural roles of food. This subject could be chosen by students from the age of 11-12.

According to Schneller et al. (2015), teaching with aquaponics could be in strong relation to STEM education. This study was conducted in the United States and it initiates that aquaponics can serve as an appropriate tool for food literacy. It claims that aquaponics

entails topics such as food systems and sustainability thus these issues could be in the center of STEM education. As it was presented in the model of Bybee, 2010 (3.Figure 1), it is necessary to utilize a problematic topic for STEM education that requires a solution. This research clearly shows that the term is not only about healthy and nutritious food choices but also includes the complexity of today's food systems (Schneller et al., 2015).

The abovementioned studies show that food systems, sustainable food production, the source of the food are important parts of food literacy. This master thesis will assess food literacy from this aspect; in the spotlight, there will be aspects such as sustainability, food production and natural resources. It appears that so far this aspect of food literacy was not emphasized, most of the studies presented in this section have put more focus on cooking skills and defining healthy food, and why this is important. The sustainability element, as argued by (Schneller et al., 2015) is just as important with regards to food literacy, if we want to raise a generation that cares about the future. By educating where the food comes from, how it is processed, what it means to 'think globally, buy locally' and the children can understand the significance of sustainability in the 21st century. The relevance of teaching these topics is part of the big picture, where we do not sacrifice today's land and water for food production in the future.

3.3. Aquaponics as a form of sustainable farming

The world's population is constantly growing and according to the United Nations Human Development Report by 2050, it will reach 9.7 billion. In 2014 more than 50% of the world's people lived in urban areas, by 2050 this number will grow to 66%. Planned urbanization has a positive effect on economics, it creates value for the global gross domestic product (GDP), nearly 80% of it is due to people living in urban areas. Therefore, it has to be followed by a modern infrastructure and networks, not to mention the higher demand for food and food transportation. On the downside, if the urbanization is unplanned the population's quality of life will decrease, issues with sanitation, transporting food and food security will grow (UNDP, 2016). If the food is not grown locally and does not come from a sustainable agricultural system then the negative effect on the environment will thrive, and the globe will keep running out of natural resources (UNDP, 2016).

The world is facing problems like soil-degradation, water-scarcity, different kinds of crop diseases and climate change. The arid regions are rising, and the availability of fresh water is highly limited (Haley, 2013). Moreover, important factors are the distribution of the food, whether it comes from a sustainable source, and also decreasing food-mile would also be a vast contributor to sustainable food production, the length of the journey from farm to fork or food supply chain. Aquaponics is a type of urban farming that could contribute to overcoming the abovementioned problems. It is an innovative way of aiming for environmental sustainability. Moreover, it can provide an alternative for other polluting technologies in the food production system, and can reduce transportation time (Lampreia dos Santos, 2016). The food can be grown locally, therefore the food-mile can be close to zero. The system is highly water efficient, and it can run without using pesticides or chemical fertilizers (Somerville et al., 2014). Growing food in a sustainable manner in the cities is not only good for the environment, but it also supports local agriculture, ensures fresh food, which is higher in nutrients and minerals. These qualities in greens and vegetables can decrease with the long transportation time and with the storage of food (Weber, Matthews, 2008).

As it was presented above, food literacy entails a big variety of topics and skills. The reason behind the focus on the sustainable food production is to allocate a problem in the middle of the STEM disciplines (3. Figure 1.) As the previously mentioned papers suggested, it could provide a discussion for STEM that other bearing of food literacy would not: where the food comes from, how it is processed, what is sustainable food production.

3.4. Aquaponics as a teaching tool to enhance food literacy

In the followings, four papers will be summarized, that have been looking for justification to utilize aquaponics systems as a teaching tool. Some of them focused on the students' perspective, while others were investigating teachers' motivations and perceptions about this technological apparatus.

A study conducted in Florida by Clayborn et al. (2017) was measuring teacher's engagement after installing and integrating a unit in the classroom. The aim was to evaluate, whether they would like to set up such system in the classroom for teaching purposes. The teachers got 'training' in aquaponics, that included knowledge about the construction and

maintenance, and they also learned about the fundamentals of the system. It was measured by taking a pretest and a posttest, and they were divided into two groups: a control and an experimental one. Clayborn et al. (2017) also focused on why gardening projects in elementary and secondary schools are getting more general in the United States. Aquaponics incorporates exploration, cooperative work and problem-solving, and it also gives an opportunity to show agricultural techniques and fresh food for the children. This can introduce challenges such as sustainability, modern food production, and urban hunger. By accessing different studies out there in this field, a trend can be identified: more and more facility has the interest to try aquaponics systems instead of regular gardens. Its main advantage that it is well suited for urban areas, urban schools especially, where the soil can be scarce (Clayborn et al., 2017). Besides the many advantages, however, it may seem like a big commitment from the teachers' point of view. The system is quite difficult to maintain, and it requires engagement, a lot of effort and technological knowledge to use it for educational purposes. Moreover, it is rather expensive to build it and to keep it running.

Another paper relevant to this research was written by Junge et al. (2014). In this study, three classes of 7th-grade students were participating in an invention, where they had to plan and construct an aquaponics system in the classroom. It was conducted in Switzerland, in Mutschellen city, the agglomeration of Zurich. The students were working in groups of six in the operational and the system monitoring processes. The main idea was to promote system-thinking by using aquaponics as a tool. It means the kids could learn thinking in models, and focusing on the connections, instead of single parts the system consists of. With these skills, they are able to explore complex problems. It was part of the daily routine that the kids had to write a diary called "Aquarium Journal" with all their observations. During these weeks the teachers were giving lectures about aquaponics in general and basic system concepts (Junge et al., 2014). A pre-test was taken by the children before the project was launched, and a post-test after it ended. Junge et al. (2014) got positive results after the program finished, the kids were able to think in relations instead of focusing on the single elements of the system. Due to the positive effects the researchers concluded that the use of AP system in the classroom can be effective to train *system-thinking*. However, some of the disadvantages of working with such system also have to be mentioned. According to one of the teachers, the aquaponics has a long installation time, and the cost of the unit is rather

expensive. Additionally, they had to supervise every movement, even though the kids were responsible for the success of the system. Nevertheless, the conclusion is that the pros of the method outweigh the cons.

Another paper used for the background is a master thesis was written at Aalborg University, Bosire, Sikora, 2017. This is an action research where an innovative aquaponics system was tested in a primary school environment. They tried to investigate the potentials of aquaponics system for education, the main goal was to build a cheap, small-scale unit as a teaching tool. The point was to enhance food literacy as the kids are using this unit in biology class. Semi-structured interviews were conducted, also one focus group interview with the pupils. The thesis also investigates what kids could do and what they could not, what do they need help with. The goal was also to make it less expensive, so the price would not be a barrier. Bosire, Sikora (2017) applied theories such as *problem-based learning, experiential learning* and the *Zone of Proximal Development*, due to the nature of a hands-on project. All three of them have their fundaments in genetic epistemology, constructivism as such.

A case study conducted in the United States investigated the potentials of indoor gardening in 5th and 6th grade, both hydroponics and aquaponics (Schneller et al., 2015). These farming techniques set up in the school provide a hands-on project for STEM education. According to Schneller et al. (2015), it creates a discussion for food systems and sustainability. As a disadvantage, they have also highlighted the extra time, money, and equipment these systems need for the construction and maintenance. The reason for these types of farming is because outside gardening is usually accessible from May until September, which period is not sufficient for schools due to the long summer break. Aquaponics with proper maintenance, however, can run indoor around the year (Schneller et al., 2015).

To sum it up the importance of changes in the current conventional farming techniques is unquestionable and inevitable in the future. The problems that our world is facing are emerging, and there is a call for sustainable solutions. An aquaponics system can be considered as one of the answers, as it entails advantages like water-effectiveness, natural purification system, and soilless gardening. Teaching food literacy in schools is a growing phenomenon in countries like Australia, Switzerland, United States or Denmark, where aquaponics is used as an educational tool. In these studies, there is not much emphasis on

students working with digital components, such as sensors for measuring water quality. This paper aims to expand the definition of food literacy and focus on sustainability and alternative farming, as well as to investigate the gap in the literature search that appears to be the digital sensors.

4. Theoretical framework

The theories in qualitative research are aimed to describe social phenomena, to create a universal concept that helps understanding it. In this section, three different kinds of theories will be presented and summarized at the end of the sub-sections. These ideas will provide perspectives for analyzing the collected empirical data and the literature review. By giving an overall view of these ideas, the aim is to make it clear and comprehensible to the reader, to present the potentials of them in order to fold out the research question.

As it was presented in the state of the art, active learning context-based learning, and experiential learning have been brought in relation with STEM education (Freeman et al., 2009, Wu-Rorrer, 2017, Bosire, Sikora, 2017). As for pedagogical tools for aquaponics, problem-based learning and the theory of the Zone of Proximal Development were investigated (Bosire, Sikora, 2017) There was a high potential of using these theories, however, after considering this option, it seemed more interesting to approach it from another perspective. Therefore, constructivism will be used as one of the theory and it will serve as a background of children's development, especially in the age of the 8th graders, 12-13 years old. Moreover, the utilities of outreach activities regarding STEM education will be explained. Furthermore, the theory of co-creation will be applied. Aquaponics is self-evidently a hands-on project, thus it seemed reasonable to investigate the utility of interpreting the aquaponics project as a co-creational process.

4.1. Constructivism and its implications

Constructivism claimed to be a psychological interpretation of constructing knowledge, rather than a scientific theory. Fundamentally it states that knowledge is not static, but a dynamic process that is created in people's minds. Human beings constantly trying to understand the world and accommodate to their surroundings, therefore they establish the structures of interpretation of the world, which becomes knowledge (Peterson, 1999). Jean Piaget was a pioneer thinker who first developed and applied constructivism. He is known most for his work on children's development, although he considered himself as a psychologist, whose primary field is genetic epistemology, genetic being defined as the way

knowledge is born. Epistemology refers to knowledge structures, the architecture of apprehension (Campbell, 2006). One of his well-known book with regards to children's development is called *The Origins of Intelligence in Children,* which determined his significance in the field of developmental psychology. In this book, he states that an object is not relevant itself, human beings are more interested in what to use objects for (Piaget, 1952). It lays the basics of constructivism, stating that knowledge does not start with the individual, or with the objects, but generates through the interactions in between the two. As Piaget stated, this development is simultaneous and reciprocal, and it can be seen as a dynamic process rather than static:

"Knowledge does not begin in the I, and it does not begin in the object; it begins in the interactions… then there is a simultaneous construction of the subject on the one hand and the object on the other." (Jean Piaget, in Peterson, 1999: 318)

This is one of the things that differentiate humans from other species. Our tool using ability is very highly developed, so much indeed that human do not really just see the objects, but see their purposes and how can we use it as tools. Children are learning through their experiences with products, artifacts, especially when these are meaningful and relevant to them (Campbell, 2006).

Piaget labored most in his life analyzing how humans structure knowledge in general. His most famous work, however, is about children's cognitive development, how they improve their process of perceiving and generating knowledge. His theory is based on genetic epistemology, also known as the 'the origin of knowledge'. He analyzed children's perception with clinical methods, using clinical interviews (open-ended questions to the children to reveal their way of thinking), but he also used ecological observation of his own children for his studies, although he did not consider himself as an empiricist. He has been a target for criticism, due to other psychologists questioning the validity of this method (Campbell, 2006). There are three different stages of knowledge that can be distinguished. First, there is initial knowledge, second, when people encounter a new situation that requires new ways of solution, they find themselves in an unexplored world. Third, when they got through the second phase and gain new knowledge they are able to use in that given new situation (which is not so new now after all). Therefore this is the ultimate

knowledge, which is the product of learning. Later on, this can become the initial knowledge again, therefore a loop is created. This means, according to Piaget, that the stages of knowledge are not real, but the process while people's minds jump between these stages (Campbell, 2006). This process can be either *assimilation* or *accommodation*. The former means that knowledge is developed by adding new information to a schema in people's mind, to learn something new in a particular scenario and *assimilate* it into the knowledge structure. This schema is developed by pattern-recognition. Accordingly humans can recognize a phenomenon and act out the schemas in similar, but new situations (Piaget, 1952). The other type of process is accommodation, when there is a new, unexplored situation where the already built schemas will not work, so a different way has to be discovered to interpret things. Humans then will try to apply what they already know and create a new schema by altering the existing one. This way we *accommodate* to the recognized pattern and build it in our knowledge structure. Therefore, assimilation is giving something to the schema, accommodation is changing the schema. The two together reconstructs the knowledge structure, quasi continually, and this process is knowledge itself. The two processes go hand in hand, both are a type of adaptation (Joubish, Khurram, 2009).

Jean Piaget identified four stages of cognitive development, which are distinguished by the level of abstraction. By this term, Piaget means that one can get to know their actions, be aware of it, or know how those actions are coordinated. It also means humans do not always have to act out certain patterns but can think it up abstractly and predicate the consequences of that action. These stages are following each other in time, building on each other (Ojose, 2008). These are as follows:

Sensorimotor Stage

In the first stage, the children learn how to act, but does not know why they act the way they do. Sensorimotor intelligence develops from birth around until the children start to speak. At this stage, they are not able to adapt to the world in an abstract form. They cannot foresee reactions, and in this age, they only learn through trial and error. They start to learn how to link numbers to objects, and numbers can be identified as the first glimpses of abstract thinking (Joubish, Khurram 2011).

Preoperational Stage

In the preoperational stage, children enhance their egocentric views, at the age of 2-7. A good example of that is one of Piaget's experiments with children. If a child faces another person across a table, and there are a number of objects on the table, they can see those from their point of view. Later on, the child is asked to show what the other person sees across the table, and pictures with different point of views of the objects are presented to the child. They will always choose their own perspective, being unable to put their imagination in the other person's view (Campbell, 2006). They are unable to conceptualize a thought and predict the potential outcomes of an action. Operational means working out a thought in the head. At this age they are not able to do that, they need to use their experiences from real life. They start to understand numbers, although they do not know the meaning of ordinal or cardinal numbers, and they need to use their fingers to count (Joubish, Khurram, 2011, Ojose, 2008) Memory also develops at this age, now children also start to develop episodical, not only procedural memories (Peterson, 1999).

It is advisable to introduce certain materials to the children. Working with clay, water, sand, etc., could help them to learn the concept of conservation, that an object may remain the same after it changed in its form, look differently. They also start to understand that an object exists after it cannot be seen it anymore. With the guidance of the teacher, who helps creating a conversation with the children during the class, the students learn how to talk about their actions and understand how they can verbalize what they are doing (Ojose, 2008).

Concrete Operational Stage

This stage begins at the age of 7 and ends when the children are around 11 years old. This is the first period of their life when they start concrete reasoning, understanding objects and actions. Concrete refers to everything that is palpable for the children, that their knowledge generates through experience. By operation, Piaget means the children are able to think through their action and start developing reasoning processes. From the mathematical point of view, it means they can do the main operations, such as adding, subtracting, multiplying and dividing. They also become less egocentric, thus they are capable of comprehending other's perspectives, and incorporate it in their own reality. Clear and understandable

examples have to be provided for explaining more complex problems, and it is preferable to do it through hands-on experiences (Joubish, Khurram, 2011). The importance of hands-on projects with such materials is crucial to include at this education level (Ojose, 2008).

Formal Operational Stage

According to Piaget, this final stage takes place in the age of 11-16. This is the closest to adulthood when the children can explain abstractly their behaviors and describe their actions. One of the most important attributes of this age is that children are learning and operating through co-operation.

"as far as intelligence is concerned, co-operation is thus an objectively conducted discussion… It is clear that co-operation is the first of a series of forms of behavior which are important for the constitution and development of logic." (Jean Piaget in Joubish, Khurram, 2011:1263)

This is where they reach the highest level of abstraction. Children in this stage are able to formulate hypothesizes, analyze them and come up with conclusions. They are able to think about the future, and the first traces of ideological concerns appear (Ojose, 2008). They can think reversely, and when they are experiencing a current situation, they do not think that is the only possible case. Therefore not only their experience is real, but there are also other alternatives and different outcomes that they can work out in their minds. This is what Piaget means by operation; to be able to think logically and abstractly. This also means that they can think over a problem and test their own hypothesizes. They are able to determine the possible solutions and try to pick the right one. This is called the hypothetical-deductive-reasoning (Joubish, Khurram, 2011). Moreover, children learn during this period how to use self-reflection for later improvement. They can work on their own projects and artefacts for a longer period of time if it has an aim that is meaningful and significant for them.

To summarize this fraction let's go through the most important characteristics of constructivism. Knowledge is constructed and organized into higher domains every time humans, in this case, children encounter a new situation. These processes have operative attributes as if knowledge structures changes, and transforms the initial perception into a more complex, abstract version of apprehension. When children shift through from a stage

to another, they use the previously mentioned accommodation process to rebuild their schemas, therefore the stages cannot be skipped (Joubish, Khurram, 2011).

4.2. STEM education and outreach activities

In the field of STEM-based jobs, there are a number of skills required, that are necessary to succeed. These are, for instance, team-work, problem-solving mind, good communication techniques; these are also known as the twenty-first-century skills. In many countries, the education of STEM is deeply strengthened by outreach activities in the last couple of years in order to enhance these important skills. The projects and activities get more and more attention due to its positive effects (Vennix et al., 2017). It is important to improve students' engagement in STEM education and to motivate them, and it also entails the possibility that they might choose it as a career later on. Consequently, outreach activities can help to bridge the gap between real life and the school environment, due to the helpful skills it can provide to adapt to our modern era (Vennix, et al., 2017).

The term outreach by definition means *"the activity or process of bringing information and service together"* (Vennix et al., 2017). This means it can be relatively short-term, for example, one guest lecture, or one day of workshop. On the one hand, a long-term project could be more effective, than just one day of excursion or visiting a laboratory. On the other hand, it takes away time from the regular subjects of the curricula. However one of the main advantages of STEM-based education is that it can be easily integrated with different kinds of subjects in primary and secondary school, such as mathematics, biology, physics or chemistry.

Vennix et al. (2017) highlighted the importance of outreach activities in STEM education in their study. The aim was to investigate the perception of students and teachers in different kind of projects, the so-called 'outreach activities' in a STEM-based learning environment. These activities included for example: working with liquid crystal display (LCD), medical imaging techniques such as X-ray or MRI, creating their own electric circuit and many others. The content of these activities is either a certain environment (company, institute, university) that the students can explore or a product that is placed in the school. The latter gives an opportunity to develop the idea or to make the connection with the scientific topic. The topics of the activities are in strong relation with subjects such as biology, physics,

chemistry, and mathematics. Another characteristic of these activities, that they are usually guided by a person from a company or educational institution. The guide plays an outstanding role in outreach activities because he or she provides a learning environment that differs from school. This person is the connection to real-life settings, to what is happening outside of school. It is their responsibility to motivate the students and to help the educators in the new context. Because of the presence of the guide students are in an environment, where they experience less of the presence of authority, these activities usually less formal than a regular class (Vennix et al., 2017). One of the characteristics of outreach activities is that it works in collaboration with a company or university. It can be determined by the location of the activity, which is either inside or outside the classroom. If it is inside, then it is also the goal of teachers, to make the environment more interesting, to quit the regular classroom settings. It can also be located outside of the school, by visiting a company or institution. In this case, the learning process occurs unconsciously, the students gain knowledge in an implicit way (Vennix et al., 2017).

There have been three elements identified that create an effective STEM learning environment, these are called the basic motivational dimensions. The first one is student's autonomy during the activity; what is their scale of freedom, to what extent are they allowed working on their own. It can be measured for example how often and in what degree the teacher or the guide intervenes in the working processes. The teacher's behavior is significant with regards to controlling the situation, the less they intervene, the better. The need for students making their intrinsic decisions is very important in order to get them engaged, and also for their personal growth (Vennix et al., 2017). The second dimension includes the competence and skills needed for executing the task, for success, there is a need for certain capabilities. The task has to be suitable and challenging, that has to be reassured with positive feedback so it gives confidence to the students. The third one is the necessity for relationships among students, the social aspect of the learning environments. The students are learning from their peers through cooperation. The students are more motivated in an environment where all the three dimensions are equally present (Vennix et al., 2017).

What Vennix et al. (2017) concluded, is that outreach activities can increase the motivation to get engaged in STEM-based subjects, thus such projects can be sufficiently incorporated

into the curricula. In the analysis part, it will be fold out why this project considered an outreach activity for STEM education and to what degree it carries the same benefits.

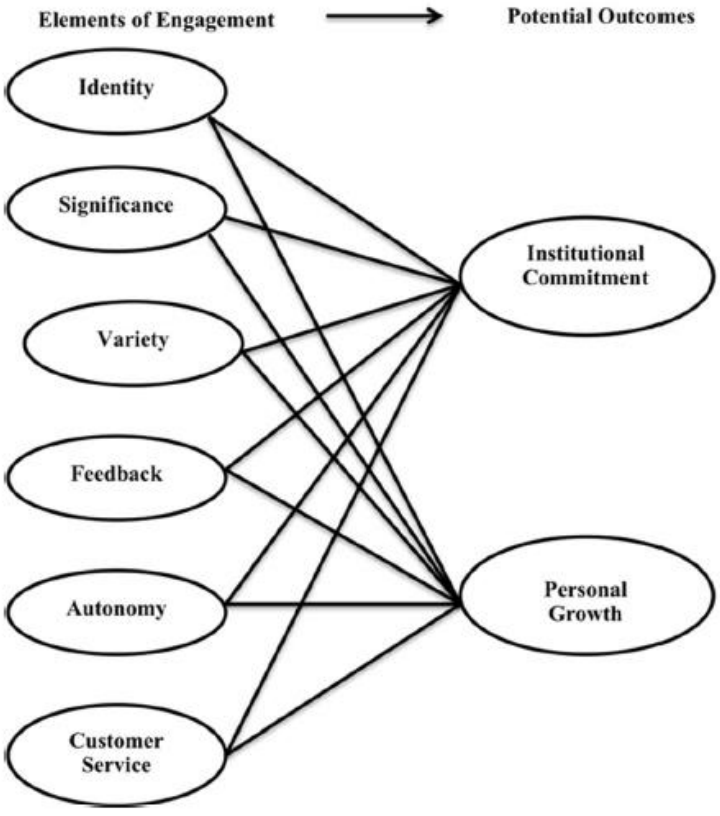
4.3. Co-creation

The term, co-creation, originates from business and marketing strategies. It was first applied in the 1980-ies when companies started to consider consumers as part of the value creation process. The main goal of co-creation is to provide value to the customers by involving them in creating the products or services. Consequently, they become co-creators of the value itself (Prahalad, Ramaswamy, 2004). Later on, it was applied in government and health care settings as well, and it was defined as a *'collaborative creation where stakeholders cooperatively and reciprocally contribute to the value creation process'* (Wardley et al., 2016). Co-creation in the educational context, however, is different if it is utilized for marketing purposes. Students are considered to be co-creators, although they are not consumers of the system. They are engaging in discourses, interactions, and activities in the classroom, thus they are highly contributing to the value production. The end product is an effective learning environment and positive learning outcomes, not consumption, as it is in the original co-creation idea. The motivation behind applying co-creational ideas in education is clear and straightforward: it can evidently enhance learning outcomes and persistence for being interested. This can be managed by adding content that inspires students, therefore there is an internal motivation that drives them. Every action they take is linked to their level of engagement, and action is in a strong relationship with perception. The more positive is the outcome of their actions the more likely they stay motivated. Umberto Eco even utilized and developed it in relation to music therapy (Stensæth, Eide, 2017). In this context the main purpose of the theory is to rehabilitate disabled people, so they can relearn certain skills. His definition is closer to educational settings:

'the act of creating… in conjunction with terms such as action, improvisation, participation, communication, aesthetics and sensory experiences coupled with joy and exploration.' Umberto Eco in Stensæth, Eide (2017).

Co-creation as a theory was adapted to educational environment by Wardley et al., (2016), to investigate its potentials at universities. It places the focus on motivations of university

students, by making the presumption that their work can evolve if they are engaged in what they are doing. Students are not considered as customers, who are the target subjects of the original theory of co-creation, although the intention is the same: trying to enhance their engagement during certain value creation processes. The required values, Wardley et al. (2016) highlight in an educational environment, are eventually personal growth and institutional commitment. These elements of engagement and their potential outcomes are part of the Conceptual Student Engagement Work Design Model (SEWDM) that was developed and exhibited for this study, and these are shown in 4. Figure 1. (Wardley et al., 2016). This model is a new alternative for management of education that is based on Hackman and Oldham's original model, and Wardley et al. (2016), seeing the possible positive outcomes of applying such model in education, altered the model for university settings.



4. Figure 1. Conceptual Student Engagement Work Design Model (SEWDM) (Wardley et al., 2016)

The six independent elements that can determine the level of engagement according to this model are as follows:

1. ***Task identity*** is defined by the degree of students feeling responsible with regards to their work. Students have to see the potential positive outcomes of their work from the get-go until the very end. The end product, in this case, the food that they are growing with the aquaponics, will be the outcome, as well as and the successful maintenance of the system. For this certain tasks has to be executed, and they also have to see, how these tasks are constructed and related to each other (Wardley et al., 2016).
2. The ***significance*** of tasks is perhaps the most difficult to incorporate in the process. It means in what degree the students see the importance of their work and the influence it can make on other people. The students may find it difficult to make their work in the school related to real-life settings (Wardley et al., 2016).
3. ***Variety of skills*** is like a toolbox, that required from students need in order to manage certain tasks and reach their target. This collection has to cover a broad range of versatile skills, so they have the competence to achieve different goals they are aiming at (Wardley et al., 2016).
4. Repeatedly giving ***feedback*** means that other people reflect on performance in an organizational setting. In an educational environment role of feedback is to keep students motivated and to confirm their efforts. Providing frequent and detailed guidance from others, (supervisors, teachers) can help in achieving these goals (Wardley et al., 2016).
5. ***Autonomy*** refers to what extent the students are able to perform tasks independently from authorization, but more importantly what is their degree of freedom. This can be determined by whether the teachers let the pupils express themselves, deal with problems and try to solve them on their own. It also entails the frequency of intervening in certain situations. Rule of thumb is that do not help them do anything if they can do it by themselves (Wardley et al., 2016).
6. The term ***customer service*** relates back to marketing context, although it has to be stressed that students are the main subjects of co-creation, not customers. It means that their experience in educational settings is in the main focus, how it could be improved. It is especially important in certain colleges and universities, where students may pay tuition for their education (Wardley et al., 2016). However it will be applied in an elementary school

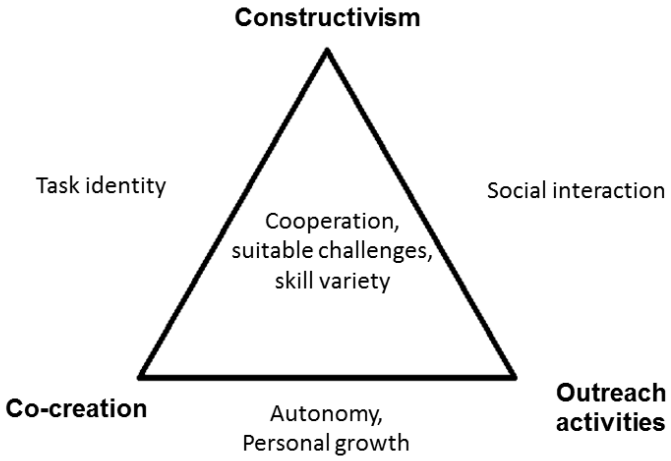
setting, thus, in this case, it is not an issue. Therefore this element of the model will be intentionally neglected in the analysis. To sum it up, these abovementioned factors are important to increase students' development and personal growth (Wardley, 2016).

The potential outcomes are the followings:

1. ***Personal growth*** is one of the possible positive outcomes, the value that the co-creational process is aimed to provide. The students' personal development is more than just gaining pure knowledge. They learn how to cooperate with their fellow students (the so-called peer learning) and their supervisors, teachers. It is grounded in this theory that students need a meaningful work that has an achievable end result so it can contribute to their self-development (Wardley et al., 2016).
2. ***Institutional commitment*** seems to be more important in university settings as well, thus for a dependent variable in the analysis, only personal growth will be in the focus as a positive outcome.

4.4. The links between the theories

To make the analysis more cohesive and coherent, the chosen theories overlap in certain dimensions. To stress the importance of these factors, it has to be highlighted that most of them appear in all chosen theories. Below there is a figure that is created in order to synthesize the links (4. Figure 2.)



4. Figure 2. The links between the theories

Links between outreach activities in STEM education and the co-creation process have been identified. *Personal growth*, the student's development is highly incorporated in both of them, as the main value of these ideas. This is the desired outcome we are aiming at by applying both theories. *Skill variety* and the student's *autonomy* are also part of both. There are certain skills that are required by working on a hands-on project. Also, their independence is important for both parts, so they feel responsible for what they are doing, and their actions and attitude will hopefully match this. The importance of *cooperation* is mentioned in all three of them. In constructivism, Piaget's fourth stage has to be pointed out, which stresses that children could learn through this process from the age of 11 to 16. Co-creation self-evidently entails co-operation, only in this theory is specified as giving feedback, creating value together with their peers or with their teacher. In outreach activities, it is highlighted that students learn from their peers by contributing to a project together with them. *Task identity* is also a factor of both co-creation and constructivism. Piaget's 4th stage of development suggests, as well as the SEWDM model of co-creation (4. Figure 1.) that children should work on their own projects, where they can practice reaching a goal step by step. This way they can feel the relevance of their work to their life and to others. The elements of outreach activities for STEM education that are overlapping with the other two theories have to be emphasized. Since co-creation and constructivism seemed to help to fold out the research question, it is important to look at the links between these and the one that is already connected to STEM education. Therefore the volume will be turned up on everything that links to the outreach activities.

To summarize this chapter it has to be highlighted that these ideas designed to understand learning environments and to make it aligned with this specific case. During the analysis there will be a screening process for abovementioned points and dimensions, so the theories will practically help to understand the current situation and help to answer the research question.

5. Methodology

For this paper, the methodology chapter consists of three sections. The first will explain the philosophy of science of this research. The second section aims to describe how the unit was built and prepared for the intervention and how it was installed in the school environment. The third section will cover what types of methods are chosen and why, as well as the data collection process will be explained. Moreover, what are the main elements to reproduce and maintain it by any other school, who would like to adapt it into the curriculum.

5.1. Philosophy of Science: doing an intervention

Ontological and epistemological considerations

When writing a research paper one must consider the ontological and epistemological views of its methodology. The philosophy of science helps to understand what aspect the researcher takes, and what the plan is for applying these aspects in the domain of the study. In terms of ontological views, there are two ways of looking at the world: *Materialism* and *Idealism*. *Materialism* follows the natural rules, it states that everything can be strictly measured and the objects in the world are following certain patterns that can be always predicted. Idealism, however, divides the world into two states of positions. It states that there is a materialistic world, but also another domain, which is the interpretation of the world. The latter one means the researcher cannot measure every bit of a certain phenomenon since it is not the world we are dealing with but how the world appears to be. To understand an archetype it has to be understood how the world is projected, not just how it is in a scientific, measurable way (Tvedebrink, 2013). This paper carries attributes from the idealistic worldview since there is not any quantitative data collected, and it aims to look at a situation as it appears to be from the researcher's perspective.

Epistemology is a subset of the realm of the certain ontological view. It means how the researcher tries to understand the certain worldview, what kind of approach is used, whether it is materialism or idealism. It determines the conditions of knowing, therefore the way knowledge is structured. Moreover, it validates this created knowledge structure with a

reflective working process (Ponterotto, 2005). *Empiricism*, the first epistemological view, has its fundaments in our experiences. It relies on the senses, as knowledge is constructed by perceiving the world. In order to analyze an object or phenomena, there are usually experiments or observations conducted, while the relevant data is collected. *Empiricism* is usually in strong relation with a positivist approach, induction and quantitative data collection. *Rationalism*, as opposed to empiricism, is producing and validating knowledge by making the presupposition, that thinking is real and can be trusted. The thinking process is more important than the sensory input, and the theories of this view represent it as well. It is usually connected to social construction theories, analyzing how the world is interpreted and what appears to be real, instead of what is real (Tvedebrink, 2013). *Rationalism* is in the nature of qualitative research, therefore this research considered to be in this subset of epistemology.

For a strategy, qualitative and quantitative way could have been chosen as well. The research was intended to be created in the realms of *Idealism* and *Rationalism*, thus a qualitative research seemed to be appropriate to use. This strategy entails that more reality exists which are subjective, therefore the perspective of the researcher proves very important. The perceptions of the individual cannot be separated from the external world, the knower and the knowledge are interconnected. In qualitative research, the theories, the methods, and the data are in strong relation, therefore it cannot be separated. These three factors have to be analysed together, so the researcher can interpret the findings as a whole (Brinkmann, 2013). The most common tactics used for qualitative research are observation, case study, field study, interviews and focus groups (Tvedebrink, 2013). The strategies used in qualitative research are often related to a hermeneutic-interpretative methodology approach. From ontological and epistemological view it falls under the umbrella of *Idealism* and *Rationalism*. This tradition entails the hermeneutic circle, which is a process of understanding and analyzing with the help of the theories. It jumps back and forth from past to future and also moves on the levels of abstraction (Tvedebrink, 2013). It has to be stressed that for this study there is no quantitative method of how the children improved their thinking and how much they learned about aquaponics. This is not a pre-test - post-test concept with quantitative data analysis and there will be no statistical taken. Instead,

empirical data from four observations, one interview, and a focus group interview will be analyzed under the chosen theoretical framework.

The research paradigm, the context of the study is guided by *Constructivism-Interpretivism*: the lived experience of the researcher has to be acknowledged. This is the most common paradigm that makes adequate preparation for the fundaments of qualitative research (Ponterotto, 2005). It recognizes multiple alternatives of reality and states that all of them can be just as important and equally accepted. The reality is not external, instead, it is constructed by the individuals, therefore it focuses on the researcher's subjective perspective. As Kant, the German philosopher says: *"human perception derives not only from evidence of the senses, but also from the mental apparatus that serves to organize the incoming sense impressions"* and *"human claims about nature cannot be independent of inside-the-head processes of the knowing subject."* Immanuel Kant in Ponterotto, 2005. This means that barely anything can be described objectively because the researcher will always influence the outcomes. For these types of studies, there is usually a longer time needed (Ponterotto, 2005). This will be provided by the intervention that takes approximately 6 weeks. The processes are monitored through observations and constantly communicating with the teacher. During this time a trusted relationship with the teacher and the class could be developed.

Developing an abductive working method

When it comes to defining the relationship between theory and research, there are three different paths. First, the inductive way is when theoretical approaches are chosen and tested after collecting data (Bryman, 2012). Integrating the sensors in the system was an idea that was developed based on previous research. It was recognized as a gap in the literature, therefore this concern became an elemental part of this master thesis. Second, there is deductive way, which is considered as a testing methodological design. For this paper the working process, data collection happened after choosing a theory. After a thorough literature search a hypothesis was developed, or as it is called in qualitative research, a qualified guess (Tvedebrink, 2013). This meant that the built aquaponics unit is placed in the school environment, it is compensated with the sensors as an additional technological part, and testing period of the hypothesis can be started. Therefore, this part is

certainly deductive, when the research is guided by a theory. Moreover, deduction is also in the nature of conducting an intervention. Subsequently, the findings will be presented with the help of analyzing the empirical data. The hypothesis can be rejected or accepted, based on the findings and the theory can be revised (Bryman, 2012). Two observations during the intervention, one interview, and one focus group interview will be conducted after the execution of the testing period. Thus the perception of the children and the perspective of the teachers will not be measured with quantitative methods, but instead, the empirical data will be used as evidence for further analysis.

Third, there is an abductive way of conducting a research, such as this paper. It can be derived from the previously mentioned ways that my design carries both deductive and inductive attributes as if it is combined together. Doing this research was a complex process, jumping between the two. After some inspiration to do this paper and defining the motivations behind it the research topic had to be investigated. By analyzing the previous research and taking them into consideration, an inductive way was followed to add a new element to the system, the sensors. This was the original hypothesis, the qualified guess (Tvedebrink, 2013). After this initiation, a testing period and a more thorough literature review took place, which can be considered as deduction. As a product of this paper there is an evaluation, and the end new ideas can be presented and a new theory can be constructed to suggest a solution to a certain situation. It can be stated that the researcher went back and forth between deductive and inductive approach. Therefore, to sum it up, the methodology is built up in an abductive way.

5.2. Planning the Intervention

For this research, an intervention will be conducted, in order to test the hypothesis in a primary school setting. After contacting Albertslund municipality and initiate launching a project with aquaponics in one of their schools, they suggested Herstedlund Skole. Then a meeting with the teachers of this school had to be arranged, who are in charge of running such projects. We agreed on that unit can be installed and the intervention can be launched from the 1st of March, so they can use it for teaching purposes.

According to Reynolds et al. (2004), an intervention on an ecological level focuses on the relationship between individuals and the environment. There is a situation, usually in schools

or in hospitals that is desired to be changed in order to induce positive change in people's behavior or knowledge, so we intervene and modify the environment. Usually, there is a pre-test or questionnaire taken that gives us a picture of the current situation. Then after the executed intervention, a sample has to be taken again for statistical trials in order to measure the outcomes as well. The difference between the two is the result of the intervention, with (ideally) the desired individual development (Reynolds et al., 2004). However, for this research, there will be no statistical trial conducted, due to the nature of qualitative research. The researcher instead will evaluate the system based on an interview, focus group interview and observations.

As it was already described in the previous section, outreach activities are usually run by employees of a company, or from higher education (for example as a guest lecturer). It means that there is a collaboration with a company or university (Vennix et al., 2017). To reflect this fact to this project, the researcher helped running the class as a workshop, therefore the guide is a student from higher education, Aalborg University. It can also be considered as a person who works for Bioteket (even though there is only a verbal agreement between the parties). Thus it is also a collaboration with a company and a university as well.

A simple, cost-effective unit was needed, one that could be considered as a minimum viable product (MVP). This term often comes up in an entrepreneurial context, as the prototype of a venture, the very first materialized form. This helps to visualize the ideas of the start-up if it has to be presented to founders or potential customers, and then it can be developed further on (Moogk, 2012). The unit had not had to be built or designed, the one from the paper of Bosire, Sikora, (2017) will be applied. It was collected from Norrebro, Blågård Skole, where it was used and tested for this previous research. Some maintenance was needed in order to make it functional because the unit had not been used for more than half a year. It mainly consists of three major parts: one plastic grow-bed for the plants and the grow-bed media, a sump bed, where the water goes from the grow-bed, and an aquarium for the fish. There is a water pump that pumps the used water (by the plants, so it also clean and oxygenized) back to the aquarium from the sump bed. This is ensured by PVC pipes and tubes. The grow-bed's water supply is secured with a siphon (also made from PVC), that makes sure that the water does not flow back to the aquarium, but instead it overflows at

the set of the cup. This has to be at the same height as the water level in the aquarium. A siphon bell is in the middle of the grow bed surrounded by the chosen media (uncoated leca stones) that controls flooding and draining the system.

5. Figure 1. Illustration of the unit used for the project of Bosire, Sikora (2017)

The aquarium will be provided by Lasse Antoni Carlsen, since the one for the previous research still belongs to Blågård Skole. The goldfish will be collected from Neonfisken shop, and also the fish feed called Spirulina, which is specific fish feed for goldfish. As for the media, uncoated leca stones will be used, that was purchased from Silvan shop. The students will experiment with both seeds and transplants. Therefore they can follow the growth of the plants and also see, whether the seeds start to germinate. The transplants are basil, parsley, and chives, and will be collected from Irma, while the string beans and the spinach seeds were provided by Lasse.

The digital sensors are a very important component of the system, this will be stressed as the main gap in the previous research. After a consultation with the teachers from Herstedlund, we agreed on to use the sensors and interfaces that they received funding for. They bought three wireless interfaces, called LabQuest2 that collects data and compatible with the sensors. All parts of the equipment were purchased from a company called Vernier. It is a pioneer enterprise that builds interfaces, and sensors, and also design software, so students can collect, analyze and interpret data sets. Their aim is to make science education more practical and to help educators with a solution for data collection. It makes it more accessible to implement STEM-based learning in the curricula with these tools. This entails enhancing students' critical-thinking and promoting hands-on experiments. The aim is not

just to gain scientific knowledge, but to understand how things function, and how the collected data could be interpreted. They claim that the targeted subjects are mostly biology, chemistry, physics, and engineering (Website 1.). It seemed to be that the sensors for STEM education can be very well implemented in an aquaponics system. Vernier has a whole range of sensors only to measure water quality, such as dissolved oxygen, CO_2, nitrate, ammonia, temperature, and pH. For the intervention pH, temperature, nitrate, and ammonia will be used, since these are the ones the school was able to purchase. The sensors could be considered as the second, additional part of the aquaponics unit from the technological point of view.

5. Figure 2. LabQuest2 Wireless Interface

5. Figure 3. Vernier pH sensor

While considering the period of the intervention, other studies were used as examples in order to see the alternatives. These studies, presented in the state of the art, used 4-6 weeks long period of time for running the project (Clayborn et al., 2017, Junge et al., 2014). Moreover, Bybee (2010) stresses that reforming the education cannot occur overnight, the projects have to be slowly incorporated into a not too long interval, thus it is not a radical change. This way it could be incorporated in STEM education. Therefore this paper suggests a brief introduction of STEM by integrating it in a program for a short period of time. The recommended interval varies by age groups: for kindergarten to 5th grade it is 2 weeks, 6-8th grade 4 weeks, and 9-12th grade it is 6 weeks (Bybee, 2010). In this case, the students are in the last semester of 8th grade. For the abovementioned reasons, an approximately 6 weeks program seemed to be sufficient as for the interval of the intervention. Four observations will be conducted during this period in the biology class, while the teacher is giving

information with regards to the system and the children are measuring different variables and collecting data. They will work with the aquaponics in groups and they will learn about biological topics, such as the nitrogen cycle in nature, and the organisms in the system. These classes will differ from a regular class, thus these can be considered as workshop days. The observations will be conducted simultaneously with the workshop days.

5.3. Empirical data collection techniques

5.3.1. Conducting a qualitative interview

Interviewing is one of the most commonly used methods for qualitative research. It highly differs from quantitative, structured interviews, where the aim is to fill up missing data with standardized questions. It is more important to go into depth with the interviewees and get to know their perspectives on a certain issue or idea. Qualitative interviewing also emphasize the importance of the informants' point of view and try to understand their frame of reference. According to Bryman (2012), it helps 'in the formulation of the initial research ideas'. The concept is more open, the conductor of the interview can, and should let the informant go into details. They can choose another direction if they find it relevant to the issue, they not just strictly answering the questions. The conductor can ask questions with regards to the emerged ideas, that was not planned before. While making the interview guide one should keep it in mind to generate open-ended questions. This way the discursive nature of the interview is ensured and there is open space for new ideas and aspects to be mentioned. Flexibility is a very valuable quality in qualitative research, adjusting to the current situation has high importance in terms of trying to get as valid information as we can. The researchers are not forcing their own ideas and concepts on to the informants, instead, trying to encourage them to reveal their own (Bryman, 2012).

There are two types of interviews that should be considered when speaking of qualitative research: unstructured or semi-structured. The first one is similar to a regular conversation, which means it is technically a discourse between the interviewer and the interviewee. There is only one question to start with, the respondent answers, and the conductor design the following questions based on the mentioned issues. The interviewer highly relies on his or her memories about the topic, to keep the conversation going. In the case of semi-structured interviews, the conductor is prepared with an interview guide, which contains

mostly open-ended questions. The questions can be switched in sequence and also can be altered if necessary; it depends on the dynamics and the content of the interview (Bryman, 2012). The semi-structured one seemed to be more sufficient to use because the focus has already been set with regards to the evaluation. This will be conducted with the biology teacher. The choice of informant seemed to be self-evident since she has spent the most time with the groups of children working on the project. She is also the caretaker of the unit and the one who gave lectures about the use of it in the class. Her engagement with the system is indispensable, and she is very enthusiastic, and she is looking forward to 'find an excuse' to use the brand new sensors. In the guide, the evaluation of the system will be stressed and it will touch upon the following issues:

- How was it like to work with the system and use it in the classroom for teaching?
- How the students relate to the project?
- How could you use it in the future for STEM education?

For this paper, there will be one person conducting the interview while recording the voice.

5.3.2. Doing active, overt observations

In order to investigate the utility of the AP unit in the classroom settings, one observation is performed. Due to the small data collection and the short period of time, it can be called micro-ethnography. This also means that there has to be a straight focus on the aspect of the research question because there is not enough time to leave it in an open structure (Bryman, 2012). This was also a reason for writing an observation guide beforehand (Appendix 2.3.), so the main focus is always in front of the ethnographer's eyes. The researcher, in this case, it is called the participant observer, also uses other methods like interviewing people, because of the relatively small sample size.

The participant observer can plan an observation in two different ways, whether it is covert or overt. The first one means the researcher is not revealed, trying to act as if he or she was part of the situation for other reasons. People in the observed environment are not aware of their role, thus it raises ethical considerations; the researcher will not ask for consent from the people involved (Bryman, 2012). In this paper, I could have adopted a covert role, and just act like someone who helps to install the unit. However, the overt role will be chosen for

the abovementioned ethical reason. It means the people, who will be present, (children, teachers) are very well aware of the fact, that I am in the situation as an observer and ethnographer, and trying to get involved in their everyday life. However, this intrusion can change people's behavior, which is another quality of overt observation (Bryman, 2012).

There is also another way of differentiating observations with regards to the environment; does it take place in a public or closed setting. According to Bryman (2012) if it happens inside an organization, for example, a firm, school or social movement, then it is considered a closed setting, framework. These are harder to gain access to, one need to ask for help to get in, where one cannot just walk in without any barrier. To reach people who are positioned higher in the hierarchical system (director, CEO, leaders) the researcher might need a gatekeeper, who is also a stakeholder with more power. In this case with the guidance of professor Bent Egberg Mikkelsen, we presented the idea to Albertslund municipality, who gave green light to run the project. In order to gain access to the classroom settings, we presented a written protocol to the teachers, and explained clearly the aims and objectives of the research, what methods are intended to be used. It can be derived that their agreement was necessary to enter the field and that we had to act in an overt manner. It also had to be decided whether if it is an active or passive observation. This is determined by the involvement of the ethnographer; to what degree he or she intervenes in the situation when entering the field. After taking this into consideration, getting involved seemed to be inevitable. Bryman (2012) also highlights the fact, that if a passive observation is planned, what if someone from the group interacts with the researcher. He or she will be worried to step out of character and engage in a discussion or assistance. Then the researchers can reveal themselves and they become conspicuous. This can make other people self-aware and it might cause changes in their behaviors. According to Bryman (2012), this degree of the involvement in the class considered quite high which makes the researcher a participant observer.

Taking notes for documentation is necessary for this kind of data collection method. One can simply not rely on their memories, and making a voice recording for a focus group is very troublesome. It is very difficult and complicated to describe due to background noises and people talking at the same time. During the observation, one should only take brief notes,

so-called jotted notes and elaborate on them later on (full field notes). However it is preferred not to leave that task for days, but do it on the same one as the observation. This way the researcher still remembers vividly of the happenings. It is not advisable to walk around with a notepad during the observation trying to document everything, as it can be disturbing for people around (Bryman, 2012).

5.3.3. Focus group with students from the class

According to Bryman (2012), for a focus group interview, there have to be at least four participants in order to get valid data. Focus group interviews were originally created for market research in order to test new products, but later on, they started to apply for social research, qualitative studies. It differs from regular group interviews because there is a certain theme that the participants go into depth. It has a very open form due to the discussion it aims to create, thus it can be quite unstructured. In a focus group, there is more space for interaction, the informants can discuss certain questions asked by the focus group moderator (facilitator). The practitioner is more interested in the conversation that the participants make about a certain topic than if they only answer one by one. Therefore, the main goal is not just to save time by interviewing more people at the same time, but also to see how they are participating as group members (Bryman, 2012).

One of the main goals here is the get to know the participants' experience regarding a certain issue. Gaining knowledge about *how* they feel about their experience, but most importantly *why* they feel that way, what are the underlying causes. They can give reasons and present examples from the past, tell certain situations they have been involved in. They can answer the questions raised by the moderator, but they can also argue about the issue, which is more valuable for the researcher. They can correct each other, reveal information that they would not have occurred to them, and modify their statements. There is an opportunity to specify their views and perspectives if it is pointed out and asked by another group member. It means they challenge each other by questions and arguments in order to reveal the truth, to dig more into the raised issue in general. This could not happen in a structured interview, even a semi-structured interview has limitations with regards to the freedom of discussion (Bryman, 2012). Therefore, the participants are revising each other's ideas, and this process creates value for a qualitative study. Besides the many advantages of

a focus group interview, there are quite a few limitations as well. The moderator has less control, less power over what is happening, after asking a question there is space for a free discussion. It differs from a regular interview because in that setting the conductor mainly owns the situation and tries to lead the way of the conversation. Moreover, due to the qualities of focus group interview, people can speak at the same time, which causes a lot of disturbance in the voice recording. It can also take a long time because the discussion can go back and forth without any controlling. This leads to an especially time-consuming transcribing process; according to Bryman (2012), one hour of data can take 8 hours to transcribe.

Recruiting informants for the focus group seemed to be a self-evident choice, as the students in the class were using the unit. Five children will be picked by the teacher, the ones who seemed to be the engaged in the new situation in the classroom. One from each group that will be working together during the classes, therefore with this specification the chance of collecting valid empirical data can be increased. This way they are actually evaluating the project, but the aim also to see whether they understood the concept and how did they gain knowledge about the aquaponics system. The reason for interviewing the children and the teacher separately is that they perceive differently the effectiveness of an outreach activity. Teachers tend to evaluate it more positively, and this fact makes it relevant to analyze and compare the two perspectives (Vennix et al., 2017).

5.4. Recordings, data collection, and transcription

Acknowledging the fact that the researcher should not only rely on their memories for the analysis, recordings had to be made. For documenting the interview and the focus group interview an iPhone will be used to record the voices, while for the observation some jotted notes will be taken. Both interviews were held in English, which is not the teacher's nor the students' native language. This can cause troubles with regards to making the transcription. If they speak in their native language during the data collection, then it might manifest in data loss (Bryman, 2012).

5.5. Ethical consideration and biases with regards to data collection

During the analysis, the names of respondents will not be used. Instead, they are going to be called Student No. 1, Student No. 2, etc., and simply the Teacher. Thus their anonymity will be kept for ethical reasons. The interview and the focus group interview will be held in English. This can be considered as a bias, given the fact that the interviewees could express themselves more effectively in their first language. In case of the students, their first language is either Danish or Arabic, while the teacher is Icelandic. The observations will be documented by taking pictures. For this purpose, a consent will be formulated and handed to the parents, so they can agree or disagree whether the observer can take pictures of the class while working with the aquaponics system.

5.6. Validity

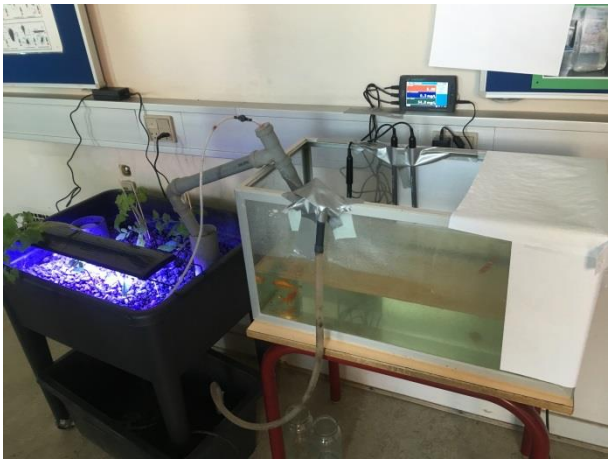
Another characteristic of qualitative research that it differs from quantitative, is validity. Instead of collecting quantitative data on a certain matter and see how the measures represent the problem that has to be investigated, we have to collect and analyze empirical data such as interviews and observations. The data is not collected in order to run statistical tests and look for correlations, but instead, it has to be analyzed by using the chosen theories. The perspective on the project has to match the respondent's, and that the work of the project is corresponding with their views and thoughts. This means the researcher actually investigates how the methodology connects with the theories, whether the choice of the abovementioned methods is appropriate (Bryman, 2012).

6. Results: Summary of empirical data

6.1. Evaluating the intervention

The project was launched on the 1st of March, 2018. A trip was organized to Albertslund, Herstedlund Skole with Professor Bent, to drop off the unit and the necessary equipment. The system was installed and set up in collaboration with them during the class. The students' daily tasks included feeding and monitoring the fish, checking the growth and health of the plants. All the other measurements, the temperature of water, pH, nitrate, and ammonia were taken during classes. The students used the Vernier sensors and the LabQuest interface to measure the certain variables, and they analyzed the data later on. Some errors occurred in the operation of the system during the 6 weeks. Some of the transplants died in the first two weeks, so the students planted new species, such as tomatoes and soybeans. Also, three of the fish died, they swam up the pipe or have been sucked up there, and ended up in the grow-bed. The water pump did not seem to be strong enough since the water flow was discontinuous most of the time. The table that the aquarium stands on was too high, so the water level was quite low in it. These can be considered critical control points: there are not any steps that correct these errors, so it can cause troubles in the continuous operation of the system. However none of these issues stopped them from implementing it during the classes, and they did use it for taking measurements with the sensors to monitor the system.

6. Figure 1. The system the first day of the intervention



6. Figure 2. The system the last day of the intervention

The pictures above show what kinds of adjustments had to be made in order to keep the system running. The aquaponics unit presented in 6. Figure 2. has the new plants and a blue-lighted lamp is set up to stimulate the growth of the plants. Moreover, the sensors are installed permanently next to the aquarium, because of the long calibration time before every class. For the data collection, the researcher used 47 days in total, but it has to be mentioned that in the meantime there was a spring break in the school. The last day, as a closure, the interview was conducted with the teacher who held the classes.

6.2. Summary of the observations

All four observations were conducted during biology class settings. Each class took 3 hours, and the theme was, evidently, aquaponics and its relevance to food literacy and biology. The first day the installation of the unit took place, while on the other three workshop day the students had other tasks related to the project. It included, for example, measuring variables with the sensors, reading about aquaponics, as well as making a presentation to show how it works. During the observation the researcher was monitoring the processes and paid special attention to the followings:

- The utility of the sensors
- Tasks of the groups
- Students interacting with the aquaponics system
- Students' behaviors and emotions, attitude (positive or negative, for example, boredom, excitement, ignorance, etc.)

It is important to point out that the observations happened before the interviews, during the interval of the 6 weeks intervention, while the interview and the focus group interview were conducted after this period.

Workshop day 1. Installation day

The first day the installation was set up in the biology classroom, next to the wall. After moving every part to the classroom, a biology class has started. The researcher introduced the system to the students and gave a brief introduction about aquaponics in general and sustainable food production. We have watched a video about how the flood and drain type of aquaponics, more specifically the siphon bell works and learned about the aquaponics

cycle. The siphon's operation was presented and the Bernoulli equation was explained by the teacher. After the presentation, we set up the system. They have independently planted the seeds and the plants in the grow-bed. In the beginning, they were a little confused about what is going to happen exactly, it was not easy to include everyone from the beginning. Some of them were very enthusiastic and tried to help with everything, they were especially excited to see the fish and the worms. Other students did not see the relevance of aquaponics, they were looking into their phones and were talking to each other.

Workshop day 2. Launching the sensors

On the second workshop day, the students have already been divided into 5 groups. The goal of this day was to introduce the sensors and the interface to the students. The class was held in Danish, and this time 16 children, the biology teacher and a social worker (and the researcher) was present. There have been 3 weeks passed since the installation day. Some of the plants died, and one of the fish (the smallest one) got injured in the pipe and died. The students were monitoring these activities during this time. The sensors were prepared on the front desk, and they had to be calibrated. In case of the nitrate sensor, it took about half an hour which seemed to be a long time that tested the student's patience. While the class has been waiting for the sensors to be ready to use, they had to watch an instructional video about the calibration on the website of Vernier (Website 1). The next step was to join their groups and start making a presentation about how aquaponics functions in general. The groups had to draw the nitrogen-cycle, present a model of how it works. Each group was working on their laptops, reading and searching for information on aquaponics. A table of the organisms' optimums was handed out, so the students can compare the measured data to the ideal ones. After the calibration was over, they tried it one by one and measured temperature, pH, and nitrate level from the water of the aquarium.

As the researcher observed, the students barely had any books, they are using their computers provided by the school. They can use it in the school and also at home for studying. They were using digital files, articles and programs to learn, the only hands-on material was the poster about the optimums of an aquaponics. The teacher explained that the students had controlled access to the internet where they can search for the specifics of what their teacher assigns to them. That is how they started to read about aquaponics as

well and do their own research. A social worker was also present during the class. After a short discussion with him, it turned out he is there every Tuesday to monitor the students' group work. It is a project of Albertslund municipality to engage all students with scientific subjects so there is no one left behind. He explained how the students received their laptops from the Albertslund Kommune, so they can use it and they are responsible for it as if it was their own from 3rd grade until 9th grade. He also pointed out that unfortunately there is no regulation on phones yet, the students can use it anytime during the class. Very often they stopped focusing on the task because of their phones distracted them.

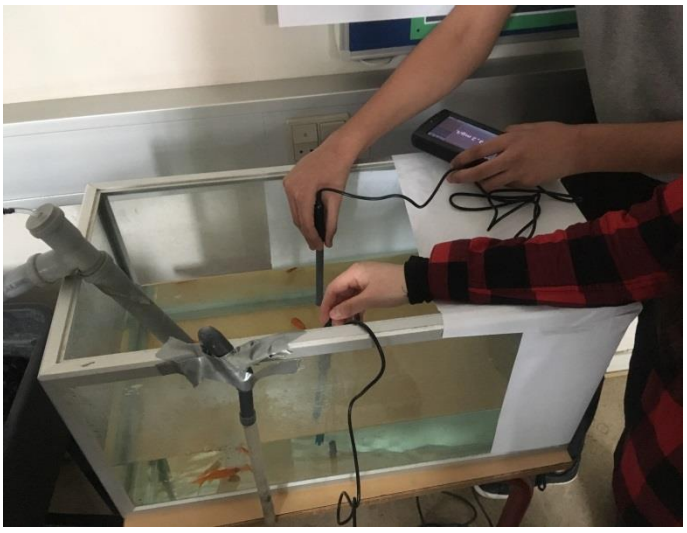
As it turned out later on, one of the students has learning disabilities. She has dyslexia, severe trouble with reading and focusing on a dense text. She found it more exciting to work on a hands-on project that does not necessarily requires too much reading beforehand. It was interesting to see that the student who had relatively low grades because of dyslexia, had a very high interest in the aquaponics system. She was very open and ready for new ideas and to seek new information all the time. She was interested in how one can work with aquaponics in real-life and mentioned how it could become her job in the future. The students' attitude in general changed positively by this time, most of the students tried the sensors and engaged in discussions about the operation of the system. It looked like they are more comfortable with the system around, and accepted the fact that it will be part of the classes now.

Workshop day 3. Measuring pH, temperature, nitrate

On the third workshop day, only 13 students were present out of 20. They joined their groups again, and the Teacher explained to them how they can prepare for final exams. We calibrated the nitrate sensor again, that took about half an hour. In the meanwhile, the students had to continue to prepare the presentation about aquaponics. They were making and editing a video with their groups and tried to draw a model of how it works. The main goal of this task was that they are creating a kind of a documentary on their own. They were using programs provided by the Albertslund Kommune to edit the video. After the sensors were ready to use, the students started measuring pH, temperature, and nitrate from the water of the fish tank again. There were three interfaces to use, so the groups could also work simultaneously. Beforehand they got a chart that shows the optimums of water quality

(pH, temperature, nitrite, nitrate, ammonia, dissolved oxygen). They compared their measured variables with the optimums and discussed the outcomes. The data could be presented in graph forms in the interface, for example, time on the x-axis and pH or the acceleration of change in nitrate level on the y-axis.

2. Figure 3. Students measuring with the sensors



6. Figure 4. Students measuring with the sensors

This time the English teacher was also present, and we had a small discussion at the end of the class about the students' attitude towards scientific subjects. They both mentioned that it is difficult to engage the students in any kind of science and it is hard for them to focus in class. Usually, it does not interest them, therefore they both think that a hands-on project would help to change that. According to them, students are already interested in the aquaponics, and that it brought a positive change in the class environment.

It was discussed during this class that the students are going to take a final exam before they go to 9^{th} grade. This exam promotes technological and engineering learning alongside different kind of projects. It is a combination of geography, biology, chemistry, and physics, and they all have to pick a topic that merges these subjects together, so they can present through that project what they have learned. The themes are for example clean water in the future, CO_2 footprint, food production effecting NH_4 and CO_2 emission, climate changes.

The Teacher explained the students, what is the structure of the exam. Four topics were mentioned that they can work with later on:

1. Drinking water supply for future generations. For example, how climate change effects the water supply, wasting water, water scarcity
2. The effects of plastic production with regards to natural resources
3. CO_2 and NH_4 emission of the society
4. Radiation impact on living organisms: e.g. solar radiation, cell phones, space travelling

Workshop day 4. Preparing for the final exam, measuring ammonia

By this day the ammonia sensor arrived as well, and so the students could try it. They were preparing for the final exams working with their chosen partners. They looked focused and almost all of them have been working committedly on their projects. They were collecting information for their presentation and looked at the collected data from the sensors. They tried to deduct, how they could balance the system, in order to reach the optimums of the organisms. New plants were planted instead of the ones that died; tomato transplants and soybeans. Both of them have been thriving for two weeks now, according to the Teacher, and a new lamp was set up that definitely helped their growth.

The students have been working in groups during each session. Until the third observation they were in groups of 4-5 and on the last one groups of 2-3. The reason for this is that on the last observation they have been already signed up for the projects for the final exam that they have to prepare for together. The observations are the evidence that this prototype has to be more strongly built because in this state it was hard to maintain due to the couple of critical points (weak pump, low water level, pipe diameter). During the observation, it turned out who are the most interested and engaged students. They separated themselves from the others and got fully engaged in the new project. It took some time until the tasks were clear and they found meaning in it. After that, they were asking questions about how it operates, what is it good for, and also started to discuss between each other. Therefore the situation was analyzed on the spot; who is motivated enough to get engaged and who is not. It also helped to pick students for the focus group interview. Thus it is not considered a random sample, instead, the researcher tried to gain different pieces of information from the ones who seemed interested compared to the ones who were not. The separation was possible

because students with less enthusiasm are not obligated to do every task, they still have a wide degree of freedom.

6.3. Interview summary

The interviewee for this paper was a biology, chemistry, geography, mathematics and physics teacher in Herstedlund Skole, Albertslund. She is responsible for what goes into the curriculum to some degree, what should be the focus in these scientific subjects. Therefore she participated in this study also as an expert on structuring the content of the classes, not only as a teacher. Furthermore, it is also an advantage with regards to STEM education that she teaches multiple, quasi all the scientific subjects. She is also the head of the 8th-grade class involved in the aquaponics project, and she has been their teacher since the 5th grade. The interview took place on the 16th of April, which can be considered as the last day of the intervention.

The questions were organized in a timeline: past, present and future perspectives. First, the interviewer asked about the intervention, how was it to use it for teaching purposes and how the kids related to it. She had a very positive response, she found it extremely useful for science education, where the children can learn several subjects through aquaponics. She mentioned that we have to teach this generation to think about the future and to make them learn about sustainability. Second, she was asked about the current situation with regards to STEM, at what age do the kids start to learn the disciplines of this theory. She thinks it is very important to include it in elementary school and she also refers to Big Bang conference that she has just visited a week ago. It is a convention that took place in Denmark a week before the interview, and it aimed to help the teachers with techniques and strategies about how to capitalize teaching scientific subjects (Website 2). She mentioned specifically the engineering part, how it is actually applied sciences, so for the children, the ability to do something is more important than to know the laws and equation related to a problem. That is why it could be included already at an earlier age, according to the hearings of this conference, from the very first grade of elementary school. She concluded that STEM education will play a big part in education in the near future, starting next year. Third, her future perspectives had to be answered, would she implement aquaponics in the curriculum. She can see the relevance of aquaponics to STEM education,

as it can exemplify sustainable food production, and provide a tool for teachers to enhance children's knowledge about certain scientific subjects.

In the interview she also talked about the students' improvement in the last four years and that she also knows them quite well now. That is relevant for data collection because her opinion and perception are more thorough, that makes the collected data valid. As it was already mentioned in the methodology part, the validity of the qualitative interview lies in the thought and feelings of the interviewee. Sometimes the interviewer tried to summarize the answers of the respondent, to be sure about what she meant. This way the former could be reassured and can reflect on it. This means that the interpretation of the hearings is clarified right at the spot by restating the subject's point of view. As it was already mentioned in the methodology section, this is a big advantage of doing a semi-structured interview.

6.4. Focus group summary

Student No. 1, 2, 3, 4 and 5 are all members of the 8th-grade class who have been working with the aquaponics system during the classes. It was seen from the observations beforehand, who was interested and who was not as engaged. Moreover, during the classes by talking with the teacher the researcher also gained some background information about the children, for instance, that for some of the children Danish is only a second language. The students did not look nervous during the interview, most of them were more excited to be part of this exercise and share their thoughts. Sometimes they were struggling with their English, but they always helped each other out if someone could not formulate what he or she is about to say in English. Student No. 5 and Student No. 3 answered most of the time, they had a lot of comments to share, and they have talked about the aquaponics system very enthusiastically. Student No. 1 did not really say much, he was just nodding all the time when he agreed with his fellow classmates. Student No. 5 appeared to be an expert, the others were all looking at her when something had to be explained and she responded accordingly. She had a very clear understanding of how the system operates, and what happens if some part of the system fails to function properly. Student No. 3 was dominating through the entire interview and she had a straightforward opinion and well-formulated thoughts about the system. Student No. 4 only spoke when it was necessary, completing the

others' sentences. Student No. 2 also wanted to explain certain things, he was very enthusiastic and eager to show what he learned. He was not so dominant though, sometimes he was cut off by the others when it felt like he still has something to say. With a little encouragement from the researcher, he revealed his thoughts more bravely or summed up what the others tried to explain.

During the interview, some of the questions were dead-end when the children did not really know what to say. Then the conductor of the interview tried to elaborate a bit more on the question or jumped to the next one. However, there was a case when the question was not asked yet, but they had already answered it previously. It was a positive thing that they commented on each other's opinion and listened to what their classmate has to say. They helped each other out if someone froze up due to the language barrier, and they tried to find the right English word together. It has to be pointed out that it was challenging for the students to express themselves in a second or third language.

7. Analysis

In this section, the collected empirical data, the observations, interview and the focus group interview will be analyzed and will be broken down into small, digestible fractions. The chosen theories will be applied to the collected empirical data, as well as the state of the art, in order to investigate the research problem. This way the theories will help to conceptualize the results and unfold the research question. The data will be classified into themes, so it is more understandable for the reader and the interpretation of it will be described.

7.1. The STEM disciplines applied for aquaponics

The hypothesis was that the aquaponics fits into STEM education and it can be used to teach food literacy. Moreover, the sensors could play a big part of it if the aquaponics system is in the center of the STEM. The following section will examine whether this project could live could live up to the criteria, what fills out the disciplines of STEM in this case and what the results show.

Science: The main framework of science was biology, the students were working on the aquaponics during their biology classes. The main focus was on this little ecosystem and how it functions, and the optimums of the plants, the fish, and the bacteria. According to the Teacher, it was a good exemplification of certain scientific topics they have been working with during the year, and she points out that the sensors could also help:

"…when the sensors came up. It was quite interesting for them to see, how it works. And I have been telling them about, they have been working for long time with the nitrogen cycle. So I think it is yeah, it is giving them a bit more idea about how it works." (Appendix, 1.2)

However, they touched upon other topics as well, for example, climate change, certain equations of physics, chemical forms of nitrogen. For the students, both the siphon and bell siphon seemed to be working on its own accord, thus this was a good opportunity to bring up the force of gravity and vacuum, as well as the Bernoulli equation. The Teacher mentioned during the interview, for what other kinds of subjects STEM could be relevant for. As a matter of fact, every other scientific subject could incorporate aquaponics that is taught in elementary school, such as chemistry, physics or geography. Moreover, as it has become

clear during the observations, it was not easy to separate these branches; as the Teacher points out, it is might not be necessary:

"They have to use all of the things, all that they have learned. They can use it from math, they can use it from physics, chemistry, biology, and geography." (Appendix, 1.2)

Furthermore, as the final exam is a combination of the four abovementioned subject, it seemed like it is not an aim to separate them, however, the opposite is true. For the presentation that students have to hold, they can show what they have learned in a holistic way, using their project as a tool for that.

Technology: This element includes everything that keeps the aquaponics system running and helps the students understanding it. As presented in the methodology chapter, the technological aspect consists of two parts. The first is the operation of the aquaponics: the pump, the electricity, the pipes, the bell-siphon, the siphon are all essential elements of the technological view of the unit. The second one is the new technology, the Vernier sensors completing the system by collecting data in order to analyze it later on. As it was observed, the maintenance of the system was not the easiest for the students and for the Teacher. Few of the technological parts appeared to be difficult to handle, such as the not so efficient water pump and the sensors. From the technological point of view, the system's operation has to be spot on in order to introduce it to the children, and this is not easy to manage due to the complexity of the aquaponics unit.

Engineering: This part includes everything that applies scientific knowledge, and requires drawing conclusions to make the system better. This is the element that was the least present during the observation. However, the Teacher mentioned the importance of including engineering, problem-solving thinking from the very beginning of elementary school.

"So they are going to think about it. So that is quite nice. So it is making more questions for some of them. And that is just what we want." (Appendix, 1.2)

The student's personal development was growing as they were getting increasingly engaged in their projects. As the Teacher mentioned above, they keep asking questions, and they initiated the idea to check the qualities of the water in the brooks nearby. For this, they were

also using the sensors, now that they learned through the aquaponics how to use it. This clearly shows, that they were encouraged to practice their knowledge outside of the class, and applied what they gained in different scenarios. Moreover, it turned out during the focus group interview, that the students had many ideas and suggestions on how to improve the system. Every time something unexpected occurred they tried to work out a solution and they discussed it with the Teacher and their peers. This shows the traces of engineering thinking process: they recognized an issue, analyzed what the causes were and they tried to create an answer to the problem. For example, when the fish swam up the siphon and ended up in the grow-bed, the children came up with the following idea:

"Yes, apparently the fish tried to escape…So maybe we should put like something, that, a filter on the tube, so it would not be able to do that." (Appendix, 1.1, Student No. 3)

Creating a filter would be, indeed, a perfect solution to eliminate this problem. It was something special, something that even the researchers ignored it during the planning of the system. Moreover, after some of the plants died, they started experimenting with different kinds, such as tomato transplants and soybeans, and also they put up a lamp.

"That something is wrong or we have done something, something was not wrong but something was not right. Or maybe the nitrogen was too high so the fish died" (Appendix, 1.1, Student No. 3)

Making deductions is the characteristic of the Piaget's 4th stage, and as it was observed the and experienced during the focus group interview, aquaponics provided an efficient tool for the students to practice that. The sensors seemed to be especially helpful from the engineering aspect, since the main goal of analyzing the variables (nitrate level, ammonia, temperature, pH) could be used for adjusting the system, to improve the conditions of the organisms.

Mathematics: To expand the mathematical aspect of this project, the sensors seemed to be essential to include. The students had to read what is on the screen of the interface and see how the certain variables change. Then the program could show these data sets in graphs, so the students can see whether it is linear, exponential, etc. According to the Teacher, reading graphs as such, fits into the curriculum, because they already had started learning functions

and their graphical representations. Then they could see the graphs on their computer as well. Vernier has their own application program to store and represent the collected data, so the children had to download this program to their laptops. These graphs provided plenty of space for the mathematical aspect of teaching. However, as the Teacher said, the kids do not necessarily think about it as being mathematics:

"They do not understand how much math they are using. Sometimes in physics or in geography and something, where they are looking at graphs and everything.

'It is math.'

'Is it?'

'Yes, it is.' " (Appendix, 1.2)

It was true in the case of aquaponics system as well. The emerging mathematical problems, such as reading and analyzing the variables, did not appear to the children as concrete, explicit issues. Instead, as the outreach activities aim to achieve, it provided a tool for enhancing an unconscious learning process (Vennix, et al., 2017). Accordingly, using aquaponics could provide an implicit way of practicing mathematics. This is also the goal from the STEM perspective, to apply mathematical equations, learn how to use them. From the observations, it seemed to be a successful way to engage the kids because they understood the connection to the real world. With problem-solving mindset, they could apply the mathematical tools right away, while they are looking for an answer.

It can also serve as an explicit tool if concrete exercises have been given out to solve with the collected data. This did not happen yet, but it was her plan:

"*They can do that. They have not done that yet, but I am going to, to show it to the girls tomorrow. And, so they can look through it and see it and think about it and see, okay, that is why."* (Appendix, 1.2)

The Teacher also talks about how the classes could be structured. According to her, STEM education requires a specific mathematics teacher, somebody who knows how to use examples from a project, and how to teach the students the applications of math. Therefore the roles of the teachers would be divided; one teacher deals with math, while the other covers every other aspect.

"*so here in the school we are, there are two who are getting the mathematicians education. So they can help me as well when I am teaching math and bring some ideas and how to begin to use it like that. So and I am going to be doing all the other in the STEM."* (Appendix, 1.2)

To sum it up the sensors provided an opportunity to add extra technological and mathematical bits to STEM education. The researcher did not find anything else that relates to mathematics but the sensors, other alternatives that came up during the intervention will be presented in the discussion. It can be concluded that the sensors help to capitalize STEM education, as it gave an opportunity to include mathematical problems. This is the way it seems to complete the STEM disciplines. The sensors highly contributed to the STEM disciplines and have become a crucial part of this teaching tool. By using them, three of the STEM disciplines (mathematics, engineering, and technology) could be fulfilled.

7.2. Food literacy and sustainability: the context of STEM

The context for STEM education was the aquaponics system which could be a subset of food literacy, with special focus on the sustainability aspect. With the aquaponics in the classroom, the researcher and the teacher aimed to provide a discussion for sustainable food production, to make them think about alternatives for the future. One of the students mentioned in the very beginning of the interview, that aquaponics is a sustainable way of producing food:

"I would say it is sustainable, … something that keeps working, like aquaponics. I think it is sustainable, but of course, there is a little water loss every time. It goes into steam. But in the long-run I think it could work, if we are good at using it….." (Appendix, 1.1, Student No. 3)

During the observation and the focus group interview, the researcher got confirmed that the students understood the main concept, why it is a sustainable way of farming. When they were asked about the advantages, they answered it correctly, this information clearly stuck in their mind, and they could also collect these positive outcomes:

"Of course you can use … less water to the plants, and again use it for the fish. So you can make meat, and also vegetables with one smaller quantity of water." (Appendix, 1.1, Student No. 3)

Their final exam, as it was revealed from the observations, centers around an issue, and they could choose aquaponics under the topic of water scarcity. The other topics are plastic production and its effects, CO_2 and NH_4^+ emission and radiation. It is clear from the state of the art that these are exactly the type of topics, problems that usually centers around STEM-based education, and it refers back to the STEM model (3. Figure 1). By preparing for the final exam, the children can learn through a problem as a context for learning scientific subjects. It is the characteristic of STEM-based learning, it just identified as such. The first topic, water scarcity, provides good opportunity to include aquaponics and learn about the relevance of it.

As it was presented in the state of the art, it is necessary to teach sustainability from an early age, if we want to raise a generation that cares about the future. Such contexts can provide an opportunity for problem-solving thinking, so the students think about how they can make other people's lives better. However, as it appeared to me from the observations and the focus group interview, these are not the only reasons to include it in the curricula of an elementary school. According to the formal operational stage, this is the age when children originate ideas about the future. Therefore, the sustainability aspect of food literacy seems to provide relevant discussions for the STEM, and it can serve as an appropriate context.

7.3. Constructivism

7.3.1. Traces of constructing knowledge

This section of the analysis will highlight the process of assimilation and accommodation, and in what forms would it occur by utilizing the aquaponics. According to Piaget, humans see objects as tools and they can gain new knowledge of how to use those objects more effectively (Peterson, 1999). It does not necessarily mean that the first alternative of utilizing a tool is wrong, but it seems more like that during the process of learning a new method of capitalizing the object will emerge and by accommodation a new interpretation of the object is created. They build up their already existing schemas in their mind into a higher resolution world, hence the term, constructivism. In this case, the main object was the aquaponics, the tool for constructing knowledge. As the project moved forward, the students developed an increasing understanding of it, and their knowledge generated through interaction with the unit. Therefore a hands-on project, such as aquaponics helps to utilize constructing

knowledge according to this theory since the children have an object to practice their collected pieces of information on. For example, if they read about the siphon-bell, the force of vacuum, gravity, then they can see that simultaneously at work, therefore the ideas can manifest themselves in the classroom. Again, it seemed to be helpful to guide abstract thinking and raise the implicit way of generating knowledge.

In the beginning, the majority of the class was not so interested, they looked puzzled, so they did not start working right away. They could not capture every bit of it, how it works, why the plants can live without soil. Aquaponics is a complex system in terms of branches of science, the students first have to have basic knowledge in the field of biology, physics, and chemistry. They have to understand the nitrogen cycle, the Bernoulli equation, what are the optimal variables of each organism. Why the siphon bell 'works on its own accord' and why it is important that it floods and drains the grow-bed every now and then. It can be concluded that it requires a lot of abstract thinking which is the characteristic of the 4th stage, according to Piaget's theory. Children reach the highest level of abstraction in this stage, and aquaponics seems to provide a versatile tool for practicing that.

The process of assimilation could be detected from the observed data, the students gained knowledge about the system during the workshop days. For example, when they learn about the nitrogen cycle they take that knowledge and use it to micro-alter their perception and view of the system. After gaining this understanding the students would look at it in a new light, as their knowledge is expanded. This is exactly how Piaget thought people construct knowledge: there is always a frame of knowledge, but when accommodation happens, the whole knowledge structure alters, new ways of alternatives emerge that were not options before. They acquire new knowledge that opens up the big picture and the knowledge itself broadens up. Therefore, it looked like as the children do not construct representations of the world or system, but the world itself. In this case, the children structure how aquaponics works, step by step.

"So they are getting some 'aha moments' and understanding how it all get together." (Appendix, 1.2)

These ‘aha moments’ that the Teacher mentioned in the interview can be described as accommodation process. If sufficient information is provided for assimilation, then it fuses into the students’ knowledge structure. After this process, there will be tipping points when the new information does not fit into their built schemas anymore. Then the students have to restructure those schemas in order to understand the system in a higher resolution. It seemed like in order to support the process of accommodation, a lot of things have to be explained beforehand, and during the intervention for the children. One of the students also pointed out, they had to do their own searching process about the aquaponics:

“We did not start just like asking what is this, what is this. Until (…) our teacher told us, okay, like that. It makes sense.” (Appendix, 1.1, Student No. 2)

“Collecting information to see step to step how the aquaponics system works.” (Appendix, 1.1 Student No. 2)

The students started looking up the websites their Teacher gave them and thereby gained information about aquaponics. This required the process of assimilation, to get new pieces of information and build into existing schemas in their mind. After collecting several new pieces of information, they experimented on the unit; checked the siphons, measured pH, temperature, nitrate, etc. By seeing it in real life, the exemplification seemed to provide a place for accommodation, when the knowledge structure transforms completely into a broader set. The last piece of information would not fit into the already existing schemas in students’ minds, they need to think up new ones. Therefore, the abstraction of aquaponics will widen up into a higher resolution form and they are able to understand it on a higher level.

After measuring with the sensors they knew the current state of the system, and they could decide by using the chart of optimum variables whether the variables are adequate or not. These new situations the aquaponics entails, call for new schemas, thus it is a sufficient opportunity for accommodation and transforming their knowledge structure by adding a new exercise that is connected with the sensors. To sum it up, aquaponics appears to be a tool providing space for both assimilation and accommodation.

7.3.2. Cooperation

According to constructivism, cooperation is a very important process with regards to children's development of the formal operational stage. The students worked in groups on the exercises on each workshop day. As the social worker told the researcher during the second observation, it is the municipality's goal to try to involve every student in the classes. The idea is that everyone participates in the project, and they learn how to divide the tasks between each other. This means the students had to cooperate when solving the tasks, for example, to collect information online, to make the video and the presentation. They also had to prepare for the final exam in groups of two or three. According to Piaget's fourth developmental stage, it is very important that children start practicing cooperation since this process considered to highly trigger logical thinking (Joubish, Khurram, 2011). As it was observed, almost every student took part in the discussions and group work in the classes. The students who were not so engaged in the beginning still had to be in a group, so they were dragged by their peers. It turned out really fast who the leaders and the pioneers were in some groups, so others could rely on them. In an ideal case the weaker students could better learn if they have to cooperate in a group, where they would be pushed to collaborate. Therefore, it seems like the municipality's goal matches this theory and the students can and will learn through the entire project by cooperation.

7.3.3. Aquaponics as the manifestation of the STEM in *elementary schools*

The main goal of this part of the analysis is to have a look at the age groups Piaget identified with regards to the development of abstract thinking. The first thing, that has to be stressed is, that the children of the class are 12-13 years old, accordingly, they are in the formal operational stage. According to constructivism, this is the stage when they become concerned about the future and ideological thinking starts manifesting itself in a more abstract discussion. Therefore, 11 years old and up seems to be the right age, to launch a project like this. Promoting sustainability could be highly incorporated into their studies when they are already in the formal operational stage. As it was presented in the theories, the children's abstract thinking peak, they are able to work out hypothesizes in their minds. Showing future alternatives for food production and getting them engaged in urban farming techniques such as aquaponics is reasonable since they are in the highest level of abstract thinking. Children who are in this phase, are able to think in connections, can build

knowledge by deducting conclusions and can see the consequences of a process. Additionally, it is also the characteristic of the formal operational stage that students learn through project works that they find meaningful.

However, when the Teacher was asked about the initiation of STEM education in the school, she revealed that it could be implemented even at an earlier age. Some of the teachers from the school, including her, visited a science conference a week before the interview. It is called the Big Bang Convention which has STEM education in the focus, where they discussed the followings:

"…when I went to the Big Bang convention, they were also talking about the engineering materials also going to be, it should be all over in the school. Just right when they are starting at 6 years old, they should work like engineers and include it." (Appendix, 1.2)

This means right before the concrete operational stage, in the preoperational stage it could be launched. The children will not understand every bit of it, but they can start working with the objects of the system. As it was mentioned in the theories part, in this stage it is very important for children to learn through their own experiences, since they have an egocentric view of the world. They will not be able to analyze and evaluate their thinking about the aquaponics, as opposed to the 8th-grade students, who did it during the focus group interview. Another argument besides this statement could also be that it is also very important at this age that children start working with water, clay, etc (Joubish, Khurram, 2011). They can see the attributes of different kind of materials and learn through their hands-on experiences.

"Because they do not have to understand it. They just have to get to know 'okay, we can make it that way'. And then we can get the water to flow. That is fine for them. And then you, as older as they get, you get them to understand more and more." (Appendix, 1.2)

What she stresses here is the idea, that engineering skills are enhanced by practice and hands-on projects, applying the knowledge the students have and interpret the system as a model of nature for example. It could be a model of a small ecosystem for the children in first grade, just like it is a model for nitrogen-cycle in the eighth grade.

To sum it up, aquaponics was an appropriate activity for 8th graders because it triggered hypothetical reasoning, making deductions and enhanced abstract thinking. These are such characteristics of the formal operational stage that has to be stimulated in the classes, so it supports children's cognitive development.

7.4. Aquaponics as an outreach activity

This intervention aimed to provide an outreach activity for the students in the classroom. As it was mentioned before in the theories section, these types of activities could be determined by location and by whether the environment or the product of a company is in the focus. It was located inside, and it is considered to be a long-term activity that uses more workshop days for reaching the goals of the project. Furthermore, in this case, product was in the center of the outreach activity, not a company environment. During the observations, the children had a lot of questions about how aquaponics works on a bigger scale to produce food. This implies that the aquaponics unit served as an object that connects the school environment with the real world for the students.

The Teacher also spoke about other, outside located outreach activities that the school is usually a part of. The students are visiting other institutions, experiencing different environments, for instance, as she mentioned, a nature center. According to her, it is exciting, but as it was presented beforehand in the theories section, does not have the same benefits as a longer, continuous project such as the aquaponics in the classroom.

"Yeah, I think it is quite useful to us, we are a quite good school in this, and in Albertslund, to go outside and be outside with the children. And there is a good nature center, where there is a really good teacher." (Appendix, 1.2)

The nature center that she mentioned above, is also another type of outreach activity that is located outside the school, more like an excursion. Therefore the students already have some kind of experience with these types of activities. It also raised their attention that there is another aquaponics in the neighbor school. This could be considered as an addition to this project, their interest motivated the teachers to investigate the other aquaponics next-door. This is an excursion, an outreach activity located outside. They were excited to

visit the other school, one of the students mentioned without asking such question, which clearly shows their interest and engagement towards the project.

"'Does some other place, not far from here, do not they have some, a bigger one, kind of this?'

'Yeah, there is going to be a system, and we can see theirs.'" (Appendix 1.1 Student No. 5 & No. 2)

This outreach activity provided an opportunity for the children to work more independently on a project, they worked in groups autonomously. The guide and the teacher only provided help, but only when it was necessary. He helped to answer their questions or explained certain things. The Teacher also talked about one of the students who turned out to be dyslexic.

"She has awful difficulties with reading and writing." (Appendix, 1.2)

For her, it definitely seemed to be a competitive edge to work with a hands-on project with less reading exercise. Outreach activities provide an implicit, unconscious way of learning. Therefore, the students do not have to read that high amount of reading materials like in a regular case of class, instead, the outreach activity provides an opportunity for hands-on projects, so students like her can also feel encouraged and successful. According to the abovementioned student with dyslexia:

"It was more fun to work with the hands, I get bored of too much reading." (Appendix, 1.1, Student No. 5)

During the second observation, the students started a discussion about the aquaponics. They gathered around and asked the observer about the siphon. After giving an explanation, they pulled it out of the water, so we could set it up again. After sucking out the air of the pipe, they understood that it uses the force of vacuum and then the water keeps flowing because of the pressure. This also provided a good example, something can be shown right away and explain it with some hands-on material on the spot.

"I just got used to it. After using it again and again I understand it more." (Appendix, 1.2)

What Student No. 5 mentioned here is a perfect example to understand the situation. As when Vennix et al. (2017) stated before, outreach activities provide such processes, where information and the application of the information happens together. The information and its service cannot be separated, it seems like the two occurs at the same time. Additionally, other examples of this phenomenon were observed as well. Representing an idea during the observation was quite easy with the aquaponics system; for example when we were talking about the nitrogen cycle with the students, or how the worms decompose everything in the grow-bed to make the nutrients more accessible for the plants. This shows, that there are two ways of learning: working on the project and asking, how it works, or learning something and see it exemplified in the classroom. Both are very important steps, the first one being accommodation, as the students gain understanding of the issue, thereby reconstruct their knowledge about the system. The second one is assimilation, constantly adding new information into the initial knowledge.

The students put the system together from scratch, placed in the worms, fish, and plants, so the construction helped them to conceptualize the system. This could be an example that teachers can use to get the children engaged in more abstract thinking, for example, food production, which they cannot see at that moment. The errors that occurred gave them the opportunity, to think about possible causes, and how they can be fixed. For example, during one of the observations, the students were discussing why the water stops flowing in the siphon. This happens when air goes into the pipe because the valve does not seal properly. They concluded that water-flow could be checked once every day, and can be adjusted if necessary by sucking out the air from the pipe and close the valve again.

7.5. Co-creation

7.5.1. Level of engagement, personal growth

In order to analyze the data with the co-creation theory, the elements of Student Engagement Work Design Model, SEWDM (4 Figure 1.) is going to be folded out and identified to what degree the intervention included these factors. To start with, let's see whether the results show any positive outcome with regards to the students' engagement.

It could be clearly seen from the observations that their level of engagement was rising during the intervention. They looked more motivated from one workshop day to the other. Also, the object of their engagement changed. First, during the installation day, they were only interested in the fish, worms and the plants. Then as we went forward with the project, they got engaged with more abstract ideas, like how it works in real life, and how you can work with it. One of the students was especially interested, and thought of that how this could be her job. However, the reason for the accelerating interest towards the aquaponics could be also because the students got more concerned about the final exam. The Teacher points out that there could be bias from the researcher's point of view:

"And you are seeing them when they are just very focused, and they are know they are going to exams and everything. So, you should have seen them two years ago, then you would not believe how they are today." (Appendix, 1.2)

She also points out one of the students' specific improvement. According to her, Student No. 5 (the student who has dyslexia, reading disabilities) went through a very positive change last year, and she has been working hard in the classes. Aquaponics has become part of her personal growth in many ways. She has got to use her skills without too much reading:

"*it is been hard for her, so I think it is for her. And she is growing and she is talking to you when you are there and she is using her English. So she is quite good… She has awful difficulties with reading and writing. And if they all worked the same as she did, they would all get twelve."* (Appendix, 1.2)

By relying on the Teacher's experience, the same presupposition can be made; Student No. 5 improved and gained knowledge during the intervention, therefore the factors of co-creation can be analysed, to see whether those were present to contribute. From the observations, we could see that she has been working autonomously, and she used her necessary skills for the exercises, because there was not too much reading required, nor too much reading material. As it was observed, she was very interested in the values aquaponics could provide for other people, thus she found meaning in it, and appreciated the significance of it. She constantly received feedback from the Teacher, the English teacher and the guide of the outreach activity, so she was encouraged on a regular basis. According

to the Teacher, this is an example of how the project reached its goal, and that aquaponics and similar projects could contribute to the students' development.

As it was experienced in the beginning, some of the students lacked any kind of interest. This could be also due to that the unit represented itself too complex. They either did not get a full grasp of understanding of the system, or the exercises were too difficult. The model of SEWDM (4. Figure 1.) shows that the level of engagement is dependent on the skill variety, which means the students have to possess certain skills to conquer a task or exercise. As it was already described before, Piaget points out that knowledge is constructed by breaking the structure of the world into small pieces. Then it can be accommodated and built up into a new structure. Too much information at the same time only shatters the worldviews of the children, therefore it can appear to them that the learning process is always a struggle. However, it is only true if the destruction and reconstruction of the view happen with a high deviation. It can also be stated that the amount of information, the changing process is too intense. In this case, the way to learn would be to open up the constructed knowledge on the outer limits of the object. Then they can step by step voluntarily transform their view of a certain situation and be able to digest bigger tasks.

As Umberto Eco very profoundly defined, co-creation is a process that involves senses and develops a connection between the co-creator and the product in an enjoyable way (Stensæth, Eide, 2017). The co-creators of the project collect new experiences by exploration. According to the Teacher the aquaponics, being a hands-on project, influenced students' senses, which could be one of the main advantages of the system:

"*It is much easier if they can see it and **feel** it. And work with it. I think that is a quite good idea."* (Appendix, 1.2)

The first question of the focus group interview referred to the students' experiences with the aquaponics. The students agreed on that they enjoyed working on it and they found it interesting to see how it operates.

"It was very fun to see how it is all used together, how it can make it, how it worked." (Appendix, 1.1, Student No. 5)

These abovementioned examples show the traces of the same values as co-creation, therefore it could be seen as such process, where the students collaborate in the act of creation. In the following, the rest of the factors of this theory will be analyzed.

7.5.2. Task identity

This term in the theory of co-creation refers to the degree students see the positive outcomes they could gain. This means students are able to recognize value, therefore, they feel more responsible for what they are doing. From the interview with the Teacher, two important ideas have to be highlighted regarding task identity. When she mentioned how the students already have been working on projects, she stresses the idea that students by now understand what they could gain out of it, and they could feel responsible for what they are doing:

"*They have been working like that for quite a lot, long time with me now. So I think it is showing now, that they are getting the idea that 'if I am working, I am reading about it and I am getting some knowledge, then I can use it later to explain for others'. So I think it works."* (Appendix, 1.2)

Therefore, they create value, and the end-product is the learning process, knowledge itself. The other bit that was picked from the interview is something different, more technological. It refers to keeping the plants and the fish alive and managing to run the aquaponics system. Accordingly, the maintenance of the system could create value for the student, because if they succeed then they can produce their own food. It also entails that then they could feel more responsibility to maintain the system. Constructivism also stresses that it is recommendable that children at this age work on their on a project that has meaning for them and they feel the relevance of it.

*"But now **they are seeing** that I had both those tomatoes and the soya beans, so they can see that you **can** do it. So after they were very interested."* (Appendix, 1.2)

What she highlights here, is that students did have the required competence, variety of skills for managing the project, and they felt the sense of achievement by doing so. This encouraged them further on to feel the identity of the tasks and kept their level of interest. Moreover, according to Vennix et al. (2017), if they find meaning while working on a project,

this can contribute to children's autonomy. It can be interpreted that it works like a chain-reaction: first, the students reach a suitable goal, which can be meaningful if they move towards that goal, so that can raise the students' level of independence.

7.5.3. Significance

The significance of a project for the students means to what degree the students feel the relevance of their work relate to their lives and to others in the future. The ways it can positively influence them defines the significance of a project. Thinking about the future and abstract ideas are also a contributing factor of the formal operational stage. According to one of the students, aquaponics is a futuristic idea:

"I think it is a pretty smart way, compared to the future, if this is what we are gonna use in the future, so I think it was pretty cool to see how it works." (Appendix, 1.1, Student No. 3)

This shows that some of the students found it important to learn about, that their project can have a positive impact on others in the future. The other reason why they can find it more significant to work on it is, that since the third observation they know that it could be one of the projects they can choose from for the final exam. This, as it turned out in the fourth observation, what motivated them is that they could see a goal they have to work towards to. It meant, now they do not only have to understand how the system works, but also they have to remember the topics related to aquaponics. As it was mentioned before, one of the students asked during the second observation, whether someone can work with aquaponics as a job. She also revealed that she likes to work on hands-on projects and would like to study as an electrical engineer. She has found significance in the project, as it could be her future job.

7.5.4. Feedback

The teacher and the guide are providing constant feedback about the outcomes is one of the main factors of co-creation, as well as the outreach activities. As it was observed, the students constantly got supported by the Teacher and the English teacher. They needed a little encouragement every now and then to stay motivated, just like in co-creation theory suggests. Getting feedback on a regular basis is essential, and they did not lack this step during the intervention. The teachers and the guide tried to keep the children on track

without interacting too much, thus the autonomy of the students can be preserved. The achieved small tasks were followed by feedback from the teacher, and this acknowledgement also collaborated to their engagement.

7.5.5. Autonomy

As the theories suggest, this factor is very important for co-creation, constructivism and also outreach activities with regards to STEM education. Therefore in this part, the traces of autonomy will be detected, and analyzed to what degree the children worked independently. The Teacher talked about project works in general, and how it helps to get the students engaged in order to work on their own.

"It is the easiest way for me to make them do anything." (Appendix, 1.2)

Also according to constructivism, children at this age have to work on a project that has an aim, and they can find its significance. Autonomy means working without other external authorization, by letting the students do the exercises with as little control as possible. As it turned out from the observations, the students have been working autonomously in groups on different kinds of tasks related to the aquaponics. The very first one was to do their investigation online about this food producing system. Their Teacher gave them links that are relevant to this project to start with. Students were 'information scavengers' in the first period of the intervention, they had to start collecting small pieces of information about aquaponics. Therefore, they were able to see the unit as a system and they had to understand all parts of it.

Not everything functioned properly, some expected and unexpected error happened as well. A few of the plants died in the first couple of weeks, which is understandable, the system has to be monitored and adjusted if necessary. For example, a lamp could have been set up that lightens the plants as sometimes it was quite warm and dark in the classroom. Moreover one of the fish died because it swam up in the siphon. The water pump stopped working at some point, it had to be strengthened and adjusted so it can function properly. These sets of flaws clearly show that there was need for the teacher's guidance, so she needed specific information with regards to operating the system. It can be stated that after setting up the unit, in the first week it is crucial to get feedback about how the organisms

doing in the system. The children could have more autonomy, more responsibility for the system, but even the teacher had some troubles with maintaining it. With a better functional unit, that we know it would function properly, we could provide more freedom for the students, which is important for the co-creation process. It could also be their responsibility to fix it if something goes wrong, they could be more responsible for the successful operation of the unit. To achieve this level of autonomy, the teachers have to be absolutely comfortable with the system to be able to provide sufficient feedback. This proves the point of Clayborn et al. (2017), as it was presented in the state of the art: teachers are more likely to use the system for educational purposes if they get a 'training' before (Clayborn, et al., 2017). According to the Teacher, this is also true with regards to the sensors:

"It took time and especially for us to get to know how to use them. (Laughing) But now that I know it, it is no problem." (Appendix, 1.2)

7.5.6. Skill variety

The installation of the system needed a lot of external assistance, the researcher had to make sure that the system functions properly, before introducing it to the children. However, as it was observed, the students are compatible to do most of the work, with a stronger, better functioning unit they could do the whole construction on their own with only a little guidance. One of the difficulties that occurred to them during the workshop was the calibration of the sensors. It was not easy for them to understand, what is going on exactly, why is it necessary to do it before we use them. It is understandable since calibration is a complex topic that can be raised to university level of measuring science and technology.

"'It was difficult to make it ready. Need it to all, I do not know, these things before we could put it in the water.'

'To calibrate it?'

'Yeah, to calibrate it.'" (Appendix, 1.1 Conversation between Student No. 5 and the interviewer)

Perhaps what was missing is a higher degree of autonomy of the students. The teacher did the calibration in every observation and the students were just listening. They could have

done the calibration by themselves, with some guidance, so they get a better grasp of its importance.

As explained in the theories section, the 21st-century skills are important to possess and outreach activities could provide an opportunity for that. The most important skills it aims to reinforce are teamwork, communication and problem-solving. The students were working in groups during all the workshops and practiced to manage the certain tasks together. This required constant communication with their peers, the teacher and with the guide. They used their computer for making videos, to communicate their view of the system, trying to explain how it operates. They have been working on a hands-on project that involved many critical points, that has to be taken care of for a properly functioning system. This way they could practice problem-solving thinking, thus whenever an error occurred they tried to think up solutions and fix it.

7.6. Summary and sub-conclusion

As it was analyzed, the elements of co-creation and outreach activities were provided by the intervention. The traces of constructivism helped to understand children's development of the certain age groups, and it can be derived that aquaponics as a teaching tool fits into the elementary school settings. In the fourth developmental stage, the 8th graders all share, the students are able to reach the highest level of abstract thinking, therefore, this project seemed to fit for this stage in particular. Aquaponics has the potential to incorporate STEM education, as explained in detail in the first section of the analysis.

8. Discussion

8.1. Summary of the paper and answering the research questions

This master thesis sought the answer to how aquaponics could be part of STEM education and how the application of sensors could contribute to this aspect. As it was presented in the state of the art, STEM usually refers to university settings, however, the importance to incorporate it in an earlier age could be crucial. As the previous research suggested setting up an aquaponics system in the classroom could help to integrate the STEM disciplines in the curriculum.

The focus of the research was an elementary school in Albertslund, Denmark, where a 6 weeks intervention was conducted with a class of 8th graders. The students used the aquaponics system to produce food in a small scale, for instance, tomatoes, soybeans, and basil. They used the system throughout the six weeks in biology class, where they learned about the nitrogen cycle, the organisms in the system and about several other scientific topics. The aim was to investigate how the children interact with the system and the sensors and to evaluate the project. Certain techniques of qualitative research were applied data collection. There were four observations conducted, all during the biology classes, while the researcher put on an active, overt role. At the end of the intervention, an interview with the teacher of the biology class and a focus group interview with five students were organized.

The results were analyzed with the guidance of the chosen theories, so the research question could be answered. The utility of aquaponics system lived up to the expectation of STEM, and the digital sensors highly contributed reaching that. The only way to provide mathematical exercises were, to collect, read and analyze data of the certain measured variables. The theory of constructivism helped to identify traces of how students construct knowledge and how the aquaponics could be a guide for developing abstract thinking. The main characteristic of the formal operational stage, the 8th graders are at, is the highest level of abstraction. In this age, the children start practicing the process of hypothetical-deductive reasoning, and aquaponics, especially the sensors provided a very suitable tool for practicing this. This is in a strong relation with engineering thinking, which is one of the main elements of STEM education. Therefore, this is one of the reasons why teaching scientific subjects in

elementary school, from the age of 11 (beginning of the formal operational stage) with the concept of the STEM is appropriate and useful. Furthermore, sustainability appeared to be an especially important topic since the children at this stage start developing ideas about the future.

The project also reached its goal by providing an outreach activity because it created an implicit way of learning for the students. The value in the co-creation process turned out to be the knowledge itself the students could gain and also the success of producing food with the aquaponics. If we pay attention to the elements of co-creation in the process of teaching with aquaponics, and those are equally present, then the students' engagement could be maintained which contributes to their development in STEM education and food literacy.

Utilizing an aquaponics system for teaching seems to be sufficient for every discipline of STEM education. There is a need for applying the sensors, so the mathematical aspect could be covered as well. As the model of Bybee (2010) suggests (3. Figure 1.), the context of the STEM has to be an issue that will promote problem-solving thinking. With aquaponics being a sustainable method of food production, problems such as water-scarcity, soil-scarcity could easily be centralized in the STEM. Furthermore, it has to be mentioned again that the context for learning was about sustainability, how can aquaponics positively effect other people's life. It ensured the significance of the project, which is a very important factor known from co-creation. According to this theory, they find their project work more significant when they feel the utility and effects of that on other people.

8.2. Evaluation of choice of theory and methods

The methodology section was divided into a technological part and an empirical data collection part, therefore it also has to be evaluated separately. The technological emphasis was on the aquaponics and the sensors, and how aquaponics can be positively used by the students. As it was concluded above, from the STEM perspective it turned out to be advantageous to apply the sensors. Another aspect, however, would have been the automatization of some variables of the system. For example, to automatize the water-flow into the aquarium, so when it reaches the required level of water, the pump would stop working. Moreover, feeding the fish would also have been operated digitally with a programmed Arduino prototyping platform. The motivation to create a system that has

automatic functions was driven by the previous research, Collins, Sikora (2017). They concluded that a half or fully automatized system would be more appealing for teachers to use and it could also help the maintenance during the summer. This idea emerged at the beginning of the project, and the plan was to design a system with certain automatically controlled variables. However, after stocking the equipment of Herstedlund Skole I decided to go into another direction and work with the interactive sensors. Furthermore, now looking back, it seems like with an automated system, the students have less chance to practice on the unit. It raises the question then, of how the children measure the variables themselves. Automatization seems to be more useful in an agricultural level food production when it is not just a model for teaching purposes. With the idea of automatization, autopoiesis could have been a good choice of theory. The main idea is to create a complex ecosystem that shows the same vegetative signs of life as any other, individual organism in order to maintain itself and its processes (Bourgine, Stewart, 2004).

For the philosophy of the research the values of constructivism-interpretivism were capitalized, therefore a qualitative research was conducted. As it was described in the methodology section, the strength of such studies is not the amount of data, but how well it is analysed (Brinkmann, 2013). As for data collection, the techniques of qualitative research have been chosen, such as interview, focus-group interview and observations to follow the progression of the students and monitor the processes. The only issue that was experienced was with regards to the focus group interview. The students struggled with explaining certain things in English, the focus group seemed to more useful to find out about their impressions and engagements. Moreover, one of the students did not say a word, and this seemed to cause an error in this method. Since the focus group only consists of five students, losing one's opinion is a quite high contributing factor. As opposed to a pretest-posttest structure, where the all the students (21 people) would have to contribute. With this type of data collection, then, if one of them refuses to answer, the data loss-gained answers ratio is way lower. Moreover, the improvement of the students would have been proven more concretely with a quantitative research. In this case, the intervention could have been evaluated with a pre-test, post-test concept, to measure whether they are more engaged in such scientific subjects and food literacy or not and how well they understand it.

The abductive method turned out to be very beneficial, as it carries the attribute to go back and forth between the findings and adjusting the focus of the research.

In terms of theories, other teaching concepts were considered as well. Other constructivists' ideas could have been applied, such as Vygotzky's Zone of Proximal development, David Kolb's experiential learning, as well as the problem-based learning. These theories origin from Piaget's constructivism, so it can be stated, that for this paper the fundaments of constructivism have been utilized. These other theories were used for the research of Bosire, Sikora (2017). The concept of problem-based learning appears to be very similar to the context of the STEM, that there is a problem that hinges the project. Therefore by utilizing the former, this research might have gotten similar results since the idea is more or less the same here. The theory of Vygotzky has also similar fundaments in comparison to Piaget's since the former is derived from the latter. In the research of Bosire, Sikora (2017) the Zone of Proximal Development of Vygotzky has been applied. It states that there are three types of tasks, children are facing during a learning process: things they can do by themselves, things they can do with assistance and things they cannot do. According to this theory, children gain knowledge the most effective way if they practice exercises they can do with the guidance of the teacher. Mainly the goal of using this theory was to identify critical points of the aquaponics system, what the students can do with assistance. In this paper, the all three of the theories supported this idea, under the terms of skill variety and autonomy. However, it differs from this paper's findings, because the previous research has not focused on the sensors.

8.3. Future perspectives

8.3.1. Suggestions for further research

For further research and utilization of the aquaponics, it seems advantageous to initiate the unit in the second semester. Then it would provide several examples of the previously learned scientific materials for the students. For example, if they learn about topics such as the nitrogen cycle, Bernoulli equation, assimilation process in plants, from September to December, then they should have enough knowledge to connect the gained knowledge to a real-world situation which the aquaponics aims to provide. Then it could be the end product of these abstractions which is hard to imagine without seeing it represented in real life. The

children's interpretation could become more complex this way, but also they possess the required initial knowledge to build on it further on and open up their knowledge structure. To put it into more simple terms, this could provide an opportunity where 'it makes sense'. Another point that has to be made is that the aquaponics was set up in a biology class. This specification did not seem to be useful since the versatile aquaponics entailed other examples from other subjects as well, as it was mentioned above. These examples could be divided into the certain subjects. Then, with each subject, the aquaponics could exemplify those topics and the system could be utilized more efficiently.

It would also be important, to start measuring variables from the get-go, or when some change occurs (adding extra fish into the aquarium) so they can monitor the changes. The students could compare the results if they start measuring from the beginning, to see how the ammonia level starts dropping and the nitrite, nitrate rising. Then with the analyzed data the students can draw conclusions and identify of what kinds of adjustments are necessary. This entails that they start using their engineering skills from the very beginning by setting up the system. Before planning further interventions, it is advisable to give a manual, maybe a training course for the teachers in charge beforehand, so they know how to handle the system, and they have less trouble with it.

8.3.2. Technological perspective

By applying an already built aquaponics unit for this research, it was also tested whether the experiment, more specifically the technological part was replicable. It was managed to set up and run it for the entire period of the intervention, although it was not flawless. It seemed like the unit is designed to be mobile, easily carried or moved. However, a stronger unit would have been sufficient to use, therefore mobility could have been for a more massive structure. The unit is going to stand in the classroom, in the same place for at least 6 month which is a long time, therefore mobility is irrelevant. Firstly, a stronger grow-bed is needed, maybe not from plastic, since its legs were unstable. Secondly, sometimes the water pump was not working efficiently, it could be replaced with one that has a higher capacity. Moreover, the grow-bed could stand on the same table as the aquarium, so it is easier to adjust the water level in the aquarium. The level of the water, because of the Bernoulli equation, is always going to be the same height as the top of the siphon. In this case, the

table was a bit too high therefore the water-level was not as high as it should have been. To eliminate this problem, one, massive wooden table would be more sufficient. Furthermore, the classroom was rather dark and the system could not have been placed near the window, because under that there were the heating devices. Putting up lamps above the grow-bed seem to be essential for the plant, or to set up the system in the greenhouse instead of the classroom, if there is any in the school. The students highlighted another problem of the unit; the fish can swim up in the pipe, the one that ensures the water flow to the grow-bed. The class started the experiment with small goldfish in order to monitor their growth, thus they fit into the diameter of the pipe. As a consequence, three fish died during the six weeks, the children found them in the grow-bed. During the focus group interview, they suggested to set up a filter which could be solving this problem. The aquarium, siphon and siphon bell seemed to be working fine.

9. Conclusion

For this paper, an aquaponics system was utilized as a teaching tool in an elementary school for a six weeks program. The intervention reached its main goal which was to provide enough empirical data to evaluate it. The results were analyzed with the theoretical framework of constructivism, co-creation and also checked whether it has the qualities of an outreach activity for STEM education. The application of digital sensors was identified as the main gap in the literature search, therefore, it was an important part of the research. The system provided an opportunity to use the sensors because there were certain variables (temperature, pH, ammonia, nitrate) the students had to measure to check whether the system functions properly. As it was analyzed, it highly contributed to the STEM perspective of the aquaponics system, it filled out the standards of engineering, technology and mathematics disciplines. As for the science part, biology was the main topic, but it turned out that it is better to use aquaponics in a universal way. It could provide a holistic view of different kinds of scientific subjects. It would be necessary to write a plan, what the topics related to aquaponics are precisely, and divide them into the certain realms of subjects. For the context of the STEM food literacy was used, the aim was to show that aquaponics is a sustainable alternative for food production. This aspect of food literacy was magnified so it can be allocated in the center of the STEM as an issue the students can think about. Another disadvantage is that the system requires continuous maintenance. The teachers need to be prepared that it is going to take extra time and effort to work with an aquaponics system.

To follow the students' development, and determine the possible implications of aquaponics for the 8th-grade students, constructivism has been guidance. Piaget's cognitive development helped to identify the characteristics of the certain stages in order to investigate, how aquaponics fit into this age group. It showed us, that the children can practice their hypothetical-deductive reasoning with aquaponics and cooperate with their peers in a project work. Using the sustainable aspect of food literacy as a context of STEM seemed to be appropriate, especially if the characteristics of the formal operational stage of cognitive development are considered. The cognitive ability to think about the future and abstract ideas is emerging at this stage, therefore, it is a suitable project to practice these

attributes. The students contributed to the value creation process, thus it raised their interest during the intervention. Two types of value were identified: the learning process, the knowledge they gain by working on a project, and the other which is to succeed producing food with the aquaponics. The intervention served as a sufficient outreach activity. The students had a chance to learn by working on a hands-on project, they practiced analyzing the data from the sensors. It is effective for STEM education, because the students learn the material implicitly, rather than explicitly. Moreover, it fits into the Danish curricula, since the students have to pick a project for the final exam before they are going to 9th grade. One of the final projects could be about water scarcity, which entails the utility of aquaponics. The system also helps to cover certain topics the students have to present at the exam, and it could provide a tool to braid the scientific subjects together. Aquaponics with the utility of sensors suits the concept of STEM and it could guide scientific subjects in elementary schools to engage the students.

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Appendix

Appendix 1. Interview transcriptions

Appendix 1. 1. Focus group interview transcription

Interviewer:

Thank you for attending guys. This is an exercise I need to do for my project, so I am going to need your help. We are going to have a little discussion about the aquaponics system set up in your classroom, how was it to use and what kind of tasks did you guys have with it. It is a group discussion, so if anybody has anything to say, just say it, do not hold back anything. So if we could just start with everyone saying their name, introduce yourself.

Student No. 1: My full name?

Interviewer: Yes, your full name please.

Student No. 1: My name is (...)

Student No. 2: My name is (...).

Student No. 3: I am (…).

Student No. 4: My name is (…).

Student No. 5: It is (…).

Interviewer: All right. Thank you so much for being here again, let's start with the first question. What do you think of the aquaponics that is set up in the classroom, how was it to use? Was it fun to work with, boring…

Student No. 2: It was fun. Yes.

Student No. 5: It was very fun to see how it is all used together, how it can make it, how it worked.

Student No. 3: I think it is a pretty smart way, compared to the future, if this is what we are gonna use in the future, so I think it was pretty cool to see how it works.

Student No. 5: It was more fun to work with the hands, I get bored of too much reading.

Interviewer: Okay. Can anybody quickly tell me how it works? What are the organisms in the system? Just to wrap it up.

Student No. 5: *(Talking indistinctively to each other in Danish)* The fish make the poops into the water, that gives the plants ahm…

Student No. 4: Nutrients.

Student No. 5: Nutrients, yeah. And the water get into the…

Student No. 3: The tube, and it get transported to the plants.

Student No. 5: Yeah. And the plants take all the (*speaking in Danish*)

Student No. 3: (*Answering in Danish*) Gets all the…

Student No. 2: Takes the dirty water away.

Student No. 3: Takes it all away, so it is cleaned water.

Student No. 5: So it takes the dirty water, because they need it. The water gets cleaned, yeah.

Interviewer: Yeah.

Student No. 3: And you can use that for the fish water.

Student No. 5: And the water get up with the pump, and the water come back to the tank.

Interviewer: Perfect. What do you know about sustainability, do you think aquaponics is sustainable way of farming?

Student No. 3: I would say it is sustainable, sustainably, something that keeps working, like aquaponics. I think it is sustainable, but of course there is a little water loss every time. It goes into steam. But in the long-run I think it could work, if we are good at using it.

Interviewer: Do you guys remember any advantages of the system?

Student No. 2: The water.

Student No. 3: Of course you can use more, ahm, less water to the plants, and again use it for the fish. So you can make meat, and also vegetables with one smaller quantity of water.

Interviewer: Yeah, anything else?

Student No. 2: I do not think so.

Interviewer: Okay. What did you guys think of the sensors? Was it easy to handle or was it complicated?

(Indinstinct group discussion, speaking at the same time in Danish)

Student No. 5: It was difficult to make it ready. Need it to all, I do not know, these things before we could put it in the water.

Interviewer: To calibrate it?

Student No. 5: Yeah, to calibrate it.

Student No. 3: Yeah it just took a long time to get ready to use, like to do so many steps. So it has to sit like 30 minutes before you can even start doing anything with it.

Student No. 2: Yes, I agree. One measuring, you take it out, and then you have to start all over again.

Student No. 3: But once you have your hand on it I think it was pretty good at doing its job and like easy to use when it was ready.

Interviewer: Yeah. I have seen that you guys set it up now, so it is in the water all the time.

Everyone: Yes, yes.

Interviewer: Does it look easier now? If it is set up and you can just read the data.

Everyone: Yes, yeah.

Student No. 5: It is much easier. When you all, all the time need to take up and out again, so it gets lifted.

Interviewer: What do we measure with the sensors?

Student No. 3: pH, I think.

Student No. 5: pH and temperature.

Student No. 3: Like the nutrients in the water.

Student No. 2: Yeah.

Student No. 3: Not sure.

Interviewer: Which one? What is the most important element?

Student No. 3: pH is one of them, ahm, cannot remember the name.

Student No. 2: Nitrogen, yes.

Student No. 3: Oh yes.

Interviewer: Why is it important to measure these things? Why is it important to know for example the temperature of the water?

Student No. 3: I think it is for the fish survival or something like that, so they do not die of bacteria or too high pH value or something.

Student No. 2: Yeah.

Interviewer: Do you have something to add?

Student No. 2: Yeah, just like she said. It is the temperature is not right, the fish will die.

Interviewer: Okay. What kind of tasks did you have with the aquaponics?

Student No. 2: We had to make a presentation.

Student No. 5: A video.

Student No. 3: We had to take some pictures for the film and also read about it how it works and what is the use of it.

Student No. 4: Put the audio over there, make a video out of it.

Student No. 2: Collecting information to see step to step how the aquaponics system works.

Interviewer: Okay. Did you feel like you are working on your project, that it is your own responsibility?

Student No. 5: We, some of us is going to use to for our exam.

Interviewer: Yes, for the final exam on the summer?

Student No. 5: Yeah, yes.

Student No. 4: We use it as a…

Student No. 5: We use it to, to see what people who do not have so much can do at home and they do not have a land to do it on. And things like that.

Interviewer: So the final exams, is it like a project, right?

Student No. 3: Yeah, you have to do some experiments and talk a lot about how all that works.

Student No. 2: *(Speaking in Danish).*

Interviewer: So it is like you use one project to show what you have learned from geography, biology…

Student No. 2, Student No. 3: Yeah, yeah.

Student No. 5: But we just need to make many components, instead of one.

Student No. 3: The topics we have chosen.

Student No. 2: We have chosen several problems, good ideas.

Student No. 3: We have to come up with our own problems, and the make some questions, and some answers that can answer.

Interviewer: Would you like to use it in the future, how many of you have chosen it for the final exam?

Student No. 5: We did.

Student No. 3: Yes, we.

Student No. 2: We did not get this, but we got something related to that, to water.

Interviewer: Okay. I also wanted to ask about the process of learning. Was it difficult in the beginning to see how it works? When you understand it more how it works, was it because you learned background knowledge about it, for example biology and geography? Or you just got used to the system.

Student No. 5: I just got used to the system. After using it again and again I understand it more.

Student No. 2: After knowing how it works, then we got an understanding of the system.

Student No. 5: Yeah. It was, when you understand, how it works it is kind of logical, after that, so…

Student No. 2: We did not start just like asking what is this, what is this. Until (…) our teacher told us, okay, like that. It make sense.

Interviewer: Okay. And also what did you guys learn, that can be used as a background knowledge for aquaponics. For example you have learned the nitrogen-cycle, right?

Student No. 5: Yeah.

Student No. 2: Yes.

Silence.

Interviewer: Was there anything else?

Student No. 5: We learned also that not all the plants can be used inside, where there is not so much sun and all that.

Interviewer: Okay. Yeah. How did you guys take it when one of the fish died, when some of the plants died?

Student No. 3: That something is wrong or we have done something, something was not wrong but something was not right. Or maybe the nitrogen was too high so the fish died or the.

Student No. 5: It jumped, like in Finding Nemo.

Laughing.

Student No. 3: Yes, apparently the fish tried to escape.

Student No. 4: Kind a like Nemo.

Student No. 3: So maybe we should put like something, that, a filter on the tube, so it would not be able to do that.

Interviewer: Yes, that is a good idea. So did you guys tried to think of solutions…?

Student No: Yes.

Student No. 3: Yeah, yeah.

Interviewer: With regards to nitrogen, did you understand how can you balance the system?

Silence.

Interviewer: Maybe it is a bit more complex question. So if you plant more, then the plants take more nitrogen.

Student No. 2, Student No. 5: Yeah.

Student No. 5: Does some other place, not far from here, do not they have some, a bigger one, kind of this?

Interviewer: Yes, they do.

Student No. 5: Because we are also going to see it.

Interviewer: Are you going to visit the other one?

Student No. 5: (*Speaking in Danish)*

Student No. 2: Yeah, there is going to be a system, and we can see theirs.

Interviewer: Okay, and when?

Student No. 5: We do not know yet, (the Teacher) just said…

Student No. 3: Soon, from our exams and not far away, so.

Student No. 2: Two month.

Interviewer: Okay, that was it from my side. Is there anything else you would like to add, if guys have any feedback?

Student No. 3: I think if this would work, you should check out the plants, how they react to it, before you start planting. Lot of them, like many of the plants died. So yeah, you should make sure to get some plants that can handle this system instead of the ones that died.

Interviewer: Okay. Thank you so much.

Student No. 2: No problem.

Student No. 5, Student No. 3: Thank you.

Appendix 1. 2. Interview with the teacher transcription

Interviewer: How did the intervention go, how was it like to teach with the aquaponics system?

Teacher: I think it is been quite interesting to see, and notice their enthusiasm, how they are going to look at it, how they look at it. And they are nosy and they are want to know something about it and it interests them. So I think it is going quite good.

Interviewer: Do you think, now that you used it, that it is important to teach aquaponics?

Teacher: Yeah, I do think so. Because it shows, it gives an idea to how you can make food in a space that is not so big. And they can it, it, it thrives. I got a friend, he lives, she lives in Norwegian, in Bergen. And their friends got aquaponics system in down in the basement. So yeah they are making greens and vegetables.

Interviewer: Okay. Did you tell the kids this example?

Teacher: No I have not done that yet. And the two girls that are working with, they are going to into town to. They have contacted someone in town, who is using it. But they have not answered them yet. So they are going to go there and here about their ideas and how it is going. So yeah. I think they are thinking about it and they can see: 'Oh that is brilliant.'

Interviewer: Do you think it could cover some of their subjects at this age?

Teacher: Yeah. Yeah I think so. Especially when you are working and getting them to understand how it is to be sustainable. I think that is, that is a quite good picture of it and telling them how it is. And also that they can measure the ammonium and nitrate, and so they get the idea of that it is something that the plants are going to use and need to use.

Interviewer: Yeah, okay. How did the children relate to the sensors? Was it easy for them to understand, or it took a lot of time?

Teacher: It took time and especially for us to get to know how to use them. (*Laughing*) But now that I know it, it is no problem. So when I got the last one, the ammonium it was just like (*snapping fingers*). And it was no problem. And they have seen me do it twice or three times. So the were saying: 'What about this, how this works? When we are going to use it?' 'Yeah, yeah, do not worry. You are going to learn it. It is not going to be any problem.1

Interviewer: Can they also use the collected data on their computer?

Teacher: They can do that. They have not done that yet, but I am going to, to show it to the girls tomorrow. And, so they can look through it and see it and think about it and see, okay, that is why.

Interviewer: Do you think that they are in the right age to understand how aquaponics works. Does the operation of the system match their level of abstraction, their abstract thinking?

Teacher: Yeah, it does, it does. And I have been, when I went to the Big Bang convention, they were also talking about the engineering materials also going to be, it should be all over in the school. Just right when they are starting at 6 years old, they should work like engineers and include it.

Interviewer: So already from the first grade?

Teacher: Yeah, yeah. Because they do not have to understand it. They just have to get to know 'okay, we can make it that way'. And then we can get the water to flow. That is fine for them. And then you, as older as they get, you get them to understand more and more.

Interviewer: That is really interesting to see and this is related to my next question. What do you think of STEM education, which is science, technology, engineering and mathematics combined?

Teacher: I think they are going hand in hand. They do. But it is funny, because the kids, they do not understand how much math they are using. Sometimes in physics or in geography and something, where they are looking at graphs and everything. 'It is math'. 'Is it?' 'Yes, it is'. (*Laughing*).

Interviewer: Okay. So they do not realize that there is actually a lot of mathematics already in their…

Teacher: No, they do not, no, because they do not think about it.

Interviewer: Okay.

Teacher: So it is quite funny to see, that they do not that just math.

Interviewer: But does that mean, you think, that because they understand it so well, that now it is just part of their thinking, and they are not conscious about it anymore? They know for example, how to read graphs.

Teacher: I think that is it. Yeah. That is one the things.

Interviewer: Is there any initiation to incorporate STEM education in the curriculum?

Teacher: Yeah, it is, because we have to use engineering and we have to use the math. And it is going to be big shit for the next few years.

Interviewer: Yeah, okay.

Teacher: And it was, so here in the school we are, there are two who are getting the mathematicians education. So they can help me as well when I am teaching math and bring some ideas and how to begin to use it like that. So and I am going to be doing all the other in the STEM.

Interviewer: Their final exam, the project, is that an idea of STEM education, it just does not called STEM. Because I have a feeling, that while they are working on a project, the STEM disciplines could be fulfilled.

Teacher: Yeah, it is. They have to use all of the things, all that they have learned. They can use it from math, they can use it from physics, chemistry, biology and geography. So yeah it is.

Interviewer: Yes, that would have been my next question that do you think aquaponics could help teaching these subjects, for example biology, geography and prepare for their final exam.

Teacher: Yeah, I think so.

Interviewer: Yeah. The next question is about the children's perception. How interested the students were, how their level of interest changed during the time.

Teacher: They have been interested and also especially in seeing about the plants. And they noticed that the plants you had come with the first time and they asked 'What about the plants?'. Yeah, it was freezing, so.

Interviewer: Yeah, they did not make it.

Teacher: They did not survive. But now they are seeing that I had both those tomatoes and the soya beans, so they can see that you *can* do it. So after they were very interested.

Interviewer: So they were more interested when they see the success, right?

Teacher: Yeah. And also when the sensors came up. It was quite interesting for them to see, how it works. And I have been telling them about, they have been working for long time with the nitrogen cycle. So I think it is yeah, it is giving them a bit more idea about how it works.

Interviewer: Did you see any improvement in their knowledge? So about these subjects, geography, biology, or was it just specifically the aquaponics that they've learned about?

Teacher: It is interesting to see, because some of them, they are getting the idea, about how, it works. The idea that the fish, the shit, and it comes around, there is some worms and

the plants. So they are getting some 'aha moments' and understanding how it all get together.

Interviewer: Also how it works in nature, in real life?

Teacher: Yeah, yeah.

Interviewer: And also I remember we talked with Maria about how hard it is to engage them in these kind of subjects.

Teacher: Yeah, it can be. It is much easier if they can see it and feel it. And work with it. I think that is a quite good idea.

Interviewer: So you said it would also work with children, who are usually not so interested in these subjects?

Teacher: Yes, because they are interested in the fish and they say 'Can I take them with me, can I get it?' (*Laughing*) And they are also asking about how it works. And normally they would not do that. So I think it is quite good, yeah.

Interviewer: So even them?

Teacher: Yeah.

Interviewer: So it looks like that no one is left behind.

Teacher: Yes, no one.

Interviewer: Did they feel they are working on their own project? That they have a big degree of freedom, so it is not just another homework?

Teacher: Yeah. They have been working like that for quite a lot, long time with me now. So I think it is showing now, that they are getting the idea that if 'I am working, I am reading about it and I am getting some knowledge, then I can use it later to explain for others'. So I think it works.

Interviewer: So you think that is like your personal goal. Because what I recognized is that the children do seem to like you, so you must doing something well.

Teacher: Yeah. I have had them since they kicked in the fifth grade. So I know them quite well now.

Interviewer: So you go through the whole process with them from 5th grade until they graduate.

Teacher: So I know the before they have got into puberty, through puberty. So I think it is been quite nice, we have been doing quite a lot of projects through the time. We have been down at the river, making (*speaking Danish*), I do not know how you say it in English. But I think we have moved two times of rocks more, down at the river to make, so the salmon can lay eggs. And the biologists could see it next year that it worked. So they are used to that I am getting them in an out over and over again.

Interviewer: So they always had some kind of projects that they are working on.

Teacher: Yeah.

Interviewer: What kind of exercises, tasks did they have with the aquaponics?

Teacher: They all got some, they all had to make a video that explained how it is working. And I have got all the videos, so I can send them also to you.

Interviewer: Okay, thank you.

Teacher: So it is just a bit, it does not have to be long, but they have to understand how it is working. And they have to get the knowledge and make sure that everybody is going to understand what they are seeing. So I think it is quite nice to see that they are trying at least. To do that, some better than others, but that is the way it is.

Interviewer: Did they also have to make a presentation?

Teacher: Yeah, yeah.

Interviewer: About technology and information in general, I recognized something. It is seems really easy to the to do their own research, search for articles and websites about aquaponics.

Teacher: They can search, yeah. And I have done that, I have given them links both with Danish sites and English sites. So they can chose so if you are good and if you are understand it all that in Danish than you can try to read it in English.

Interviewer: For me it was really surprising how good in English they are. And are afraid to use it, but there is nothing that they cannot say or explain.

Teacher: No. And it is very funny, because (…) (Student No. 5), it is been hard for her, so I think it is for her. And she is growing and she is talking to you when you are there and she is using her English. So she is quite good. And she is awfully, *hvad hedder det?* She has awful difficulties with reading and writing. And if they all worked the same as she did, they would all get twelve.

Interviewer: I remember we talked about this, that she is dyslexic.

Teacher: Dyslectic yeah.

Interviewer: So do you think projects like this can be helpful for those who are not so good at reading?

Teacher: Yeah, it is. Because of course you have to read something, but when you are reading and you talking to the others and you have to get a presentation or you have to get a video done that, that explains what it is. And you have to use it. So I think it is, that is quite good. I know they do not think that always, but… It is the easiest way for me to make them do anything. Sometimes like that, or make a presentation also. So, and they are getting quite used to it. And you are seeing them when they are just very focused, and they are know they are going to exams and everything. So, you should have seen them two years ago, then you would not believe how they are today. (*Laughing)*

Interviewer: Okay. So they improved a lot.

Teacher: Yeah they improved quite a lot. All of them. So that is nice to see too for me. Also that I can lay back now, because they are harvesting now all the hard work being, that I am trying to teach them. Yeah.

Interviewer: That must feel good.

Teacher: Yeah. That is quite nice.

Interviewer: That now they are just doing their thing. How do you think you can use it for the future for teaching. You have mentioned before that to maybe start it in an earlier age, or any other suggestion or feedback you have.

Teacher: Yeah, I think it is quite useful to us, we are a quite good school in this, and in Albertslund, to go outside and be outside with the children. And there is a good nature center, where there is a really good teacher. And if you book and go out there she is going to, into the water holes and she get salamandras and frog and everything you can see and fish and everything. The plants and everything that is in the water, something like that. So they are used to it, the kids.

And we went to the (*speaking in Danish indistinctively*) It is a place, where there is been from a glacier, a hole water, and it is going, it is going to disappear because the moss is overtaking the water. And we went out there and the kids had to talk about plants or something else, trees or anything. And tell it to all the other ones who were there also. And the water is awful, it is just brown. But there are salamandras and everything in it. So it is quite nice. And you can see lots of plants and blueberries.

And there is no more, *engelsk*, (*pause*). They are starting to appreciate that you are going outside with them and see and talk about things and see things. It takes time to get them there. And it is been a lot easier to do a project. Like the projects that they are going to have to use, like that, the aquaponics. I think it is brilliant, so they can see it and maybe they can use it some of them to get ideas to their other projects. And we are going to have, some of them to work with the larva of *hvad hedder det, myg? Hvad hedder det på engelsk* It is the thing that is sucking your blood. And then they go lay eggs.

Interviewer: Mosquito?

Teacher: Yeah, mosquitos. And they are going to use it and to try to see if they can get a water drop of koge sulfate, down at the water where they are. And then two and three and four, so they can go and have some larvas in a water glass, and to see how long do they, or can they survive. How much do we have to put down to see when they are going to die. So they get some ideas and they are going to work with it and see it. Just like that if we started

to set, to put something in the water here, they would also perceive it, and the plants and the fish. Can I get the question again?

Interviewer: Yeah. It was: how do you use it for the future?

Teacher: Yeah. For the future I think it is, for the small children, they could see that there is some system, and they could see that the fish are thriving and the plants are thriving. And then you can talk about that with them. And how important it is to make sure that we do not throw everything out or spill it, the water. And you think about where we, how much we use about medicine and chemicals. It is important, because if we do not think about it, then it is us who are going to die.

Interviewer: Yeah.

Teacher: So, yeah, I think it is quite nice. And teach them that if you are working like in the nature center, or here in the river or everywhere there is some problems to talk about, then the importance of seeing which plants are there. Which animals are there. Because it is telling you the quality of the water where you are. And it was quite, *hvad hedder det?* Two of the girls, they went out with the pH and they went to three or four waters at the river and checked the pH. And they were like 'There it was awful, there it was good'. It is quite, quite nice to see that they were interested and they were getting to think, how can it be, that the water there, the pH looks so good, and there it was not. So they are going to think about it. So that is quite nice. So it is making more questions for some of them. And that is just what we want. So I think it is quite nice. And I, we would very much like to use it for further on.

Interviewer: Okay. I do not have any more questions so if you have anything else to add.

Teacher: No I do not think so. Yeah. I think it is been nice to try it. And to see it and how it works.

Interview: All right. Thank you.

Teacher: You are welcome.

Appendix 2. Guides

Appendix 2. 1. Interview guide

1. Do you think it is important to teach aquaponics? Why?
2. Do you think it could cover some of the subjects at this age?
3. Do you think they are in the right age to understand how it works? Does the operation of the system match their level of abstraction?
4. What do you think/ know of STEM education, science, technology, engineering and mathematics?
5. Is there any initiation to incorporate STEM in the curriculum?
6. Do you think an aquaponics could help teaching biology, geography and help them prepare for their final exam? Could you please talk about their project they have to do for their final exam?
7. Were the children interested they with regards to the aquaponics?
8. Did you see any improvement in their knowledge?
9. Did it the aquaponics help to engage the children in the certain subjects (biology, chemistry, geography?
10. Did they feel they are working on a project together, that it is not just given?
11. What kind of exercises they had with the aquaponics? (presentation, searching information
12. How do you think you can use it in the future for teaching?

Appendix 2.2. Focus group interview guide

- What do you think of the aquaponics set up in the classroom, how was it to use? Was it fun to work with?
- Can you guys tell me how it works? What kind of organisms are there in the system?
- What do you know about sustainability? Do you think it is a sustainable farming method? (less water, no pesticides, no soil)
- What did you think of the sensors, was it easy to handle?
- What did you measure with the sensors?
- Did you guys understand why is it important to do these measurements work?
- What kind of tasks did you have with the aquaponics? How were those like?

- Did you feel you are working on your own project?
- Would you like to use it in the future? How many of you chose it as a project you have to do on the summer, for the final exam?

Appendix 2.3. Observation guide

Focus points:

- Tasks of the students
- Autonomy of the students
- Engagement of the students
- How they collaborate in groups
- Topics of the class and the upcoming exam
- Utilization of the sensors
- Examining the system, whether there is something to improve
- Interacting with the students

Appendix 3. Consent for observation

Dear Parents,

My name is Viktor Toth, a student and researcher at Aalborg University Copenhagen. As you may know I am doing a research about aquaponics system (sustainable agriculture technology) in collaboration with Herstedlund Skole. For the research I need to conduct an observation in the class, while the students are learning about this system, and I would like to document this also with pictures. In this letter I would like to ask for your consent, whether I can take pictures or not in the class while the students are working with the aquaponics.

Thank you so much for your time!

Viktor Toth

Please put a cross in the box next to your choice, and sign it below:

☐ I **do not agree** ,

☐ I **agree** with taking pictures in the class

Signature:

_____