UNIVERSITY OF GOTHENBURG

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DEPARTMENT OF PEDAGOGICAL CURRICULAR AND PROFESSIONAL STUDIES

TEACHING PHOTOSYNTHESIS:

IMPLICATIONS ON SUSTAINABILITY

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Level:	Second cycle
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Supervisor:	Eva Nyberg and Sally Windsor
Examiner:	Irma Brkovic

Abstract

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Aim: Education for Sustainable Development (ESD) is about empowering and motivating learners to become active sustainability citizens who are capable of critical thinking and able to participate in shaping a sustainable future, (UNESCO, 2017). This study centres on how the teaching of photosynthesis in Science can help students understand sustainability issues. It looks at the relationship between sustainable development and Science education in the compulsory school (grades 1-9), in Sweden. It analyses how teaching of important ecological processes like photosynthesis can be connected to environmental sustainability.

The aim of this study is to explore if, and in what ways, teaching photosynthesis at different grade levels is linked to sustainability issues.

Theory: Constructivism is used to frame this study as it emphasizes on the learning experience and the active process of learning.

Method: Semi-structured interview method involving five teachers from a compulsory school in Stockholm, Sweden, was incorporated. The compulsory school in Sweden consists of the primary section (grades 1-3 and 4-6) and the secondary section (grades 7-9). Questions regarding teaching methods, what the teachers perceive their students understand about photosynthesis and what they, as teachers, think could help them make the link to sustainability issues in their teaching, were asked.

Results: The results showed that although the teachers are committed to making the link to sustainability issues in their teaching, constraints like time, lack of resources and a packed curriculum have an impact on their teaching. The teachers are also aware that photosynthesis is a difficult concept to grasp and their students hold misconceptions. However, they do not seem aware of how they could be contributing to some of those misconceptions.

Preface:

Two years ago I felt I needed an extra challenge. This full-time, fully web-based Master's in Education for Sustainable Development was exactly what I was looking for. With what's happening around us in the world today, I do not need to explain how crucial such education is in these times. I am impressed I completed it within the two-year frame and am determined to use the knowledge gained to find opportunities to make a difference in schools, among teachers and students.

It is obvious that I could not have achieved this alone. So, besides my students (I was their 1st and 2nd grade teacher) and colleagues, who have been extremely encouraging, many thanks go to the teachers who gave their valuable time for letting me conduct the interviews. I would also like to thank my course mates, teachers and supervisors. You have made my work the kind of stimulating and collaborative experience it should be.

Needless to say, I am ever grateful to my family and friends who encouraged me throughout these two years of full-time work and study – especially my husband and daughter who never doubted my capabilities.

Table of contents

Abstract.....2

Preface.....3

Table of contents.....4

Abbreviations.....6

1. Introduction.....7

1.1 Background - The importance of understanding photosynthesis.....7

1.2 Research Focus.....8

1.3 Overall research aim and individual research questions.....8

1.4 The Swedish curriculum.....8

1.5 Outline of research methods.....10

1.6 Contribution of this study.....10

1.7 Outline structure.....11

2. Literature Review.....13

2.1 Introduction.....13

2.2 Defining Environmental Education, Sustainable Development and Education for Sustainable Development.....13

2.2.1 Environmental Education.....13

2.2.2 Sustainable Development.....14

2.2.3 Education for Sustainable Development.....15

2.3 Learning for sustainability through the teaching of photosynthesis.....16

2.3.1 Misconceptions about photosynthesis.....16

2.3.2 Linking scientific concepts to ESD.....18

2.4 Summary and emerging issues.....20

3. Theoretical Framework.....22

3.1 Constructivism –Introduction.....22

3.2 Development of Constructivist learning theory.....22

3.3 Active learning and the value of experience.....23

3.4 Constructivism in Science education.....24

3.4.1 Integrating the cognitive and the affective in Science education.....25

4. Research Methods.....26

4.1 Introduction.....26

4.2 Research strategy.....26

4.3 Data collection: site and sample selection.....27

4.4 Data collection techniques.....28

4.4.1 Pilot interview.....28

4.4.2 The interviews.....28

4.5 Data analysis.....29

4.6 Study limitations and potential problems – Reliability and Validity.....30

4.7 About the researcher.....30

4.8 Ethical considerations.....31

5. Results – Interview study findings......32
5.1 Description and Analysis of Results......32
5.1.1 The importance of teaching photosynthesis......32
5.1.2 The sustainability connection in teaching......33
5.1.3 Teachers' perception of students' knowledge......35
5.1.4 Students' sustainability practices......35
5.1.5 What teachers need to make the sustainability connection......36
5.3 Summary of Results......37
6. Discussion......39
6.1 How is photosynthesis taught at different grade levels and to what extent is it related to sustainability issues like climate change?......39
6.2 How do teachers perceive students' understanding about photosynthesis and its relation to global warming issues ?......40
6.3 What do teachers feel they need to help them connect the teaching of photosynthesis to climate change?......42
7. Conclusion and Recommendations......44
7.1 Conclusion......44
7.2 Future research......44
8. References......46
9. Appendices......49
Appendix 1: Participant information sheet and Consent form......49
Appendix 2: Interview guidelines (Teachers)......51
Appendix 3: Extract of Science curriculum – English translation (Lgr11)......53

Abbreviations:

DESD 2005-2014	UN Decade of Education for Sustainable Development
EE	Environmental Education
ESD	Education for Sustainable Development
ESD for 2030	ESD for the period 2020-2030
GAP for ESD	Global Action Programme on Education for Sustainable Development
IBSE	Inquiry-based Science Education
Lgr 11	Curriculum for the compulsory school, preschool class and school-age educare, 2011 (revised 2018)
SC	Sustainability Consciousness
SD	Sustainable Development
SDGs	Sustainable Development Goals
SDG 4	Sustainable Development Goals: Quality Education
TA	Thematic Analysis
Target 4.7	Sustainable development and global citizenship
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
WCED	World Commission on Environment and Development

1. Introduction

1.1 Background - The importance of understanding photosynthesis

This research analyses how the teaching of photosynthesis (an important ecological process) is, and can be, connected to environmental sustainability issues in the compulsory school (grades 1-9) in Sweden. This is important because most living beings depend on the process of photosynthesis, directly or indirectly, for the following reasons:

1. It creates oxygen - which supports cellular respiration and is vital for the creation of the ozone layer
2. It provides energy for nearly all ecosystems
3. It provides the carbon needed for organic molecule

Hence, knowledge about photosynthesis will allow us to understand how the world functions as an ecosystem. Although it is included in national curricula around the world and is repeatedly taught at different age levels, it is often taken for granted that teaching of photosynthesis will be clearly linked to sustainability and develops positive environmental attitudes.

How well students understand matter cycling into and out of the atmosphere as a result of plant processes is a prerequisite for making informed decisions about key societal issues such as global climate change. However, evidence shows that teaching students the law of conservation of matter can be a challenge because the experiments done during science lessons to demonstrate conservation of matter do not exhibit the key role of plants in matter cycling (Thompson & Lotter, 2014). Helldén (2004) mentioned how he observed students "had difficulties describing how certain aspects of ecological phenomena take place" (p. 60). Hungerford and Volk (1990) proved that if we want behaviour to change through instruction, then schools must allow students to develop ownership and empowerment of knowledge to become responsible and active citizens.

Interestingly, Kollmuss and Agyeman (2002) cited research in their work, which demonstrated that environmental knowledge does not necessarily lead to pro-environmental behaviour. Jensen (2002) believed this could be due to a number of factors, questioning both, how knowledge is defined and the teaching process itself. Quinn et al. (2015) agreed that educators need to prepare students for "lifelong informed and ethical decision-making" (p. 91) by providing Science education supported by ESD principles and practices.

1.2 Research Focus

I have chosen this area of focus due to a personal interest. I am a lower primary school teacher (grades 1-3) and work in a school with students from the preschool class to grade 9. I have always been conscientious about teaching content, following the curriculum and testing for understanding. However, during the course of the Master's in Education for Sustainable Development program through the University of Gothenburg, I was surprised to learn of the misconceptions / alternative conceptions students hold about scientific processes. This has led me to question how Science is taught in schools and the role of the teacher in affecting ”sustainability competence” (Wals, 2012, p. 641). My personal interest therefore lies in a strong will to contribute to changes in how we teach basic ecological processes (especially photosynthesis). Research shows that adopting an emancipatory perspective whereby interaction, dialogue, reflection and experience are incorporated in the learning process, can strengthen students' capacities and confidence and help them understand how their actions impact the earth (Wals, 2012).

1.3 Overall research aim and individual research questions

The overall aim of this research is to:

Explore if, and in what ways, teaching photosynthesis at different grade levels is linked to sustainability issues.

The research questions are:

1. How is photosynthesis taught at different grade levels and to what extent is it explicitly related to sustainability issues like climate change?
2. How do teachers perceive students' understanding about photosynthesis and its relation to global warming issues?
3. What do teachers feel they need to link the science curriculum to sustainability issues effectively?

Constructivism frames this study as it emphasises integration of knowledge through ”an experiential, process” (Littledyke, 2008, p. 6) and an enquiry-based curriculum with interdisciplinary links to foster students' engagement with environmental education.

1.4 The Swedish Curriculum

As my research involves looking at Science education in Sweden, I present here what is defined by the Swedish curriculum for the compulsory school, pre-school class and school age educare 2011 (The Lgr 11). The Lgr 11 (Skolverket, 2011) begins with the fundamental values and tasks of the school, which is based on democratic foundations aiming at pupils acquiring and developing knowledge and values. It states explicitly that, “each and everyone working in the school should also encourage respect in the intrinsic value of each person and the environment we all share” (p. 5), allowing students to exercise direct influence and form opinions about global environmental issues. Teaching should therefore provide students with the knowledge of how our lifestyles can be adapted to create sustainable development.

The Lgr11, lists the goals of the school and the guidelines for teachers and of all who work in the school. As part of the overall goals of the school, each pupil should show “respect and care for both the immediate environment as well as the environment from a broader perspective” (p. 10). Amongst the sixteen goals listed under knowledge acquisition upon completion of compulsory schooling, these two explicitly mention the care of the environment, (Skolverket, 2011, p. 12):

1. The student has obtained knowledge about the prerequisites for a good environment and sustainable development.
2. The student has obtained knowledge about and an understanding of the importance of the individual's own lifestyle and its impact on health, the environment and society.

The Lgr 11 lists the core content of each subject, is divided into the following grade levels: 1-3, 4-6, 7-9 and includes knowledge requirements to be achieved at the end of year 6 and year 9. The curriculum for Science concentrates on the relationship between *health, nature and the society*. Since sustainable development is not included as a separate subject in the Swedish school system, but included within each subject in the curricula, all teachers are expected to include sustainability issues in their teaching, as is evident in the curriculum (see Appendix 3).

The Lgr 11 (Skolverket, 2011) connects the knowledge of “nature and people” (p. 166), “energy and matter” (p. 177) and “the structure and indestructibility of matter” (p. 188) to the contribution of sustainable development. The aim for teaching Science in grades 1-3 centres around biological and ecological sustainability. Students are taught basic processes, without the introduction of the human. However, when sustainable development is introduced in the 4-6 curriculum, one sees the emergence of the human in it too, with the impression that nature and her resources are at our disposal - for example “Nature as a resource for recreation and experiences” (p. 168). The Comments to the Biology Curriculum (Skolverket, 2017) explains although the curriculum claims that the human is part of nature, it does use “human and nature” (p. 6) in its description when there is a need to highlight the human in relationship to nature (author's translation from Swedish). Photosynthesis is directly mentioned for the first time in the curriculum at this grade level, grades 4-6. The Science curriculum in grades 7-9 mentions Photosynthesis again. It then goes on to cover sustainability issues very comprehensively, introducing recycling, energy use, the greenhouse effect and climate change.

These points will guide me in formulating my interview questions to the teachers and will be referred to later in my paper when analyzing the data collected.

Appendix 3 contains an extract of the aims for biology, chemistry and physics that focus on contents which highlight teaching of plant science, photosynthesis and sustainability / environmental issues with a direct link to climate change.

1.5 Outline of research methods

The empirical data was collected through an interview study from an inner city public school (grades preschool - 9) in Stockholm, Sweden. The means of collecting the empirical data was based on semi-structured interviews, involving teachers who teach Science at the lower primary, middle primary and secondary grade levels. A literature review was used to help position this study in relation to previous scientific knowledge in the field. The Literature review examines elements of action-oriented transformative pedagogy, specifically learner-centered approach as recommended by UNESCO (2017) and Dewey's (1963) "experiential continuum" (p. 28). The combination of a literature review and semi-structured interviews will allow theory and practice to be compared.

1.6 Contribution of this study

My interest in this research is piqued by Boeve-de-Pauw et al. (2015) who conducted their study because there is very little empirical evidence for the effects ESD has on student outcomes (such as their knowledge, attitudes and behaviour towards sustainable development). I, therefore, believe that this research will benefit the academic research community by contributing to the field of ESD in the area of Science education. The result of this work can be used to enrich existing research, particularly in relation to teaching methods when dealing with ecological processes in Science education and relating them to students' conception of knowledge about climate change. Today, climate change is by far "the biggest environmental crisis facing humanity" (UNESCO, 2016, p. 32). This paper could also point out how the care of the environment can be used as a factor for motivation in learning.

Although the output from this research cannot be generalized, the literature review findings and the empirical interview study, however, can be used to inform teachers in primary and secondary schools on efficient methods of teaching ecological processes, like photosynthesis, to bring about sustainability understanding in their students. This research does not aim to generalize how photosynthesis is taught in the different grade levels in schools, but, instead seeks an understanding of the elements which contribute to students' understanding of sustainability through the teaching of basic ecological processes.

1.7 Outline Structure

Chapter 1: Introduction

This chapter provides the reader with background information on the relationship between Science education and sustainability in the compulsory school environment, including an illustration of how the Curriculum for the compulsory school, preschool class and school-age educare (Lgr11) connects sustainability into the Science curriculum and defines the aim, core content and knowledge requirement of each grade level. The focus of this research is discussed and justified and the *overall research aim* and *individual objectives* are identified. Research methods and timescales are outlined together with the value of this research.

Chapter 2: Literature Review

This chapter defines the terms Environmental Education (EE), Sustainable development (SD) and Education for Sustainable Development (ESD) and connects them in helping to promote sustainability. It also looks at the importance of teaching basic ecological processes, with an emphasis on photosynthesis, while identifying best practice approaches for transformative learning. It presents literature that deals with students' misconceptions about ecological processes and the reasons for it.

Chapter 3: Theoretical Framework

This chapter presents *constructivism* as the main theoretical framework that is used for analyzing the study. Constructivism is defined and a brief history of its development is provided. It also takes a look at Active learning and the role of constructivism in Science education.

Chapter 4: Research Methods

This chapter discusses and justifies the research strategy (an interview study) and data collection techniques (semi-structured interviews), which are adopted in the empirical collection of data for this study. Details on the site and sample are provided, together with a framework for analysis of the qualitative data. In addition, the limitations of the adopted approach to this research are discussed, in terms of validity and reliability, as well as potential problems related to implementing an interview study in one school.

Chapter 5: Results - Interview Study Findings

This chapter reports on the findings from the interview study. The results of the interviews with the teachers are presented and discussed under the following themes: *The importance of teaching photosynthesis; The sustainability connection in teaching; Teacher's perception of students'* *knowledge; Students' sustainability practices* and *What teachers need to make the sustainability connection.* A summary of the findings is presented.

Chapter 6: Discussion

This chapter revisits the overall aim and research questions of this study. The empirical findings are summarized against each of the stated research questions, based on relevance to the theoretical framework, the literature review and the curriculum, the Lgr11.

Chapter 7: Conclusion and Recommendations

This chapter presents the results in a concise manner. It gives a brief explanation of how this study has contributed to previous research. Recommendations for future research are provided.

Chapter 8: References

This chapter contains an alphabetical listing of the resources referred to in this work. The APA system of referencing is used.

2. Literature Review

2.1 Introduction

With this literature review, I hope to provide a meaningful discussion and analysis of how the teaching of ecological processes can facilitate the understanding of climate change in a structured way. In this paper, EE and ESD will be used interchangeably when talking about Climate change.

2.2 Defining Environmental Educational, Sustainable Development and Education for Sustainable Development

2.2.1 Environmental Education

Historically, Environmental Education (EE) focused on pollution, population growth, depletion of natural resources and environmental degradation, representing national and global issues like air and water pollution in the 1960s.

Sandell et al. (2005) named three traditions to EE which have developed in schools and are still present in schools, in Sweden, today – Fact-based EE in the 1960s and 1970s; Normative EE in the 1980s and ESD in the 1990s, in conjunction with the Rio conference in 1992. When comparing the goals of these traditions, one sees the connection to the educational philosophy existing during the corresponding periods. Fact-based EE is influenced by "essentialism" (p. 158) where the content of education is based on the sciences and the teacher is the expert, transferring knowledge and facts to the students. Normative EE is influenced by "progressivism" (p. 158) where the student is central and teaching s organized around the needs and interests of the students, emphasizing cooperation, problem-solving skills and first hand experience of the natural world and society. ESD is influenced by "reconstructivism" (p. 159) where the school is seen as the place in which the development of democratic ideals take place, teaching content is stressed and students are taught to be critical.

Although EE stresses on the importance of people's experiences with nature and focuses on active learning processes, Wals (2012) pointed out its two distinct strands. One maintains that if people get to experience nature, they will learn to appreciate, value and protect it, and in the process, develop values and ethics necessary for environmental behaviour. The other strand proposes that EE needs to focus on environmental problem solving and not be afraid to criticize existing value systems and economic models and be willing to address these issues in formal, informal and non-formal settings. This model is criticized by some as it can be used to influence people's values, moral positions and behaviour in a predetermined and expert-driven direction.

To move away from the narrow definition of EE from the past, Bellino and Adams (2017) emphasized the importance of recognizing the lived experiences of youths from socially and ecologically complex urban environments, instead of only considering the political and personal agendas of the dominant communities. Therefore, to address global problems, there was a need to create a link between environmental and social equity. This process has led to a shift from EE to ESD.

2.2.2 Sustainable Development

Sustainable development (SD) concerns how we can sustain the natural environment and our planet's resources while developing wealth and well being for a growing population, combining environmental concerns with social and economic development. The study on students' sustainability consciousness (SC) by Boeve-de-Pauw et al. (2015) identified the following critical ingredients that must exist if change is to happen: a better understanding of sustainable development, more positive attitudes towards sustainable development and behaviors in line with sustainable development. To avoid the risk of indoctrination, the study recommended empowering students with "sustainability competences through a holistic, interdisciplinary perspective of content and pluralistic learner-centered democratic teaching strategies" (Boeve-de-Pauw et al., 2015, p. 15694). It showed that when teachers implemented such strategies, students did, in fact, gain a better understanding of the complexity of sustainable development, exhibiting more frequent sustainability behaviours.

In presenting the different perspectives of sustainability, Taylor et al. (2015) referred to weaker and stronger sustainability. Weaker sustainability reflects an anthropocentric perspective, where nature is to be utilized for human benefit, sustaining development rather than the environment. Stronger sustainability adopts a more ecocentric outlook, valuing nature for its own sake by reducing our demands on nature.

Interest in sustainable development and of the need to identify solutions to environmental and social issues faced by the world, have risen globally over the last 50 years. The Brundtland Report, released in 1987 by the World Commission on Environment and Development (WCED, 1987), stated that development is only sustainable if "it meets the need of the present without compromising the ability of future generations to meet their own needs" (p. 5). Its release by the United Nations had a very powerful influence on the world's environmental and social agenda. It called for an immediate start in an educational campaign, which will bring about changes in attitudes that are crucial for the security, well-being and very survival of the planet.

Seghezzo (2009), however, questioned the UN definition of SD and accused it of being weak or anthropocentric by pitching human needs against environmental constraints. This, he believed, limited its use as a comprehensive conceptual framework because the WCED report places an economic value to the preservation of species and ecosystems, making human welfare the ultimate reason for the protection of natural capital.

2.2.3 Education for Sustainable Development

Since the Brundtland report linked sustainability to education, other authors and organizations have followed suit (Taylor et al., 2015). Education for Sustainable Development (ESD) came about as a result of international policy agreements and ”new forms of governance that emphasize citizen involvement in visioning and decision making” (Wals, 2012, p. 631). Examples include Agenda 21, produced at the 1992 Earth Summit in Rio de Janeiro and the 2002 World Summit on Sustainable Development in Johannesburg. This led to the creation of the United Nations' Decade of Education for Sustainable Development (DESD 2005-2014), of which UNESCO was the lead agency.

Wals and Benavot (2017) showed that education has been mobilized to respond to ecological and environmental challenges since the late 20th century, beginning with Nature Conservation Education (NCE), to Environmental Education (EE) in the 1960s, to Sustainability Education (SE) in the 1990s to the present Education for Sustainable Development (ESD). According to Wals (2012) when ESD is viewed broadly, it links the environmental to the socio-cultural, the local to the global, the past to the present and future, and the human to the non-human world, while narrow interpretations emphasize the environmental and ecological dimensions. He also believed that EE and ESD are almost synonymous, whether we look at them from a content-based perspective, the types of learning processes used or the type of aims pursued. While evidence suggests that education-based responses to environmental challenges have been influential, criticisms do exist. One such criticism is that because such education supports economic and technological development and distribution, it prepares people for a lifetime of unsustainable work and consumption, encouraging individualism and materialism. This is turn could lead to individuals “rationalizing and popularizing environmental destruction” (Wals & Benavot, 2017, p. 407). Franck and Osbeck (2017) cautioned us of the conflicting interests of such education.

UNESCO provides information about the nature, characteristics, subjects that should be included and the potential outcomes of ESD. When the GAP for ESD (2014-2019) came to an end, we are presented with ESD for 2030 (covering the period 2020-2030). The implementation of ESD beyond 2019 is in the proposed framework Education for Sustainable Development, towards achieving the SDGs (ESD for 2030). It aims to look at the individual transformation process of each learner through the acquisition of knowledge and to focus on helping the SDG 4, targeting 4.7 in particular, to emphasize “the contribution of learning content to the survival and prosperity of humanity” (UNESCO, 2019, Annex1-p. 2).

A key feature of the 2030 Agenda for Sustainable Development is its universality and indivisibility, addressing all countries to take urgent action. This path requires a profound transformation of how we think and act, challenging individuals into sustainability change-makers and placing education in the role of a catalyst to meet the challenges and aspirations of the 21st century. It is believed that education will provide the knowledge, skills, values and attitudes that are required, hence safeguarding the individual and the future of our planet. The aim is that ESD 2030 will enable all individuals to contribute to achieving the SDGs by equipping them with the knowledge and competencies they need to bring about the necessary transformation (UNESCO, 2017).

2.3 Learning for sustainability through the teaching of photosynthesis

2.3.1 Misconceptions about photosynthesis

Several studies (Chabalengula et al., 2012; Dimec & Strgar, 2017; Thompson, 2014) have shown how students hold misconceptions about plant energy transformation and photosynthesis. Maeng and Gonczi (2019) pointed out how even teachers (through their teaching methods and use of language) and misrepresentations of such processes in school textbooks can contribute to these misconceptions. Their examples included teachers uttering “Plants do photosynthesis and animals do cellular respiration” or describing the energy production process in plants and animals as “making energy” (p. 28). To help high school students understand the relationship between photosynthesis and cellular respiration in plants, they implemented a conceptual change approach to get students to “unlearn to relearn” (p. 29). A conceptual change approach is characterized by four key instructional features:

1. revealing students preconceptions
2. discussing and evaluating preconceptions
3. creating conceptual conflict with preconceptions
4. guiding conceptual restructuring (Maeng & Gonczi, 2019, p. 29)

This method was found to be highly effective in developing students' accurate conception of the process of cellular respiration in plants and animals – that both plants and animals do cellular respiration all of the time. Most of the students admitted that their previous misconception was learned in a prior science class because “When talking about plants, we talk about photosynthesis and when talking about animals, we talk about cellular respiration” (p. 33). Therefore it is important to teach plant processes in conjunction for students to develop an understanding of their inter-related nature (Thompson & Lotter, 2014).

In their study on the existence of fragmented knowledge amongst students, Thorn et al. (2016) identified the term “alternative conception” (p. 2) to define how a learner explains how scientific knowledge makes sense to him/her based on his/her experiences. This situation arises because students try to construct a coherent and logical view of the world from the limited knowledge they possess. This makes alternative conception resistant to change and therefore “difficult to overcome by traditional methods” (p. 9), the result being, students “keep both” (p. 10) instead of replacing alternative conceptions with scientifically correct ones. Chabalengula, et al. (2012) suggested this could be because students “rote-learned” (p. 257) concepts, have seen them in textbooks or the language differences between Science and every day use make it difficult for students to consistently apply what they have learned.

Another result from the above-mentioned study by Thorn et al. (2016) showed that because prominent alternative concepts about photosynthesis existed as far back as the 1980s, alternative conceptions of the 1980s can still be taught to the next generation. That is, if teachers are teaching according to their own conceptual understanding, which can differ from a scientifically correct one, students' alternative conceptions could be echoing a teacher's understanding. Hence, there is a need to support students in reorganizing their accumulated knowledge through student-tailored interventions to promote a conceptual change, by providing hands-on experiences or confronting students directly with their alternative conceptions. Even student teachers openly expressed a lack of confidence in making wise decisions or taking appropriate action concerning sustainability issues, and have requested that teaching about sustainability be included in teacher education programs (Stir, 2006).

Hartley et al. (2011) established that students with misconceptions about the carbon cycle lacked a robust understanding of atoms and molecules. This resulted in informal reasoning and the use of informal language, hence preventing the students from tracing matter and energy across scales. In contrast, students using principle-based reasoning were able to trace matter and energy across scales. However, the use of scientific words does not necessarily mean students have a scientific conceptual understanding of the terms or that sophisticated reasoning showed understanding as they could have ideas that contradict scientific explanations. Leach et al. (1996) disclosed many pupils had trouble understanding that the body matter of all organisms is made up of chemically transformed food and that plant body mass comes from “an invisible atmospheric gas and water” (p. 31).

Interestingly, Chabalengula et al. (2012) discovered that first year university biology students failed to apply the energy conservation principal (energy cannot be created or destroyed) to biological systems because they lacked the conceptual understanding of the difference between photosynthesis and respiration. These students wrongly thought that “energy for metabolism and life processes is made available during digestion in animals and during photosynthesis in plants” (p. 242).

2.3.2 Linking scientific concepts to ESD

To tackle substantive environmental issues, it is important to develop practical knowledge and provide hands on experience, taking children outdoors and providing them with opportunities to create personal and emotional connections to nature (Wals & Benavot, 2017). On drawing students' attention to plants, Nyberg and Sanders (2013) agreed there should be a shift in focus to include both the affective and the cognitive domains when dealing with plant-based learning, as personally encountering living organisms can evoke emotions and help develop an interest in organisms. Possibly because teachers rarely receive training about plants, there is a decline in both the use of living plants in classroom teaching and learning in the natural environment, leading to "disengaged students, poor instruction, inherent disinterest in plants, general plant blindness, and infrequent precollege exposure to plants or botany" (Uno, 2009. p. 1754). Therefore it is suggested that when restructuring or reorganizing teacher education programs, features of ESD should be incorporated. The key outcomes of the syllabus should include features such as effective communication and decision-making processes and ethical considerations of the impact of Science on people and the environment, while the definition of learning should involve active partnership, social justice principles, diversity and investigative and learner-centered strategies (Stir, 2006).

Among the number of ways to respond to environmental challenges, the most promising is the "whole school" approach, as recommended by Wals and Benavot (2017, p. 410). Here, schools reconsider and redesign:

1. curricula (Are emerging subjects and concepts covered and new competencies being taught?)
2. operations and environmental management (Does the school conserve water and energy, provide healthy food, minimize waste and provide green and healthy school grounds?)
3. pedagogy and learning (Are teaching, learning and participation in decision-making adequate and appropriate?)
4. community relationships (Does the school connect with community issues and resources?)

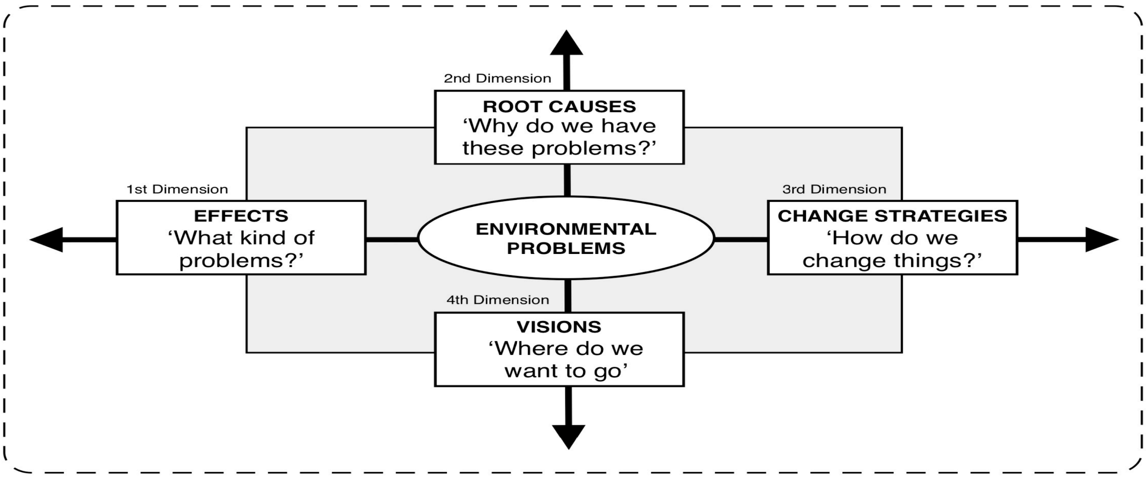
The instrumental and the emancipatory methods are seen as being complementary, often existing concurrently while serving different purposes and yet reinforcing each other's significance. Instrumental education contributes to changes in environmental behaviour through the development of knowledge, awareness, skills and technical solutions. It promotes learning that is instruction-oriented, social marketing based and expert and policy driven by its ability to reach a large and varied target group. The emancipatory approach aims at long term changes relating to public support, engagement and involvement which transforms learning and develops competence and creativity in citizens to co-design a more sustainable world (Wals & Benavot, 2017; Wals et al., 2008).

Bellino and Adams (2017) noted that since EE formally gained inclusion into schools, it has aimed at solving environmental problems by focusing on individual behaviour and choice instead of collective or group solutions. This focus on small changes at the individual level reduces large and complex environmental problems to simple, individual solutions.

However, to connect how acquiring knowledge about key ecological processes like photosynthesis can help students understand climate change and its consequences, we need to look at how knowledge is defined. Jensen (2002) proposed an action-oriented form of knowledge, consisting of the following dimensions, through which a given environmental problem can be viewed and analyzed. Figure 1 shows that by incorporating *root causes* and *change strategies* into discussions concerning environmental problems, we can provide students with the insights into possible solutions (p. 331), increasing students' competence in taking action and bringing about behavioral change in relation to the environment.

Figure 1

Landscape for action-oriented knowledge within the four dimensions of environment-related knowledge



Note: Adapted from: Jensen (2002)

A study by von Uum et al. (2016) displayed the effects of inquiry-based science education (IBSE). IBSE allows pupils to develop their conceptual understanding of scientific phenomena and their inquiry skills. It focuses on pupils' own interests and stimulates active learning, making it an effective approach for learning scientific concepts and understanding the nature of Science. IBSE consists of four domains – the conceptual, the epistemic, the social and the procedural domains. During each process the teacher plays the role of facilitating, supporting and supervising their pupils. Strategies used by teachers include questioning, scaffolding, providing explanations, connecting concepts, making real-world connections, linking prior knowledge, facilitating pupils' collaboration and reflection through feedback. These strategies help foster pupils' understanding of scientific inquiry, making them aware of their current knowledge and allow them to collaborate and communicate with peers and teachers.

2.4 Summary and emerging issues

The literature review traces the development of EE and ESD from the late 20th century and provides different and conflicting views on them. Although EE focuses on the problems of environmental degradation and on national and global issues, some believe that it is not doing enough as it neglects the needs, cultures and values of diverse communities. ESD hence evolved out of this need to create a link between the environmental and the societal. The Brundtland Report defines sustainable development as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, p. 5). This brought about a start to an educational campaign that requires people to change their attitudes for the "security, well-being and survival of the planet" (WCED, 1987, p. 14).

Despite the presence of research to indicate that when teachers integrate holistic, inter-disciplinary and learner-centered democratic teaching strategies into their teaching, their students become better equipped to perform sustainable behaviors, one can also find research which supports that it is not evident ESD can or will enhance pupils' willingness to act sustainably.

Studies exploring students' understanding of photosynthesis show the most commonly held misconception by students is that plants get their nutrients "from the soil" (Hartley et al., 2011, p. 31). The reasons for misconceptions are plenty. Examples include teaching methods employed, language used during instruction, misrepresentation of such processes in textbooks and inadequate teaching. It also reveals that scientific and alternative conceptions can coexist in students as they are difficult to overcome by traditional methods.

To respond to environmental challenges, the literature recommends that teachers help students develop practical knowledge, provide hands-on experience and make connections to nature. Additionally, it highlights the whole school approach (where schools redesign their curricula, operations, pedagogy and community relationships); action-oriented knowledge development (where effects, causes, strategies for change and visions are incorporated into environmental-related studies) and the effect inquiry-based science education (IBSE) has on science education. There is also research that encourages the use of both, the instrumental and emancipatory methods, to compliment each other in learning situations.

To be able to engage students to connect photosynthesis and the carbon cycle to climate change, it is critically important for Science teachers to understand the best practices in Science education. I believe my study can provide useful information for teachers seeking to understand the role scientific knowledge plays in helping students to understand sustainability issues because it aims to investigate how photosynthesis is taught (in a municipality school in Stockholm) and to what extent it is related to climate change. This background I have acquired in reviewing the related literature shaped the context and design of my research methods.

3. Theoretical Framework

3.1 Constructivism - Introduction

Constructivism is a learning theory that argues learners actively construct knowledge and make meaning, based on their experiences, individually or socially, where "prior knowledge always influences the formation of new knowledge and learning is an active process" (Narayan et al., 2013, p. 169). This means learners are not blank slates, as they bring cultural knowledge and experiences to learning situations, thus influencing the new knowledge they will construct or modify. From this point of view "knowledge cannot be transferred intact from the head of a teacher to the heads of students" (p. 170), which means teachers in a constructivist learning experience take on the roles of "coordinators, facilitators, resource advisors, tutors or coaches" (p. 170).

The learner's background and culture is essential to constructivism because it shapes the learner's local and global views of themselves and the world, suggesting the uniqueness of the strengths and needs of each learner.

3.2 Development of constructivist learning theory

Piaget (1896-1980) was a cognitive constructivist who believed discovery is the basis of intellectual growth or learning and involved assimilation, accommodation and equilibration (Narayan et al., 2013). Assimilation occurs when a child encounters something new and in order to understand it, he incorporates it into his pre-existing knowledge. Accommodation occurs when the child modifies his existing interpretation to accommodate the new information. So, by interacting with the world around them, children add new knowledge, build upon existing knowledge, adapt previously held ideas to accommodate new information in the process and achieve a state of equilibrium (Illeris, 2018).

John Dewey (1859-1952) was a constructivist theorist who believed education depended on action and emphasized the importance of experience in education (Narayan et al., 2013). However, he pointed out that experience and knowledge cannot be directly equated to each other (Dewey, 1963). He was against rote learning and suggested students engaged in "real-world practical workshops, through which they could collaboratively and creatively demonstrate their knowledge" (Narayan et al., 2013, p. 171). Dewey (1963) coined the term *experiential continuum* - the principle of the continuity of experience. He pointed how the importance to discriminate between experiences that are "worth while educationally and those that are not" (p. 33) because not all experiences are genuinely or equally educative. Experiences which are "mis-educative" (p. 25) arrests or distorts the growth of further experience. The role of the educator, therefore, is to expose students to experiences, which will lead to future desirable experiences.

Lev Vygotsky (1896-1934) emphasized knowledge production and learning "through collaboration and socialization, bringing about social constructivism" (Hershberg, 2014, p. 187). The *Zone of Proximal Development* - which is the area of qualitatively new learning towards which the teacher should lead the learning child - and the concept of *scaffolding* - whereby a more knowledgeable other provides support to promote a child's cognitive development - developed out of this social aspect of learning (Illeris, 2018). In this perspective, each learner is distinctive from one another and brings with them their own strengths, background knowledge and needs (Narayan et al., 2013).

Jerome Bruner (1915-2016) had views similar to Piaget, where learning is an active process and learners construct new concepts based on existing knowledge. He, however, placed more emphasis on the social influence impacting development and his theory includes the following primary features: (a) predisposition towards learning (b) structure of knowledge (c) effective sequencing / scaffolding process and (d) use of consequences (Narayan et al., 2013). In this way Bruner felt "any subject could be taught to any child at any age" because one starts "where the learner *is*" and "*whenever* the student arrives" (Bruner, 1960, p. ix).

3.3 Active learning and the value of experience

Active learning is a key component of constructivism. As part of the learning objectives for Education for Sustainable Development Goals (UNESCO, 2017) recommended pedagogical approaches are learner-centered, action-oriented and transformative. Narayan et al. (2013) quoted numerous research which showed that students who were guided to construct their own knowledge could apply it to new settings as they exhibited superior generalization skills; students who worked in small groups developed superior critical thinking skills and had longer retention power than those working alone; students with learning differences performed at a higher level and are engaged in the activity, when supported by peers and, when learning is connected to real life experiences, the content becomes more accessible to all. By coaching, mediating, prompting and helping students develop and assess their understanding and learning, the teacher's role shifts from being the "keeper of knowledge" who transmits it into students, to being a "facilitator of the activities and classroom discussions" (Narayan et al., 2013, p. 173).

To be able to provide students with experiences that lead to growth, teachers should know how to utilize the surroundings to build experiences that are worth while, at the same time, considering the strengths and experiences of the students so learning does not become accidental. To remain in the spiral of the experiential continuum, teachers must see to it that the problems presented to the students (i) grow out of their present experiences and that it is within the range of their capacity and (ii) arouse in the students an active quest for information, bringing about new ideas (Dewey, 1963). The new facts and new ideas become the ground for further experiences in which new problems are presented.

3.4 Constructivism in Science education

To be able to understand sustainable issues and their possible solutions, especially in regards to the environment, one requires *scientific literacy*. Quinn et al. (2015) provided the definition of scientific literacy from the National Academy of Sciences as "the knowledge and understanding of scientific concepts and processes required for personal decision-making, participation in civic and cultural affairs, and economic productivity" (p. 91). Littledyke (2008) agreed that Science education has an important part to play in developing understanding of the scientific principles that underpin environmental issues believing students with science knowledge to be more environmentally active than those with poor knowledge.

A central challenge of EE then becomes how we are to encourage and develop in children a sense of relationship with the environment so they develop pro-environmental behaviour that follows through adulthood (Littledyke, 2008). One way is to explicitly integrate the cognitive and affective domains, which will develop a sense of relationship for environmental care and respect, leading to informed action. Dewey (1963) believed it is important for students to be introduced to scientific subject matter in their everyday lives as it will help them to understand not only Science better but also the economic and industrial problems of present society.

To move away from the negative stereotypical model of Science which has existed in the past, Littledyke (2008) recommended looking at Science from the constructive postmodern point of view. By integrating the effective and affective components of learning, it becomes more appropriate for environmental education. It contains features that could reverse whatever disillusionment and cynicism pupils hold towards science, which include:

> i) Interpreting and understanding the world
>
> ii) Creating meaningful personal frameworks
>
> iii) Critical analysis and application of ideas
>
> iv) Critical evaluation of the social and environmental implications of ideas
>
> iv) Fostering a sense of interest, enjoyment and excitement in learning
>
> vi) Incorporating a sense of beauty, respect, reverence and awe to the environment
>
> vii) Understanding our place in the universe. (Littledyke, 2008, p. 5)

3.4.1 Integrating the cognitive and affective in Science education

Looking at how constructivism can be used in Science education, Narayan et al. (2013) quoted another study which showed that when Science teachers allow students to conduct hands-on observations, experimentation and report on findings, they allow students to "make active meaning" by connecting to what they are reading in their textbooks; when incorporating group work in class activities, teachers provide students with opportunity to "verbalize and justify" their own ideas; when teachers allow for students to use prior knowledge, they are provided with opportunities to "clarify their understanding" (pp. 178-179).

Littledyke (2008, pp. 8-12) suggested how teachers could link the cognitive and the affective in science instruction through:

1. attitudes	by fostering positive attitudes to learning (curiosity, interest, confidence and creativity) and modelling positive attitudes
2. contexts	by incorporating students' personal experience, social interaction, care and empathy of living organisms and incorporating variety in learning and teaching strategies (discussions, experiments, peer collaborating and computer simulation)
3. curriculum integration	by developing scientific understanding of key concepts and linking them to environmental issues and how human activities affect the environment, and providing direct experience with nature to instil awe and appreciation of nature, resulting in informed action and an issues-based approach.

In presenting an overview of learning theories, Illeris (2018) reminded us that when learning comprises of the two simultaneous processes of interaction and acquisition, together with the cognitive, emotional and social dimensions, it leads to active learning, encouraging problem solving to accommodate new information in the process. We need to ask how can an educational experience contribute to an individual's learning, where learning is a personalized, active, multi-dimensional process that is influenced by prior experience, contextual settings and social situations (Littledyke, 2008). So, as educators, the questions "*what is taught, how it is taught, why it is taught"* and "*what you educate for"* are important questions to consider (Dahl Madsen, 2013, p. 3773).

4. Research Methods

4.1 Introduction

The focus of the empirical work in this research study was to gather data through interviewing teachers on how they teach photosynthesis. The interviews also sought their views on what they thought they needed to make the connection between photosynthesis and sustainability. The opportunity to gain teachers' views ought to contribute, not only to the study of how basic ecological processes are taught in general, but also to a richer understanding if teachers are making the sustainability connection in particular. With this study I hope to highlight the issues teachers have connecting science education to sustainability.

4.2 Research strategy

The research questions were answered by semi-structured interviews, which provided a form of qualitative data. This method was chosen because it enabled an exploration of the aim of this study to understand how teaching processes and methods used in teaching core ecological processes, such as photosynthesis, can help students to make connections to environmental sustainability. I wanted to hear it from the teachers themselves - the methods they use, what they think the students understand and if they have noticed any changes in students' thinking or behaviour towards sustainability issues. As Bryman (2016) mentioned “in qualitative interviewing, there is greater interest in the interviewee's point of view” (p. 466) unlike in quantitative research, the interview reflects the researcher's concerns. I prepared a semi-structured interview guide with a list of questions that addressed how photosynthesis is taught, the connection between photosynthesis and climate change, teachers' skills and training and teachers' observation of changes in students (See Appendix 2). The semi-structured nature of the interviews provided the interviewees with leeway in how to reply. It also gave me (the interviewer) the freedom to ask further questions as I picked up on their replies. All the questions in the interview guide were asked and, as much as possible, a similar wording was used from interviewee to interviewee (Bryman, 2016).

A main point I had to keep in mind was to steer away from using leading questions (Bryman, 2016). Another possible issue when using a qualitative approach is to consider how researchers can influence the cultural process under investigation if they cannot or do not separate their influence on their environment (Reunamo & Pipere, 2010). I have also chosen this method due to the time constrain of the project, because it is flexible and also because I believe that a qualitative method will allow me to extract the data required for answering the research questions.

4.3 Data collection: site and sample selection

The interview site was an inner-city municipal school in central Stockholm, Sweden, serving about 700 students from the pre-school class to grade 9. All schools in Sweden, whether run by the municipality or by a private organization, need to follow the Swedish curriculum (Lgr11) – apart from international schools, which have their own curriculum.

The principal of the selected school was contacted via email and a face-to-face meeting was planned to explain the purpose of the study and to request permission for teachers to participate in the study. After securing the principal's permission, I was invited to present my study to the teachers at a staff meeting to recruit volunteers for the interviews. Five teachers, who teach the 3rd, 5th, 6th, 7th and 9th grade classes, volunteered. The 7th and 9th grade teachers are Science subject teachers. The other participants are classroom teachers, teaching Science together with all the other core subjects. In Sweden, classroom teachers in the lower and middle primary grades follow their class for three years before being given a new group. This means they teach the same group of students from grades 1-3 or grades 4-6. This is due to how the teacher education program is laid out in Sweden. One either chooses to become a lower primary teacher (preschool class-grade 3), a middle primary teacher (grades 4-6) or subject teachers for grades 7-9. The sample consisted of 3 female and 2 male teachers, with teaching experiences ranging from 5 years to more than 20 years. All were contacted by email to schedule the interviews. It is worth mentioning here that this study is not intended to be a study of how all the Science teachers in the school help students to construct an understanding of sustainability. Such a study would be too time-consuming for the amount of time available for this thesis work. Table 1 provides information regarding the interviewees. Pseudonyms are used for confidentiality.

Table 1

The Interviewees

Pseudonyms	Year grade	Years teaching
Anna	3rd	26
Tom	5th	4
Paul	6th	6
Kay	7th	8
Malin	8th and 9th	10

4.4 Data collection techniques

4.4.1 Pilot interview

Initial pilot interviews, consisting of 5 interview questions, were conducted with two teachers to test for relevance and relation to the research questions. They were carried out to test how well the interview flowed and to give me some experience in the process. However, before embarking on the pilot interviews, I went through the Swedish curriculum (Lgr11) and the commentary materials to the curriculum in biology, chemistry and physics for all the 3 school levels (1-3; 4-6: 7-9) as they are the steering documents for teachers to follow and will provide focus to my questions. Two teacher friends agreed to help me pilot my interview.

The first pilot interview took almost 60 minutes while the second one took almost 80 minutes because the second interviewee had experiences from 3 grades when answering the questions and that took more time. These interviews took longer than expected, possibly due to my lack of experience as an interviewer. This point was ratified in the actual interviews where I was aware of the time and managed to scale them down to between 30 – 40 minutes. After the 2 pilot interviews, I was convinced that my interview questions would provide sufficient data to answer my interview questions. As a result of the pilot interviews, I did, however, change the order of asking some of the questions.

4.4.2 The interviews

Although the questions were prepared beforehand to establish a framework, participant responses also generated new questions, which as a qualitative researcher, I was open to. Before the start of the semi-structured interviews, participants were informed of the purpose of the study, how the results will be disseminated and to whom. The assurance of confidentiality and their rights as participants were presented. The participants were then given a consent form to sign and were informed that they could withdraw their consent at any time during the research process. The contact information of the researcher is provided on the consent form (Appendix 1). With their permission, all interviews were audio recorded. This was done for two reasons: to ensure that the analysis of data would be based on an accurate record and to allow the interviewer to concentrate on the interviews - to be able to follow up on interesting points made, to prompt and probe where necessary and to draw attention to any inconsistencies in the interviewee's answers. The face-to-face interviews lasted between 30 – 40 minutes. The interviews were conducted in different classrooms after lessons and at a time that was convenient to the interviewees. These were predominantly in the afternoons after 15.00. In order to protect the privacy of the participants, no identifying information was requested. Interviews were later transcribed by the researcher. Appendix 2 contains the collection of semi-structured interview questions that were used.

4.5 Data analysis

Thematic Analysis (TA) is a method for identifying, analyzing and interpreting patterns of meaning (themes) within qualitative data and was used in this study. The aim of TA is to identify and interpret key factors of the data, guided by the research question. Since it is flexible and can be used to analyze virtually any data type, it is an attractive tool to use in qualitative research (Clarke & Braun, 2017, pp. 297-298).

In this study, the empirical data was analyzed using the six phases as recommended by Braun and Clarke (2006), with a reminder that analysis is not a linear process but more a recursive process and should not be rushed. The six phases mentioned above are:

1. Familiarizing yourself with the data
2. Generating initial codes
3. Searching for theme
4. Reviewing themes
5. Defining and naming themes
6. Producing the report (Braun & Clarke, 2006, p. 87)

The initial process of transcription of the interviews (data), although time consuming, provided me with the opportunity to familiarize myself with the data. Five categories were identified when going through the process the first time. These categories/themes were used when reading through each transcription, sentence by sentence. Each sentence that seemed to fit into any of the categories was colour-coded. Each category was supported by a definition and an example from the transcript. After several “back and forth movements through the phases” (Braun & Clarke, 2006, p. 86), and in consultation with my supervisors, the following four themes were identified in the data:

1. Teaching photosynthesis
2. The sustainability connection in teaching
3. Students' sustainability thinking and practices.
4. What teachers need

This process, besides being very valuable, also helped consider the validity of my individual themes and if they accurately reflected the meanings evident in the data as a whole, keeping in mind the aim and research questions of my study.

4.6 Study limitations and potential problems – Reliability and Validity

Like all research studies, this one has its strengths and limitations. Firstly, due to the short timeframe, the sample size is modest, based primarily on data from just five individuals. However, despite that, I was able to identify recurrent themes, both in relation to how teachers connect sustainability to Science education and what they claim they need to make better connection between the two. Also due to the small sample size, this research may not reflect the general views and experiences of Science teachers. Therefore, this study does not claim to be random or representative.

Despite the limitations of sample size and representativeness, I believe this study has given me some insights into what happens in the classroom and helps answer the overall aim of my study, which is to: *Explore if, and in what ways, teaching photosynthesis at different grade levels is linked to sustainability issues.* However, I am well aware that another result might have appeared if additional and / or alternative methods were applied, such as spending some time in the classrooms to observe the teachers and interview the students.

4.7 About the researcher

This discussion of methods would not be complete without addressing my own background, biases and interests in the area of both Science education and ESD / EE. I am a classroom teacher in the lower grade, teaching Science, together with the other core subjects. I share the same struggles of coping with the realities of teaching – time frame, crammed curriculum, large classroom sizes, children with varying abilities and interests, etc. Also, over the years, I have noticed how children usually bring their misconceptions to the classrooms and my own experiences have led me to wonder if other teachers are experiencing similar concerns and do they consider it crucial to make sustainability connections in their teaching.

This report is not meant to critique Science teachers. It is inspired by the concerns and challenges I have faced when trying to relate photosynthesis and the carbon cycle to sustainability issues like climate change, in my Science lessons. Although it is built on limited data, it is hoped that other teachers would read this report and reflect on the urgency / necessity of relating Science education to sustainability and help students make the connection, at all grade levels.

4.8 Ethical considerations

The recommended Code of Ethics by the Swedish Research Council for researchers to follow (Vetenskapsrådet, 2002) state that the researcher must inform the participants of the true purpose of the research, their role in the project, the conditions for their participation – its voluntary nature and their right to change their mind without suffering any consequences – and that the data collected will only be used for the purpose mentioned. The researcher must also provide full confidentiality for the participants, making sure no identifying markers are exposed.

When conveying the purpose of my research study to the participants, I emphasized the importance of transparency, allowing for opportunity to ask questions on any aspect of the study. To make sure that I obtained an informed and voluntary consent from the participants, I included the following in the consent form (Appendix 1):

1. Identification of the researcher with contact information, if questions arise
2. Identification of the associated university
3. Explanation of the purpose of the research
3. Guarantee of confidentiality to the participants
4. Assurance that the participants can withdraw at any time

During analysis and interpretation of the data, I made sure that the anonymity of the participants was protected by using pseudonyms and by not exposing too much information when describing the school. When writing the final research report, I kept in mind the importance of presenting an accurate, honest and realistic account of the findings, without misinterpretation and without misleading the reader; observing anonymity and confidentiality and also disclosing limitations of the research (Swedish Research Council, 2020).

5. Results – Interview study findings

5.1 Description and Analysis of Results

This chapter presents the findings found in the views of five teachers from an inner city school in Stockholm, within the compulsory school system and is structured on the following themes:

1. Teaching photosynthesis
2. The sustainability connection in teaching
3. Students' sustainability thinking and practices
4. What teachers need to make the sustainability connection

5.1.1 The importance of teaching photosynthesis

The interviewees were asked to specify what they believe is important for students to understand from the lesson(s) on photosynthesis. They were encouraged to describe what they regard as the key purpose of photosynthesis, how they teach the lessons and the experiments they employ. All the teachers mentioned the importance of knowing the formula - the elements that must be present for photosynthesis to take place and the resulting products. The students must know how to draw/illustrate that process. Only Paul directly mentioned that teaching should cover the flow of energy and the production of sugar.

> I guess the flow of energy, how it is stored/produced and without this we wouldn't have a source of sugar, which is one of the purest form of energy we can have to sustain us as animals. (Paul, grade 6)

Malin and Kay indirectly made the same claim by connecting photosynthesis to the source of the food chain.

> Photosynthesis is the source of all food, the food chain starts with plants. (Kay, grade 7)

> Photosynthesis is important for life to continue on Earth. (Malin, grade 9)

Both Anna and Tom see the relationship between plants and humans to be most important - the connection and interdependence.

> How they work for the existence and the processing of how they make oxygen. The trees growing to provide us with our oxygen so we can survive and our food. (Anna, grade 3)

> But if you can't connect it to how it affects us human beings, then I don't think you have taken away the key part of the unit or the lesson. (Tom, grade 5)

This shows that while Paul, Kay and Malin identified glucose as a vital product of photosynthesis, Anna and Tom felt that the purpose of photosynthesis is to produce oxygen.

When describing the experiments they administer with their students, unlike the other teachers, Paul described a strict regiment of dividing the class into three groups with specific guidelines on how to set up their experiments and with the purpose of witnessing the production of sugar.

> We planted open air where you have to water, closed eco-system that you don't have to water and we had a closed eco system in a black bag that received no sunlight so that they could see the difference in the production of sugar. After about 6 weeks, we had pods on our beans from the open aired one and the closed eco system but the one in the black bag turned out all white. It's still building starch but it can't store sugar in the same way so it hasn't built any pods for peas for reproduction. I thought it was a fun little thing to show them because it doesn't get the sun energy, it's like an albino plant. (Paul, grade 6)

The other teachers claimed doing similar experiments, however, they did not mention in the interview that they had discussions with their pupils about the production and storage of sugar. The purpose of them doing the experiments was to reconfirm the importance of the elements which have to be present for photosynthesis to occur.

> We plant seeds and observe and record growth and we also usually observe how plants absorb water through the stalks. (Anna, grade 3)

Kay (grade 7) mentioned she would usually show an online film after such experiments, proving there is no change in the amount of soil but that "plants create its food from thin air, through photosynthesis."

When responding to my question about teaching methods, they all mentioned that, besides using the allocated textbook (at varying degrees), they supplemented their information resource with online resources. They also pre-tested current knowledge and always incorporated discussions and presentations in their teaching.

> Of course we watch videos and have class discussions. We are not just reading out of the textbook. (Tom, grade 5)

5.1.2 The sustainability connection in teaching

For this theme, I collected evidence on if and how the participating teachers make the connection to sustainability when teaching the unit on photosynthesis. In the lower and middle grades (grades 3, 5 and 6 in this study), the unit on *plants and photosynthesis* is taught together with the units on *food chain and food-web, habitats, eco systems and animal life*, providing ample opportunity to make the connection to sustainability. Tom, the grade 5 teacher, explained that connections were indeed possible when he said:

I'd be surprised if anyone can have a Science lesson about plants and not talk about global warming. (Tom, grade 5)

However, neither Anna nor Tom brought up how they connected photosynthesis to the carbon cycle or made explicit connections to the role plants (trees) play. They did mention global warming and how it is fervently discussed.

They might have difficulty understanding the actual process of photosynthesis but I think they understand the connection better and how the plants provide our basic needs. (Anna, grade 3)

Both Kay (7th grade) and Malin (9th grade) mentioned that photosynthesis is taught only in the 7th grade for 4 weeks and is taught in an ecology unit. Kay explained that she explicitly makes the connection to her students because she does not see them making the connection themselves.

I have been planting this idea in their minds that to handle climate change is not just about reducing carbon emissions but we need to plant more trees - this perspective is not coming from the kids. (Kay, grade 7)

The primary grade teachers managed to make the connection because of the cross-curricular learning that happens in their classrooms. They also expose students to documentaries and news online to keep up with the issue of climate change. Global warming and climate change are also visible everywhere in society.

It's on billboards, it's on TV, on radio. It's on nearly everything you look at in the store. Climate smart options. I can't think of a day when you don't see someone or something bringing up climate change. (Tom, grade 5)

The thing is, global warming has been such a huge topic lately and we have talked a lot about deforestation already, even before we started this project. We have watched the BBC news reporting how the palm oil industries are destroying forests and about how, if we don't have trees, we can't bind carbon. (Paul, grade 6)

All the teachers interviewed mentioned the influence of Greta Thunberg[1] on children's awareness on climate change with her strong presence last autumn in the fight against climate change. By talking to their students about the *School Strike for Climate* and screening her speeches in class, teachers have utilized a strong tool in making the sustainability connection in their classes.

I think Greta Thunberg has brought an awareness to the kids that they can relate more to because she is young. I think what she's doing is really creating a much larger awareness than we can possibly do. (Anna, grade 3)

1 A Swedish youth environmental activist who initiated the *Fridays for Future* movement.

> ... and we actually watched Greta Thunberg where she talked to the scientists about the trees, how these are the most amazing things that can actually solve this problem on their own because that's all they do, is to bind carbon. (Paul, grade 6)

> Especially with Greta. They can connect with her, she's about the same age as them. She has helped them to think that it's everybody's responsibility to do something about the climate change. (Malin, grade 9)

In the secondary classes, on the other hand, climate change is covered in all three grades (7th, 8th and 9th)– in physics, chemistry, biology and technology – but connections are not necessarily made to photosynthesis. So while photosynthesis is only explicitly taught once throughout the 3-year period as stipulated by the curriculum, climate change, is a concept revisited and taught in Science throughout these three years.

> Climate change is not taught as a unit but is mentioned everywhere. We talk about sustainability and how it can affect the climate. We will even deal with it in genetics when we work with biology in grade 9. We will talk about how it impacts the environment. (Malin, grade 9)

5.1.3 Teachers' perception of students' knowledge

When asked how they think their students would explain how a tree gains its mass in its process of growth from a seed, all five teachers believed that, because photosynthesis is a difficult concept for their students to understand, their students would provide explanations filled with misconceptions.

> I think the actual process of how it works they have trouble understanding. But the idea of the connection between global warming and the plants providing us, as I said, our basic needs, they get that. (Anna, grade 3)

> I think there would be a lot of misconceptions. The most common would be that plants eat soil. Also the teachers' guide to our textbook has a huge section on clearing up misconceptions. (Tom, grade 5)

> Half of my class will say it's the air because we talk a lot about the carbon from the carbon dioxide. A quarter will say it's a combination of air, water and sun and a handful I think would not have grasped it yet. Even though we keep churning throughout that carbon dioxide is carbon which is bound, which is sugar, and two oxide which is oxygen, which gets left over. (Paul, grade 6)

> I can picture one student who can say the mass of trees come from air but most won't. Students don't get it because it is very abstract. They can explain solid-to-liquid and liquid-to-gas transitions but to explain air to matter is difficult for them. (Kay, grade 7)

> They will talk about the soil and the nutrients they get from the soil. (Malin, grade 9)

5.1.4 Students' sustainability practices

Although most of the teachers could give concrete examples of their students' sustainability practices, which they witness, in school, not all of them believed that the students have become more consciously sustainable. Paul believed that the two students in his 6th grade class who chose to be vegetarians, did so because of the influence of their parents and not consciously to make less of an impact:

> I don't think I see it in my students in that sense. They are still very driven by what their parents want. (Paul, grade 6)

Although Kay believes there is an increase in awareness among her 7th graders, she echoes his sentiments:

> Awareness (about sustainability) has improved. Students can make posters and they can speak but they buy new iPhones, etc when they appear. Students haven't come up with practical projects by themselves but schools provide the solutions to improve awareness. (Kay, grade 7)

Malin's examples from her students all revolved around their assignments. She could not provide concrete examples of sustainable practices amongst the nine graders and was certain that unless she gave them the lead and informed them she was looking for a connection, they would not mention it. She elaborated how in an essay on Global warming, the students could talk about recycling, alternative energy sources, bio fuels and using alternative mode of transport (train vs. plane), on a personal level but she also realized it could be due to how she had framed the question:

> Probably also because that is one thing I have asked in the essay - how this can be helped at the governmental level, at the community level, at the family level and at the personal level. They had to discuss about it and they had to put themselves in there. (Malin, grade 9)

When it comes to the lower grades (in this case grade 3 and grade 5), the teachers could give numerous examples of how they believed their students had definitely become more sustainably conscious.

> A good example is when we do Art. They save every little piece of paper and put it in the recycle bin. They automatically think – this does not go in the wastebasket, it goes in the recycling. Same with using water. (Anna, grade 3)

> They have initiated a no-trash snack amongst themselves and they challenge each other to not waste food in the lunchroom. They care about sustainability. They jump on their friends when they see wastage. (Tom, grade 5)

5.1.5 What teachers need to make the sustainability connection

In this theme is included teachers' responses related to, if and what, they feel is missing or lacking in their day to day teaching of Science in general and photosynthesis, in particular, and why do they need certain things to improve.

Paul believed that photosynthesis is "fairly well covered" since it is a subject that comes up "again and again" and could not see what could be cut out from his curriculum that is of lesser importance. Amongst the others, more time, up to date knowledge and more hands-on resources were at the top of their lists. The upper grades teachers also felt that the curriculum is too packed.

> Time is a big issue where our curriculum is 11/2 hours in 1st grade for Science and 2 hours in 2nd and 3rd grades per week. That is not adequate enough to give an in-depth

> understanding of Science. It does not seem to be prioritized. We can definitely use more hours in the subject. (Anna, grade 3)
>
> ... updated textbooks, materials, the nuts and bolts of learning. (Tom, grade 5)
>
> It would be good with teaching resources, which are up to date and easily available. (Kay, grade 7)
>
> I would like my students to have something hands-on. That's the only thing that is missing. But the curriculum is a lot, actually – it's impossible to cover everything. Things which have been covered before can be done superficially. (Malin, grade 9)

5.2 Summary of Results

When looking at what teachers find important for students to understand about photosynthesis, the data shows that the teachers who teach the upper grades (6, 7 and 9) refer to the chemical reaction that takes place and names the production of sugar and the flow of energy. They also relate it to the transfer of energy by mentioning its role in the food chain and the continuation of life on Earth.

Anna (grade 3) and Tom (grade 5) refer to the relationship that exists, between humans and plants – suggesting an anthropocentric viewpoint. This appears again when they claim that they do make the connection to sustainability when teaching photosynthesis. For example, Tom thinks that if students cannot see the "connection to our life, ... to us as human beings" then they "have not taken away the key part of the lesson."

Another observation from the data is that the teachers of the lower grades (Anna and Tom) believe their students have become more aware of sustainability issues over the years. They see signs of self-initiated practices like recycling, saving water and not wasting food in the lunchroom. The teachers working with the older students (Paul, Kay and Malin), however, have made different observations about their students. They have not seen any signs of practical sustainable efforts. In fact, these teachers claim they have seen the opposite, that most of their students are "self-centered" (Paul, 6th grade teacher) and "haven't come up with practical projects by themselves" (Kay, grade 7 teacher).

There could be various reasons for this. One could be because as classroom teachers, they see their students throughout the school day, teaching other subjects to the same group of students, enabling cross-curricular teaching. This automatically sets up a different kind of relationship. On top of that these teachers are also responsible for the same group of students in the lunchroom (daily) and even at playtime (a few times a week). Compared to them, the subject teachers only meet their secondary students two and a half hours a week for Science, eat lunch with them only if they are scheduled to on certain days of the week and as mentors they are only assigned to half the class, as each class has two mentors responsible for it.

Secondly, the classroom also plays an important role in this equation. With the younger grades, the classroom is their homeroom, where they have fixed seating spots, drawers to keep their books and stationery, a reading corner, plants in the windows, their work on display and classroom rules and duties – with the sole purpose of promoting a sense of belonging and responsibility for the child. Compared to them, the students from the secondary grades do not have a homeroom, they move from classroom to classroom throughout the day, depending on the subjects.

A third observation that came out of this research is the 6th grade dilemma. The 6th grade class seems to be caught between the primary school and the secondary school. The teacher has them for most part of the day, teaching not only Science but most of the other subjects too. He eats lunch with them everyday and they do have a classroom to call their own. Yet, his observations of his students have more similarity to the secondary students.

6. Discussion

What follows is a discussion of the results from this study as they relate to my individual research questions.

6.1 How is photosynthesis taught at different grade levels and to what extent is it related to sustainability issues like climate change?

The results from the teacher interviews showed that the methods used by the teachers are in line with some of the key pedagogical approaches recommended by UNESCO's Education for Sustainable Development Goals – Learning Objectives (2017). The most prominent being a learner-centered approach where “the learners' prior knowledge as well as their experiences in the social context is the starting points for stimulating learning process in which the learners construct their own knowledge base” (p. 55). This was, at times, carried out through brainstorming as a class to find out what is known / remembered at the beginning of the lesson, encouraging the scaffolding of knowledge. Since students bring with them their own strengths, background knowledge and needs, this is important as they have everyday meanings to science concepts, which may conflict with their understanding (Chabalengula et al., 2011, p. 259). From a constructivist point of view, here learning is shaped by both the students’ prior learning experiences and by the social interaction.

Group work, discussions and project work “incorporating what they know and collaboration with peers” (Malin, 9th grade teacher) were used by the teachers when assessing the students to test for understanding. Here we see how project-based instructions are incorporated “to engage students in rich conversations as they negotiate and codesign” their learning (Narayan, et al., 2013, p. 177). The Lgr11 mentions these skills as knowledge requirements for Science from grade 6 onwards, where “students must develop their reasoning skills and be able to take the discussion forward” (Skolverket, 2011, p. 173). Especially in 9th grade, the students are asked to place themselves in the sustainability discussion in all their essays and projects to help them understand how vital it is. In the Comments to the Biology Curriculum (2017, p. 4) it is stated that the definition of sustainable development from the Brundtland report is used as a guide throughout the curriculum. Although the Science curriculum for grades 7-9, mentions Climate change explicitly. the primary Science curriculum here in Sweden, like the ones in Australia and New Zealand (Quinn et al., 2015) does not mention Climate change. I find this noteworthy “given the magnitude of the issue, its widespread coverage in media that children are likely to encounter, and the science that is needed to understand and articulate its causes and effects” (p. 92).

There was also mention of field trips to nearby parks and experiments in class, which involved observing the growth of plants. However, these experiments were limited with a predetermined set of results that the students were supposed to observe - an example of a mis-educative experience. O'Connell (2008) called such experiments students are supposed to perform “cookbook” where they follow “explicit step-by-step instructions that verify important scientific content” (p. 350) but fail to inspire curiosity. It is unfortunate such experiences were not better planned because, it is proven that for youths to be environmentally engaged, it is important for them to be exposed to nature and social and environmental issues from a young age (Fisher, 2016). What teachers should do is use an inquiry-based approach where lessons begin with a mystery, naturally stimulating students to ask questions and search for explanatory concepts (O'Connell, 2008).

All teachers mentioned it was important for the students to know the photosynthesis formula and be able to draw/illustrate it. This is required from 3rd grade onwards. However, Chabalengula, et al. (2011) alerted teachers that just because students could provide definitions to scientific concepts does not mean they fully understand the concepts. Teachers should not assume that if students “are able to provide some answers” that they understand (p. 230).

The teachers in the primary section felt they do make the sustainability connection mainly because of how photosynthesis is taught in collaboration with other units like the food chain, the food web, habitats and the different ecosystems. They claimed the predominance of climate change issues in the media and the influence of Greta Thurnberg have also helped make the connections. They did not, however, mention the use of the carbon cycle in their teaching to connect the different units taught, indicating that although these units follow after one another in the implementation stage, they are still taught in isolation. Photosynthesis in the secondary section is covered in 7th grade, after which, as the curriculum clearly shows, biology, physics and chemistry are heavily loaded with issues concerning sustainable development, lacking evidence of connection between the two. As Hartley et al. (2011) pointed out, being able to trace matter and energy into and out of the atmosphere as a result of photosynthesis and respiration is necessary before one can understand the causes and consequences of global climate change.

6.2 How do teachers perceive students' understanding about photosynthesis and its relation to global warming issues ?

The teachers believed that their students have various misconceptions about photosynthesis, as it is a difficult concept for them to understand. The most difficult concept to grasp according to the results from the data is that plant mass comes from the air. Even the secondary school students have difficulty making the connection “because it is very abstract” (Kay, 7th grade teacher). “They will talk about the soil and the nutrients they get from the soil” (Malin, 9th grade teacher). This is reflected in the research conducted by Leach et al. (1996) where “plants obtain their food from soil” (p. 22) was one of the two most common misconceptions reported to be held by children concerning plant nutrition.

One teacher (Paul, 6h grade teacher), however, believed most of his class would be able to say “it's the air” since they have talked a lot about it. This I found interesting because if teachers believed photosynthesis is a difficult concept for students to understand, they might not make an effort to try to incorporate methods and experiments to help repel or reduce the misconceptions amongst their students. In fact, the results from the data showed a few teachers were probably ignorant of their contribution to the students' misconceptions – this could include the language they used and their teaching methods. The third grade teacher, Anna, talked about how plants “make oxygen” possibly contributing to the other most commonly held misconception, that photosynthesis is “the plant's form of respiration in which carbon dioxide is taken in and oxygen passed out” (Leach et al., 1996, p. 22).

Since students will likely have everyday words like “mist” and “fog” to describe scientific processes, as shown in Thompson and Lotter (2014, p. 60), Chabalengula et al. (2012) recommended that teachers explain why certain words are unacceptable and discourage students from using them. Related scientific vocabulary and concepts like “precipitation, condensation, evaporation and the water cycle” (Thompson & Lotter, 2014, p. 60) should be encouraged instead.

The results also showed that the teachers believed their students might not fully understand the connection between photosynthesis and global warming. The 7th and 9th grade teachers mentioned their students do not make the sustainability connection in their work unless it is specifically asked for. The 3rd and 5th grade teachers feel their students have understood “if the trees are gone, we will lose our oxygen and our food sources” due to the extensive media coverage linking global warming to natural disasters. It was only Paul (6th grade teacher) who felt his students could make the connection because they had been talking a lot about how trees have a very important job – “to bind carbon.”

Interestingly, the teachers in the secondary section do not feel that their students have become more sustainable as they do not see evidence of changed behaviour, despite the teachers incorporating measures to promote sustainability. The primary school teachers however, felt differently. They noticed an increase in sustainable behaviour amongst their students, like recycling and not wasting food in the lunchroom. A reason for this could be tied to a combination of how the older students see Science and the teaching of Science. As Littledyke (2008) pointed out “attitudes become less positive as pupils progress through school” (p. 2). What teachers could incorporate are the features recommended by Littledyke (2008) to reverse the disillusionment held by students and link the cognitive and the affective in Science instruction (see pp. 24-25 in this paper for both recommendations).

6.3 What do teachers feel they need to help them connect the teaching of photosynthesis to climate change?

Several variables that affected the teacher's ability to connect the teaching of photosynthesis to climate change were highlighted through results collected from the teacher interviews. Time was one factor mentioned by all, but in varying degrees, involving various constellations. The 6th and 7th grade teachers did not think more time is needed as photosynthesis comes up in all three grade levels and can be taught across the curriculum, especially in Social studies as well. The 9th grade teacher felt the curriculum is too packed and time is such a factor that subjects which have been covered previously are usually only done "superficially" and this includes photosynthesis. At the other end of the spectrum, the 3rd grade teacher also talked about time and the packed curriculum. She was concerned about how there is not enough time to go through concepts that are new to the students and hence, there is hardly ever time to give an "in-depth understanding of Science."

Time is also described as the hours allocated to Science in the curriculum and in relation to the school yearly calendar. The teachers who felt time was an inhibiting factor brought up the number of hours allocated for Science in the curriculum each week in the school. This ranged from 1.5 hours in grade 1 to 3 hours in grade 9. Tom (5th grade teacher) also complained about how Spring, being the best time to teach about plants and plant processes in Sweden, is also the time of the school year where "there are always extra activities which steal your lesson time."

Time plays a major factor when incorporating constructivist learning. Research has shown that when constructivist methods are in place, the learning process can be "uneven" where the learners at times "reversed back to their misconceptions" proving that "learning is indeed a complex undertaking and takes time" (Narayan et al., 2013, p. 179).

The other variable mentioned is resources. This included mainly updated books and hands-on materials and those catering to increasing teachers' knowledge and keeping teachers updated. The teachers felt this would in turn help safe time as they do not have to spend time looking for reliable materials on-line or spending time looking for materials for experiments. There was a need for the school to provide basic updated resources both for use with the students and for the teachers to upgrade their knowledge so they could "help them better" (Anna, 3rd grade teacher). This sentiment is reflected in the study by Stir (2006) where a survey revealed that student teachers felt what they really needed were "*strategies and we need convincing that it really matters"* (p. 833). This study also revealed that these student teachers wished that sustainability issues were infused throughout their teacher training. The Global Education Monitoring Report (UNESCO, 2016) identified the critical role of teacher training in making education responsive to climate change and related sustainability challenges. These skills are important in a constructivist classroom, where teachers are to scaffold students' learning (Narayan et al., 2013).

What I found interesting was that, although due to the recent upsurge of media coverage of natural disasters around the world, none of the teachers seemed concerned about how they can make their students “aware of current problems without depressing them, or giving them a feeling of hopelessness” an issue that was brought up in the study by Stir (2006, p. 834). However, research which shows why students perform sustainable behaviour in their lives (Perrault & Clark, 2018) named the environment or Earth as a motivating factor and see it as their responsibility to protect it – “I feel it's the right thing to do” (p. 38). Information and knowledge were the reasons for motivating students to perform more sustainable behaviour. This shows that teachers can assign structures that encourage personal and social responsibility towards environmental and sustainability issues as goals to motivate and direct students (Pintrich, 2003).

7. Conclusion and Recommendations

7.1 Conclusion

In this thesis, five teachers from the lower primary to the secondary section in a compulsory school in Stockholm were interviewed individually. They shared their thoughts and reflections on how they teach photosynthesis to their students. The purpose of the interviews was to collect data to see if the teachers connect photosynthesis to sustainability issues in their teaching and the implication this has on their students. Face-to-face interviews were conducted, each lasting between 30 to 40 minutes. Their answers were transcribed and coded via Thematic Analysis to discern and organize the data into themes. This helped to locate similarities and differences in their arguments.

The findings suggest that the teachers do implement certain aspects of learner-centered approach in their teaching, encouraging scaffolding and the social aspect of learning by incorporating group work and discussions. However, when implementing experiments, the teachers did not provide opportunities for the students to "discover and construct knowledge" (Bruner, 1960, p. ix).

Results also showed that related topics in plant science were taught in isolation, without emphasizing the cycling of matter and the flow of energy. This could be why students have misconceptions concerning key understanding of photosynthesis. The teachers are not aware of the role they play in contributing to their students misconceptions, be it through their choice of words, the methods they use or the experiments they administer. Since the results pointed out that even the secondary school students had misconceptions that hindered them from understanding the sustainability connection, it shows how crucial it is to teach interconnected plant functions, matter cycling and conservation of matter already from the lower grades.

The findings of this thesis also confirm what is known from previous research about connecting scientific knowledge about photosynthesis to environmental education and the reasons why students develop misconceptions. The teachers who participated in this study find themselves in similar situations to other teachers. For example, time, in combination to a packed curriculum, proves to be some teachers' greatest worry in covering the curriculum, without having to sacrifice knowledge or content.

7.2 Future research

A future area of research may be to thoroughly explore how plant processes are taught in a school by concentrating on grades 3, 4, 5 and 6 - both, observing lessons and interviewing all teachers involved in teaching Science to those groups. This is because in the curriculum (Lgr11), the teaching of photosynthesis is highly concentrated in the middle school years (grades 4-6) and it is taught for the last time in 7th grade. So, it is crucial that these processes are taught well in the middle school and that students do not have misconceptions when they come into secondary school, being well prepared to handle sustainability issues. Also, there are hints among the raw data in this study, which indicate what I was looking for could be influenced by teachers' years of experience, their qualifications, personal interests and access to continual education. I feel having a larger data base will bring out how these qualities are an influence. Finally, it is crucial that the results of these studies should be shared with schools so teachers can change the way they teach, where necessary.

It would also be interesting to explore if a school that adopts a whole school approach to EE would show a more positive and homogeneous result.

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9. Appendices

Appendix 1 – Participant information sheet and Consent form

Research title: *Teaching photosynthesis: Implications on sustainability*

Research institute: *University of Gothenburg*

Research method: *Semi-structured interviews*

Purpose of this interview: *To collect data to understand how teachers teach about photosynthesis and its possible connection to sustainability issues.*

Researcher (including contact details): *Vasugi Ribbarp*

vasugi.ribbarp@gmail.com

Tel: 0730 512456

****For your participation, I would need your written approval, as proposed in the consent form on page 2.**

Participant Consent Form

Participant statement:

The purpose of this research work has been explained to me, including the use to which this research will be put and my part in this research project. I also understand that my details will remain confidential and that my anonymity will be respected. I can also choose to hop off from this research, if I so desire, at any point during the research.

Consent to participate in data collection for a Master's thesis.

Participation is voluntary and can be discontinued at any time during the process. Please tick the appropriate statement below to confirm your participation.

_____ Yes, I agree to participate in the study.

_____ No, I do not agree to participate in the study.

Signed: ....

Name: ....

Date: ....

Opening instructions for interviewer:

Introduction of research

Consent form (explain/read)

Ask if interviewee has any questions

Consent form (signature)

Interview Questions:

1. Teaching photosynthesis:

(a) How do you teach about plants' photosynthesis in class? Please elaborate on the following:

- the length of the unit (how many lessons)

- when is it usually taught and is it taught together with other units?

- the materials you use (books, movies, etc)

- teaching methods (how you introduce the lesson, experiments, etc)

- assessment at the end of the unit? How do you assess?

(b) What do you think is important that the students understand from the unit?

2. Connecting photosynthesis to climate change:

(a) Show a picture of a seed and a tree. Say: Some scholars argue that understanding core processes like photosynthesis is important to understanding climate change. If I were to show a picture of a seed and a tree and ask your students to explain how a seed can grow into a huge tree, how do you think they will explain where all the mass came from?

(b) How do you think discussions such as the above could help students to understand the role of photosynthesis when it comes to global warming issues?

OR:

Would an understanding of the fact that plants use the carbon dioxide from the air to build up their mass help students to understand, for example, why it is good to plant trees in order to reduce global warming?

3. Skills and training:

(a) Do you feel you need support in any way in order to make better connection to sustainability issues in your teaching to deepen students' understanding of the issues at hand? Can you please elaborate?

4. Changes in students:

(a) Do you see signs of sustainability thinking or practice amongst your students? Can you give examples and what do you think has brought this about?

5. Final question:

Are there any other factors that we have not discussed which you think could be vital to this study concerning the teaching of photosynthesis and its relation to sustainability / climate change?

Closing instructions for the interviewer:

1. Do you have any questions or comments about the interview or research study for me?
2. Thank you (acknowledging the time and information shared by the participant)

Appendix 3: Extract of Science curriculum - English translation (Lgr11)

Aim (Grades 1-3)	Core content
The general ***aim*** *for teaching* ***Science*** *is to:* 1. question issues on natural resource use and ecological sustainability 2. use concepts and theories to explain biological relationships.	• Seasonal changes in nature and how to recognize the season. The life cycles of animals and plants and their adaptation to different seasons of the year. • Simple food chains describing the relationship between organisms and ecosystems. • Basic properties of water, its various forms and transitions between forms. • Basic properties of air and how they can be observed.

Aim (Grades 4-6)	Core content
The general ***aim*** *for teaching* ***Biology*** *is to:* 1. provide students with knowledge to question issues on natural resource use and ecological sustainability. 2. help students develop scientific concepts and theories to understand biological relationships.	• People's dependence and impact on nature and its effect on sustainable development. • Life of animals, plants and other organisms. Photosynthesis, combustion and ecological relationships in regard to activities like agriculture and fishery. • Ecosystem services like decomposition, pollination, purification of water and air. • Nature as a resource for recreation and experiences.
The general ***aim*** *for teaching* ***Chemistry*** *is to:* 1. provide students with knowledge about health, economical resource use, development of materials and environmental technology. 2. understand the factors that contribute to sustainable development.	• Matter – structure and properties; transition between solid, liquid and gas. • Properties of water and the water cycle. • Properties and composition of air. • Basic chemical reactions – e.g. Photosynthesis, combustion • Fossil and renewable fuels - in energy use and impact on climate.
The general ***aim*** *of teaching* ***Physics*** *is to:* 1. understand how energy and matter can contribute to sustainable development.	• Energy – properties, sources, impact on the environment. • The use of energy in society.

Aim (Grades 7-9)	Core content
*The general **aim** for teaching **Biology** is to:* 1. provide students with knowledge to question issues on natural resource use and ecological sustainability. 2. help students develop scientific concepts and theories to understand biological relationships.	• People's impact on nature locally and globally. Understanding sustainable development. • Energy flow of ecosystems and recycling of materials. Photosynthesis, combustion and other ecosystem services. • Understanding biological diversity and the factors favouring and threatening it. • Understanding local ecosystems from an ecological perspective – population vs. resources, local vs. regional vs. global. • Current societal issues involving biology.
*The general **aim** for teaching **Chemistry** is to:* 1. provide students with knowledge about health, economical resource use, development of materials and environmental technology. 2. understand the factors that contribute to sustainable development.	• The structure, recycling and indestructibility of matter. • Matter - properties, phases, phase transitions and distribution in air, water and the ground. • Water - as a solvent and carrier of substances; Solutions, deposits, acids, bases and pH values. • Chemical processes - in the ground, air and water from environmental and health perspectives. • The carbon atom - its function as the building blocks of all living organisms; the circulation of carbon atoms. • Photosynthesis and combustion, and energy conversion in these reactions. • Use of energy and natural resources and its implications on sustainable development. • Chemical processes in the manufacture and recycling of metals, paper and plastics. Life-cycle analysis of some common products.

*The general **aim** of teaching **Physics** is to:* 1. understand how energy and matter can contribute to sustainable development.	• Energy flows from the Sun, through nature and society; ways of storing energy; types of energy – their advantages and disadvantages. • Electricity production, distribution and use • Supply and use of energy – past, present and future • Weather phenomena and their causes. • Earth's radiation balance, the green- house effect and climate change. • Particle radiation and electromagnetic radiation – their impact and use. • Movement of particles and the distribution of matter in nature.