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# Understanding wider aspects of photosynthesis for citizenship and society

## A descriptive study incorporating perspectives on language and interest for science and nature

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**Sammanfattning**

Syftet med studien är att beskriva förståelsen av de bredare aspekterna av fotosyntes i förhållande till dennes innebörd för livet och miljön hos elever på grundskolans senare år. Dessutom syftar studien undersöka sambandet mellan elevförståelsen och språket som talas i hemmet samt elevens intresse för biologi, natur och miljön.

Studien omfattar en enkätundersökning bestående av tio frågor; Två frågor om språk och intresse, och åtta frågor som pröva förståelsen av fotosyntesens innebörd. Undersökningen genomfördes med ett urval av 171 elever (116 som pratar bara svenska hemma; 55 som pratar både svenska och ett annat språk hemma) på 4 kommunala skolor. Medelvärdet för de korrekta svaren hos svenska elever såväl som tvåspråkiga elever var 3,5. Medelvärdespoäng för de korrekta svaren för elever som var ointresserade i biologi, natur och miljön var 3,0, medan elever som var intresserade i biologi, natur och miljön uppnådde en signifikant högre medelvärdespoäng av 3,8. Resultaten visar att det inte finns något samband mellan elevförståelsen av de breddare aspekter av fotosyntes och språket som talas hemma, fast det finns ett samband mellan elevförståelsen och intresset för biologi, natur och miljön. Studien fann även att majoriteten av eleverna hade svårigheter att förstå sambandet mellan koldioxid och syntes av organisk materia liksom även omvandlingen av solenergi till kemisk energi samt bevarandet av kemisk energi inom näringskedjor.

Nyckelord: naturvetenskap, samhälle, fotosyntes, liv, växthuseffekt, språk, intresse

**Summary**

The aim of this study is to describe secondary school pupils understanding of the wider aspects of photosynthesis in relation to its implications for life and the environment as well as to investigate any correlations between pupils understanding and the language spoken in their home environment as well as their interest for science and nature. The study comprised of a survey questionnaire containing ten questions in total, two questions relating to the pupils language and interest and eight knowledge-based questions related to aspects of photosynthesis. The survey was completed by a sample of 171 pupils (116 speaking only Swedish; 55 speaking both Swedish and another language at home) from 4 secondary schools. The mean score for correct answers for both the Swedish pupils and the bilingual pupils was 3.5. The mean score for correct answers for pupils uninterested in science and nature was 3.0, whilst pupils interested in science and nature achieved a significantly higher mean score, 3.8. The results show that there is no correlation between pupils understanding of wider aspects of photosynthesis and language spoken in the home environment, although there is a correlation between pupils understanding and interest for science and nature. The study also found the majority of pupils have difficulty in grasping the relationship between carbon dioxide and the synthesis of organic matter as well as the transformation of solar energy into chemical energy present in food and the preservation and transfer of this energy within food chains.

Key words: Science Society Photosynthesis Life Greenhouse Effect Language Interest

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# 1. Introduction

Photosynthesis has been called the most important chemical reaction on earth (Arnon, 1982). A simplified reaction for the process can be written as $CO_2 + H_2O \rightarrow C_6H_{12}O + O_2$ and takes place in the presence of solar energy (Nationalencyklopedin, 2010). Photosynthetic reactions involve the transformation of solar energy to chemical energy in organic matter that is food for plants and animals, as well as providing atmospheric oxygen essential for aerobic cellular respiration. Furthermore photosynthesis plays a key role in the recycling of atmospheric carbon dioxide which may have a positive impact on the greenhouse effect and global warming (*ibid.*).

It can be argued therefore that an insight into the process and implications of photosynthesis is necessary if we are to understand important natural processes, not only in plant biology and botany, but also within ecology and the environment. Ecological and environmental concerns and issues have become important factors in politics as well as in society's democratic debate. The potential to acquire an appreciation of the importance and impact of photosynthesis should therefore be available to everyone (Sutherland *et al*, 2005).

A key role of compulsory education in Sweden is to foster pupils to become responsible members of tomorrow's society. Because of its importance photosynthesis appears twice in the compulsory school biology syllabus (National Agency for Education, 2000a). In addition to this, the photosynthetic process and implications of it can also be applied as an important concept within many other goals for biology, chemistry and physics within the science syllabus (National Agency for Education, 2000b).

Photosynthesis is conceived by pupils as abstract and many studies have confirmed that photosynthesis is a difficult concept for pupils to understand. This study builds upon existing studies on pupils understanding of photosynthesis with a focus on understanding the implications of photosynthesis in a wider perspective. This includes the synthesis of organic sugars from inorganic carbon dioxide, the source of all atmospheric oxygen that sustains most life on earth, the transformation of solar energy into to chemical energy within the chemical bonds of the molecules of sugar which constitutes the source of energy throughout ecosystem food-webs, as well as photosynthesis' role as a regulator of atmospheric carbon

dioxide as a factor within global warming and the greenhouse effect. The motivation to focus on these areas instead of areas such as factual knowledge regarding the photosynthetic reaction is that understanding of these concepts should equip all pupils, not only future scientists, with the knowledge required to make informed judgments on and to participate in debates on topics such as ecology and the environment as a democratic member of society. An inability to grasp and understand these concepts implies that school is not completely fulfilling its goal to prepare pupils for their future democratic role in society.

The second dimension to this study is a survey comparing levels of understanding between pupils with Swedish as their mother tongue and with Swedish as a second language. Previous academic studies as well as reports carried out on behalf of the National Agency for Education in Sweden have shown that pupils with Swedish as a second language attain lower grades in education compared with pupils that have Swedish as their mother tongue (Skolverket, 2005a & 2010). The same studies also show that fewer of these bilingual pupils are eligible to apply for high school studies than the national average. Language difficulties have been suggested as a key factor influencing school grades.

A third dimension of the study is to compare the pupils' understanding of the wider aspects of photosynthesis and the possible influence of learning in a second language with their interest for science and nature. Previous studies, including one conducted in 2006 by PISA (Skolverket, 2005), demonstrated a strong correlation positive between pupils interest for science and their results

## *1.1 Problem formulation*

An important goal for secondary education is to prepare pupils for their role as future citizens of a democratic society. Over the past few decades, ecology and the greenhouse effect in environmental studies have become prominent elements of the democratic debate at local, national and democratic level. A challenge facing schools is therefore to enable all pupils to develop an insight on interrelated and abstract scientific concepts and related topics that impact society. Photosynthesis and its implications for life and the environment is one of these concepts.

For 9th grade pupils, understanding the significance of photosynthesis requires redefining everyday misconceptions, understanding of the meaning of new and abstract terms and concepts, as well as interpreting and synthesising information at a higher cognitive level than remembering facts and describing processes. For pupils for whom Swedish is a second language an additional challenge is interpreting the semantics of the Swedish language in a way that supports learning. On the other hand an interest for the science and natures may promote and incentivise understanding.

## *1.2 The purpose of the study and question formulation*

The purpose of the study is to i) describe the level of understanding that pupils in the 9th grade of compulsory secondary education have of the wider aspects and implications of photosynthesis, ii) describe the relationship and differences of understanding of photosynthesis between pupils who speak Swedish as their mother tongue and pupils for whom Swedish is a second language, and iii) describe differences in understanding between pupils who are interested in science and nature with pupils who do not have an interest in science and nature.

In order to achieve the purposes of the study the following questions are posed:

- Are pupils able to apply knowledge on carbon dioxide's role in photosynthesis and the impact it can have the greenhouse effect?
- Are pupils able to apply knowledge on the transformation of solar energy to chemical energy to the source of energy on food for the majority of organisms?
- Do pupils apply knowledge on photosynthesis to the presence of atmospheric oxygen that is necessary for most forms of life?
- Are there differences in the level of understanding between pupils who are interested in science and nature and pupils who are not interested in science and nature?
- Are there differences in the level of understanding between pupils who are native Swedish speakers and pupils who have Swedish as a second language?

## *1.3 The relationship between the study and Swedish school curriculum and science syllabus*

Within the curriculum for the compulsory school system (The National Agency for Education, 1994, p.8) it is stated amongst goals to strive towards within norms and values section that school should strive to ensure that pupils *"show respect and care for the immediate environment as well as for the environment in a wider perspective"*. Furthermore, under section 2.2 *"Knowledge",* school is responsible for developing the knowledge pupils require as a member of society. More specifically, a goal for attainment is that pupils should *"know and understand basic concepts and contexts within the natural sciences as well as within technical, social and humanistic areas of knowledge,"* (*ibid.* p. 10)

The National Agency for Education (2000a) has divided the biology syllabus into four central dimensions; *Ecosystems, Biological Diversity, The Cell and Living Processes* and *Human Beings*, which characterise the structure and nature of biology education. The Agency reasons that an understanding of the aspects of these dimensions prepares pupils to deal with existential issues relating not only to science but also to the individual and the whole of society.

Photosynthesis is specified within the dimension of *"The cell and living processes"*:

*"Scientific explanations for most of the phenomena and functions, which pupils experience and observe within them and their surroundings, can be found in knowledge of cells. This knowledge, and particularly knowledge about a cell's internal processes, has opened up new opportunities in e.g. genetics. These opportunities create change in Man's living conditions, which involves important ethical aspects. An understanding of this change requires knowledge of* ***photosynthesis****, combustion and the genetic code."*

Moreover, the dimensions of "*Ecosystems"* and "*Biological diversity*" cover topics related to the wider aspects of photosynthesis which fall within the scope of the study:

*Ecosystems*
*"The subject of Biology introduces the concept of ecology and provides a view of the interaction between organisms and their surroundings. The subject covers, amongst other things, a knowledge of subsystems involving producers, consumers, recycling and raw materials, as well as a knowledge of dynamic processes in the ecosystem, such as the flow of energy through the system and the recycling of substances. Studies of individual organisms, populations and their societies provide the foundation for this."*

*Biological diversity*
*"The subject presents the way in which the biological sciences organise and systematise the diversity of nature. Fundamental starting points are theories about the ecosystem and*

*evolution, as well as knowledge of different species and a knowledge of the living conditions and relations between plants and animals."*

Furthermore, one of the biology syllabus' *"goals that pupils should have attained by the end of the ninth year in school"* stipulates that pupils should:

*– have an insight into **photosynthesis** and combustion, as well as the importance of water for life on earth.*

In addition, photosynthesis can be implicated within other *"goals to aim for"* and "goals to attain" *w*ithin the biology syllabus in relation to the study. Regarding *nature and Man*, school should strive to ensure that pupils:

*– develop their knowledge of the interaction between organisms and their environment.*

*– have a familiarity with some of the world's ecosystems and how interrelationships between organisms can be described in ecological terms.*

*– be able to give examples of recycling and accumulation in an ecosystem*

Regarding *use of knowledge,* pupils should:

*– be able to use not only scientific, but also aesthetic and ethical arguments in issues concerning the preservation of different types of nature and diversity of species, as well as the use of genetics.*

The above statements from the school curriculum and the biology syllabus support the inclusion of photosynthesis and its implications for the wider aspects of ecology and the environment in secondary school education.

# 2. Theoretical background

## *2.1 Understanding photosynthesis*

Studies on pupil's misconceptions of photosynthesis began in earnest in the 1980's. Haslam and Treagust (1987) developed a two-tier diagnostic multiple choice test to investigate misconceptions based on pupils identifying and then justifying correct statements on photosynthesis. This involved not only displaying factual knowledge of photosynthesis but also an understanding and reasoning of the processes involved. Results suggested that many

pupils possess knowledge on photosynthesis but are not able to synthesise and apply knowledge with justification on broader aspects of photosynthesis. Waheed and Lucas (1992) conducted a study in England investigating pupil's understanding of the ecological, physiological, and energy transformation aspects of photosynthesis and the relationship between them. Pupils displayed an understanding of all aspects apart from energy change when each area was tested individually. When tested on the interrelationship between the aspects understanding as very low, with only 1% displaying understanding of the interrelationship between all four areas, and only as many as 30 % understanding relationships between two or three groups, demonstrating that pupils have difficulty synthesizing individual areas of knowledge to develop a thorough understanding.

A similar, more recent study, carried out by Marmaroti and Galanopoulou (2006) confirmed that pupils display some understanding of many, but not all, individual phenomena related to photosynthesis but again have difficulty in synthesising and applying knowledge across interrelated areas.

In Sweden much work has been carried out by Björn Andersson on pupil's everyday misconceptions of science. Amongst the 1992 results from the Swedish National Assessment among 3103 Swedish pupils (Skolverket, 2005, Andersson, 2006 & 2008) only 5 % of the pupils displayed an understanding that air (more precisely carbon dioxide) is the source of the majority of plants and trees biomass. This increased to 8 % in 2003. Moreover, less than a quarter of the pupils were aware that carbon dioxide in air decreases and oxygen increases as a result of photosynthesis. Regarding pupil's knowledge of the greenhouse effect, 68 % of 15-16 year olds identified *"planting more trees"* as a strategy to control greenhouse gases (Andersson, 2008). Andersson (2006) and Britta Carlsson (2002) explain that much misunderstanding of photosynthetic processes is due to their remoteness from common everyday concepts and the fact that the topic involves a synthesis of not only biological but also chemical and physical knowledge involving reactions, matter, phase changes and energy. Furthermore, Andersson (2006) suggests that the teaching of photosynthesis consists in many cases of the simplified reaction formula for the process in the presence of sunlight, with little coverage of the wider implications or interrelated aspects.

Carlsson (2002) suggested that an insight of photosynthesis, along with the cycling of matter and the flow of energy is essential for understanding the function of ecosystems, especially from the perspective of preparing tomorrows citizens for a responsible and well-informed role in a democratic society. Carlsson argued that a factual understanding of the intricacies of photosynthetic reactions, as taught in schools, is wide of the mark, and proposes a phenomenological approach to teaching containing relational, experiential, content-oriented and a qualitative focuses to broaden educational horizons. A similar approach is advocated by Helena Näs (2010) emphasising that inclusion of photosynthesis in compulsory education is beneficial because:

*"almost no life can exist without photosynthesis"*

*"the carbon dioxide in the atmosphere that has a big effect on global warming can be reduced by increased photosynthesis…"*

*"an understanding of carbon recycling generates general knowledge about chemical, geological, physical, and biological course of events"*

The study reported a 50% increase in pupils understanding based on implementing an enquiry-based approach that offers a broader understanding of important concepts.

Carlsson and Näs' reasoning and justification for how photosynthesis can be taught have stimulated many own thoughts on teachers contributions to pupils' understanding of the area. Although the results of their studies are qualitative and based on teaching methods they cannot be directly compared to the results of this survey. They are included here because they acknowledge the importance of photosynthesis in a broader role in the education of the decision makers of the future.

## *2.2 Language*

Studies on the performance of pupils with a foreign background suggest that apart from socio-economic background, reading, writing and oral proficiency in Swedish are factors in the achievement of lower subject grades compared to their Swedish counterparts (Skolverket, 2005a). Results from OECDs Programme for International Student Assessment (PISA) published by the National Agency for Education (Skolverket, 2003) show that those

pupils with a foreign background who born in Sweden scored 484 points in reading comprehension compared to native Swedes 524 points. Pupils with a foreign background born outside Sweden scored 451 points. Furthermore, those pupils with a foreign background who speak Swedish at home, both born inside or outside Sweden, scored more points than those who speak another language at home. According to Holmegaard and Wikström (2004) there is a strong connection between reading comprehension and performance in science subjects. Similar results where reported for 8th grade pupils in the Trends in International Mathematics and Science Study (TIMMS) (Skolverket, 2008a). Four of the twenty-eight biology questions where directly connected to photosynthesis (Skolverket, 2008b)

The difference in school performance between pupils with Swedish or other background is confirmed by the 2010 National Education Results (Skolverket, 2010). The proportion of foreign background 9th grade pupils qualifying for high school education was 15.7 percentage points less than Swedish pupils. Of Swedish pupils 6.9 % did not achieve a pass grade in natural science and biology respectively compared to 21.2 % and 16.9 % of foreign background pupils.

### *2.3 Interest*

According to the TIMMS 2007 study (Skolverket, 2008), 52% of 8th grade pupils had a positive attitude towards biology. Results published in the 2006 PISA study (Skolverket, 2007) indicate that there is a strong positive correlation between interest and performance in science.

# 3. Method

Prior to choosing the method, previous research was studied in order to reflect upon and ensure prior understanding of the field of research on pupils understanding of natural science. According to Essaissaon *et al* (2009, pp. 289-290), a good prior understanding involves the identification of gaps in the coverage of earlier studies.

## *3.1 Method Selection*

The question this work attempts to answer is *are pupils prepared for their role as future citizens of a democratic society by describing the level of pupil's understanding of the wider aspects of photosynthesis, and to describe the relationship between levels of understanding and i) language spoken in the home environment and ii) interest for science and nature.* A descriptive study is suitable for this study and empirical data is central to answering the questions (*ibid.* p. 37). Therefore a quantitative perspective has been chosen to answer the questions posed. As the study is descriptive, a broad range of data on a general group within a population should be collected and then analysed statistically to study the results and the relationship within and between the surveyed population. A quantitative study is therefore suitable for this task. In order to save time and resources a respondent questionnaire survey with a standardised format of multiple choice style questions is used for data collection (ibid. pp. 259 & 262).

## *3.2 Sample selection and data collection*

The pupils participating in the study attend four secondary schools in a large town in central Sweden and were randomly chosen from a selection of schools in areas with multi-ethnic populations within the town. This was done to ensure that a substantial proportion of the respondents spoke languages other than Swedish in their home environment. It was estimated that a sample size of over 150 pupils would be sufficient to enough data to obtain a satisfactory conclusion to the posed problem. Originally, one round of data collection had been carried out at one school by 101 respondents. A second round of data collection was carried out at three other schools by 82 respondents providing a sample size of 183. Of the 183 questionnaires received 12 were discounted due to incompletion, leaving 171 for analysis. Emails were sent to the principals and vice-principals of the selected schools introducing myself, presenting information on the survey and requesting permission to carry out the study at their schools. Names of natural science teachers sent in return and these were contacted with information about the study. Permission was granted to visit the schools personally to carry out the survey.

## *3.3 Ethical considerations*

Consideration is given to the ethical aspects of the study, especially as the survey involved children. When schoolchildren are respondents for a research survey approval needs to be obtained from either the children's parents or the teacher responsible for the class. In this case permission has been granted in lieu by the respective teachers. The introduction to the survey questionnaire (appendix 1) includes information relating to the purpose, voluntary consent to participate, confidentiality and use of study data corresponding to the ethical guidelines stipulated by The Swedish Research Council (Vetenskapsrådet, 2002).

## *3.4 Questionnaire design*

The questions in survey questionnaire (appendix 1) have been formulated to create observable and measurable variables. The variable values isolate the phenomena as well as separate individual concepts and explanations. The dependent variable is the pupils understanding of photosynthesis. The independent variables are language spoken at home and interest in science and nature in general.

Part one contains two questions on language and interest. The language spoken at home has been chosen as the language question in preference to other alternatives in order to prevent encroaching into areas that may be conceived as ethically precarious, such as ethnicity and nationality. Three values for language have been chosen; Pupils speaking only Swedish at home, pupils speaking both Swedish and another language at home, and pupils speaking only another language at home. Three values have also been chosen to distinguish interest for science and nature. These are pupils interested in science and nature, those neither uninterested nor interested in this area, and pupils interested in science and nature. The wording "s*cience and nature"* rather than "*biology"* has been used to distinguish between a general interest in the area rather than an interest in the school subject, which may have negative connotations for school weary pupils.

Part two covered questions relating to the wider aspects of photosynthesis. Questions 1, 2, 3, 6, 7 and 8 were designed by me. Question 4 was sourced from a pupil multiple choice questionnaire on photosynthesis developed by NORDLAB-SE (Andersson, 2006). The idea for question 5 originated from question 3 on pupils knowledge of biology in the National

Assessment of Schools 2003 (Skolverket, 2005b). The questions were checked by a university lecturer and high school teacher in biology for accuracy.

Questions 1 and 2 investigate carbon dioxides role in photosynthesis and its effect on carbon dioxide levels in the atmosphere relating to the greenhouse effect. To be able to answer the question correctly pupils should identify that that carbon dioxide is taken up from the air by plants and trees during photosynthesis.

Question 3 is designed to test pupil's knowledge of photosynthesizing plants as the source of atmospheric oxygen. Question 4 investigates the link between photosynthesis and ecology by testing understanding of vegetations role as an autotrophic primary producer providing energy in food to all organisms higher up the food chain whether carnivores or herbivores.

Question 5 tests understanding of the reactants and the products of photosynthesis and the connection between inorganic carbon dioxide and organic sugars that constitute the majority of vegetation's biomass.

Question 6 and 7 investigates two interrelated aspects. Firstly the understanding of solar energy as the original source of energy in all food due to its transformation to chemical energy bound in organic sugars by photosynthesis, and secondly the transfer of this energy through food-chains. Question 6 relates to a simple food-chain, involving a primary producer and a consumer. Question 7 requires the same knowledge to be applied to a longer food-chain involving a number of organisms in the chain.

Question 8 is designed to summarise pupil's awareness of the three important aspects of photosynthesis in relation to the study; its role in producing oxygen and converting energy in food to sustain life, and its potential to reduce global warming due to the take up of carbon dioxide.

# 4. Results

The survey was conducted with 183 pupils from nine $9^{th}$ grade classes at four secondary schools in Uppsala, Sweden. Of the 183 questionnaires received, 11 contained incomplete answers and were discounted from the analysis. Of the 171 completed questionnaires, 116 (67.8 %) were completed by pupils who speak only Swedish at home, 54 (31.6 %) were

completed by pupils speaking both Swedish and another language at home, and one (0.6%) was completed by a pupil who spoke only another language at home. No conclusions would be able to be drawn from the data representing the one pupil who spoke only another language at home, and for this reason this result was pooled within the category of pupils speaking both Swedish and another language at home.

## *4.1 Pupils interest in science and nature*

Amongst the sampled pupils, 16.4 % described themselves as uninterested in science and nature, 46.2 % where neither uninterested nor interested and 37.4 % where interested. Within the Swedish only speakers 21.7 % rated themselves as uninterested, 47 % rated the area as neither uninteresting nor interesting and 31.3 % were interested. Of the sampled pupils speaking both Swedish and another language 5.5% rated science and nature as uninteresting, 45.5% were neither uninterested or interested, and 49.1 % where interested (*figure 1*).

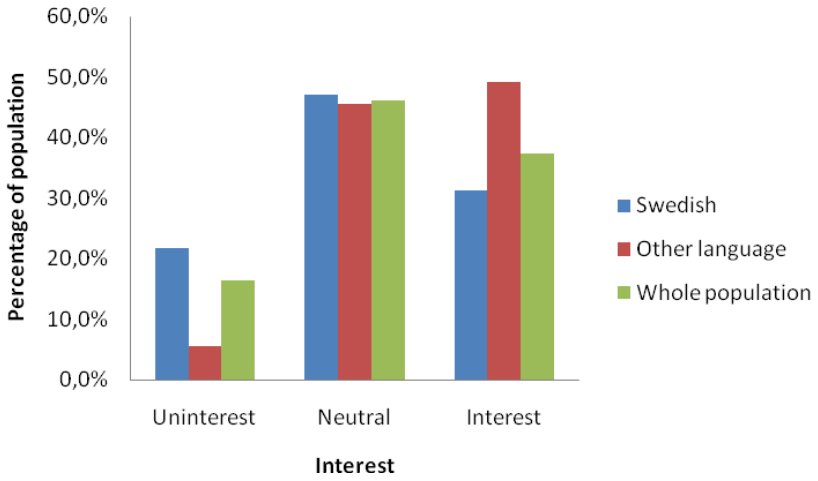


*Figure 1: Pupil's ratings of their interest for science and nature for the whole population (n = 171). Blue bars indicate the distribution of pupils that only speak Swedish at home (n = 116) and red bars the distribution of pupils that speak both Swedish and another language at home (n = 55). Green bars show the distribution of the whole sample.*

## *4.2 Understanding of the wider aspects of photosynthesis*

The table in *appendix 2* shows the quantity and proportion, in descending order, of pupils in total and within each sample subset that selected the correct answer alternatives for each question. *Figure 2* shows the proportion of correct scores per question for the whole sample as well as pupils speaking only Swedish and those speaking both Swedish and another

language at home. *Figure 3* shows the proportion of correct scores per question for the three interest subsets within the sample. The question that scored the highest correct scores was question 3, on the source of atmospheric oxygen, 88%. The uninterested subset of pupils scored lowest, 71%. Correct scores for the question on the fate of all the animals on an island if all the plants there die, question 4, dropped to 61 %. Uninterested scored highest with 71 %. In third place, 56 % of the pupils chose the correct answer for question 6 on the original source of energy in potatoes. Swedish speakers scored 50 %, speakers of both Swedish and another language 69 %. Uninterested, neutral and interested pupils scored 39 %, 58 % and 61 % respectively (*figure 3*). Question 1 on the effect of planting more trees on the amount of carbon dioxide in the atmosphere related to the greenhouse effect received 55 % correct answers. Uninterested pupils scored 46 %, neutral 53 % and interested 61 %.

The questions that received the lowest total of correct answer alternatives (*figure 2)* were those relating to the organism or process that consumes carbon dioxide (question 2), 41%, the original source of energy the energy in egg, herring and sour milk, (question 7), 22%, the importance of photosynthesis for humans (question 8), 17 %, and the source of increased biomass in harvested potatoes (question 5), only 12%.

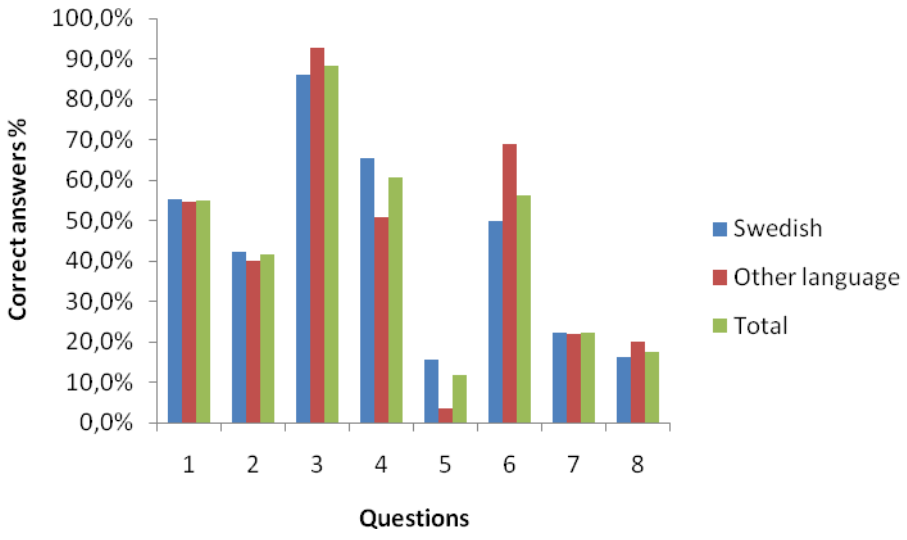


*Figure 2: The frequency of correct alternatives chosen for each question regarding photosynthesis by language spoken at home. Blue bars show the frequency of correct answers within the sample of pupils that only speak Swedish at home (n = 116) and the red bars show the frequency of correct answers within the sample of pupils that speak both Swedish and another language at home (n = 55).The green bars show the frequency of correct answers for the whole sample (n = 117).*

Uninterested pupils achieved the lowest percentage of correct answers for six questions. Interested pupils scored the highest percentage of correct answers for six questions (*figure 3*). Scores for pupils speaking only Swedish at home and pupils speaking both Swedish and another language at home scored within 5 percentage points of each other on four questions (*figure 2*), and 7 percentage points of each other on five questions.

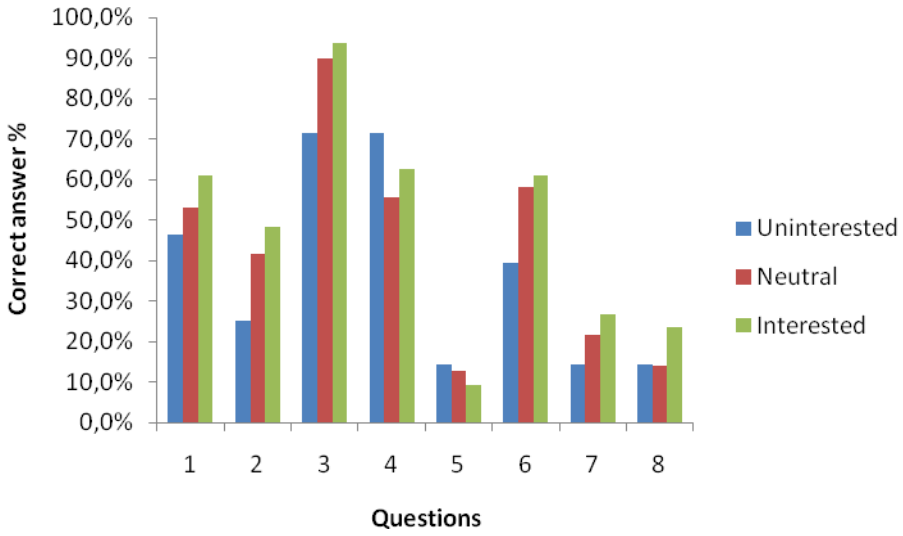


*Figure 3: The frequency of correct alternatives chosen for each question regarding photosynthesis by interest for science and nature. The blue bars show the frequency of correct answers within the sample of uninterested pupils (n = 28). The red bars show the frequency of correct answers within the sample of neither uninterested nor interested pupils (n = 79). The green bars show the frequency of correct answers within the sample of interested pupils (n= 64).*

The mean scores for the number of correct answer alternatives for each subset of pupils (*Table 1*) were calculated using the two-way ANOVA statistical test (SPSS Statistics 18, 2010). The variance between the Swedish speakers and the other language speakers mean correct answer scores as well as between the uninterested, neutral and interested correct answer scores was calculated using a two-way ANOVA (*Table 1*). There was no variance between the mean scores of Swedish speakers and other language speakers (*Table 1).* There was a significant variance between the mean scores between the interest subsets (*Table 1).* A post-hoc Tukey HSD (Honest Significant Differences) test (SPSS Statistics 18, 2010) was performed on the mean scores within the interest categories to establish that a significant difference

lay between the uninterested and the interested groups (*Table 1*). The other variations were not significant.

| Means scores for subsets of population | | | | | |
|---|---|---|---|---|---|
| Subset | SW | OT | U | N | I |
| Mean score | 3,53 | 3,53 | 2,96 | 3,47 | 3,84 |

*Table 1: Mean scores for each subset of the sampled population from a possible maximum of eight correct answers. SW = pupils speaking only Swedish at home, OT = pupils speaking both Swedish and another language at home: F(1,169)=0.00, p=>0.05. U = pupils uninterested in science and nature. N = pupils neither uninterested not interested in science and nature, I = pupils interested in science and nature: F(2,168)=3.089, p= 0.05.Post-hoc Tukey HSD group U versus group I p=<0.05, group N versus group I p=>0.05.*

# 5. Discussion

There is a large disparity between the percentages of correct answers for each question (*Figure 2*). The difference indicates that pupils understand some aspects of photosynthesis more than others. The score of 88 % for question 3 shows that pupils understand that photosynthesis is the source of atmospheric oxygen. On the other hand, for question 2, only 41 % identified a growing tree as something which takes up carbon dioxide from the air from a choice including burning wood, growing fungi and driving a biogas car. Furthermore 55 % of the pupils were able to identify a carbon dioxide decrease as a result of planting more trees and plants to control the greenhouse effect in question 1. Compared to a similar question from 1992 and 2003 Swedish National Assessments (Skolverket, 2005, Andersson 2006 & 2008) pupil's scores were much higher in this study.

The difference may be a result a pupil's familiarity with the everyday concept of oxygen as a prerequisite for life, whereas understanding of carbon dioxides role in nature is not as self-evident. If asked "*which gas is taken up by trees and plants in photosynthesis?"* a higher proportion of pupils may well answer correctly because they know this fact. However, when confronted by a choice of answers choosing incorrectly suggests that they do not posses a broader knowledge of the area. Similarly, question 3 was embedded within a question on the greenhouse effect which tested pupil's knowledge from a different perspective. This may reflect Waheed and Lucas (1992) and Marmaroti and Galanopoulou (2006) conclusions that

pupils have more difficulty understanding the interrelationship between different phenomena than displaying a knowledge of individual facts.

Likewise, comparison of the scores for question 6 (56 %) and question 7 (22%) shows that the majority of pupils make the connection between solar energy as the original source of energy in potatoes as food. Fewer where able to apply the same basic knowledge to energy transfer through a more complicated food chain including animals. This suggests that students are less able to understand concepts that require a deeper understanding of interrelated and abstract topics.

Paradoxically, the correct answer to question 4 requires the application of knowledge of primary producers, ecological food chains and transfer of energy through the food chain. This can be considered as difficult an area as those in the questions discussed above, if not more so than the exchange of gases. However pupils have, according to Andersson (2008) traditionally struggled with topics relating to matter and gases that are invisible to the naked eye and therefore more abstract. The concept of plant's and animal's relationship in an ecological community is closer to everyday understanding and probably easier to relate to. Waheed and Lucas' 1992 study also suggests that pupils have a better understanding of the ecological processes than physiological, biochemical and energy change.

The question that scored the least correct answers was question 5. At least half of the pupils tested have some understanding that carbon dioxide is taken up by plants and trees but few displayed an understanding of the connection between carbon dioxide before photosynthesis and the sugars and starches that are synthesized as a result. This lies within the abstract domain of gases, matter and chemical reactions which are among the most difficult concepts for pupils to grasp properly. The results achieved here are similar to those presented by Andersson (2005) from the Swedish National Assessment.

In total less than one-fifth of the sampled pupils correctly identified the three important processes that resulting from photosynthesis that are of importance for mankind. This can be a consequence of pupils not possessing the basic knowledge on the difference aspects of photosynthesis, or the inability to take the knowledge they possess and synthesise and apply it on problems at a higher cognitive level. It should be pointed out that this question

contained a higher number of answer alternatives than the other questions which may have had a slight negative effect on the percentage of correct answers. Also some pupils may have chosen alternative A & B, A & C or B & C without assessing all the alternatives thoroughly. Compared to scores for other questions on oxygen (88%), carbon dioxide (55 % and 41 %) and energy in food (61 %, 56 % & 22 %) it is likely that both these explanations apply, with knowledge of photosynthesis importance for transforming energy and the transfer of energy up the food change as the weakest area.

The pattern of the results is similar to those published in earlier studies such by Haslam and Treagust (1987), Waheed and Lucas (1992) and Marmaroti and Galanopoulou (2006). Pupils have a greater knowledge and understanding of individual topics of photosynthesis as well aspects that are closer to everyday conceptions of nature. The higher the level of abstraction and the greater the knowledge of the interrelations required between individual topics to understand phenomena the more difficult it becomes.

Analyses of the results indicate that that the language which is spoken at home does not affect pupils' level of understanding. The mean scores obtained by each language group where the same. There were only small differences between the percentages of correct scores for individuals between the two groups, other language speakers scoring marginally higher on five questions, and Swedish language speakers scoring marginally higher on four questions. The distribution of the number of correct answers by individuals in each group was also similar. These results do not coincide with previous data published by PISA, TIMMS and National Agency for Education. It is difficult to explain the reasons for the disparity as the only language criterion for this study was the language the pupils spoke in their home environment, whereas in the larger national and international studies many variables where accounted for. Here, no data was collected on the length of time the pupils had lived in Sweden, if they were born there, if one or both parents came from another country or if they classed Swedish as their mother tongue. Interestingly, all but one of other language speakers also spoke Swedish at home which suggests that the pupils where not isolated from Swedish outside of their learning environment. Many of these questions were excluded from the study because of time restrictions, and for ethical reasons. However as the schools partaking in the study where situated in neighbourhoods with a higher than average

immigrant population, it was surprising that there were no more pupils speaking only another language at home.

There were significant differences in understanding between the groups of pupils based on interest for science and nature. The group of uninterested pupils obtained the lowest mean score of all five subsets covering language and interest. Both neither uninterested nor interested pupils and interested pupils scored higher on average than the mean score for the whole study (*Table 1)*. The percentage of correct answers for uninterested individuals shows very few were able to answer more than 4 questions correctly. These findings fit with the conclusions of the 2006 PISA survey published by the National Agency for Education.

A final question to be answered is if school equipping teenagers to participate in democratic role in society with regard to nature and the environment (Sutherland et al, 2005, Carlsson, 2002). In this study 47 % of the pupils attained a score of 50 % correct answers or more. Only 29 % achieved scores of 62% or over. This suggests that many pupils leave compulsory education without enough knowledge in areas in natural science related to democracy and society and this may have an effect on their ability to make informed and relevant choices in the future.

The results can be viewed as a reliable indication of the level understanding of the wider aspects of photosynthesis of the pupils who participated in this study. However, the validity of the results as representative for the wider population of 9$^{th}$ grade pupils understanding of these concepts cannot be confirmed, as the study was conducted within a small sample of pupils from a small number of secondary schools in only one town in Sweden.

The goal of this study was to measure pupil's understanding of the important aspects of photosynthesis important to mankind and life in general. It measures the result of the pupil's education rather than what the education consists of. Motivated by the work of Carlsson (2002) and Näs (2010), a potential area for future study would be to investigate the teaching methods and the scope of photosynthesis education in secondary schools. The study would contain a combined quantitative and qualitative approach. The qualitative part would consist of respondent interview with science teachers to establish methods and content (Essaiasson *et al*, 2007). An important factor would be a comparison between a traditional

approach with a focus on plant physiology and other wider ranging teaching methods including environmental and ecological aspects. Another factor would be how the teachers unite knowledge of biology, chemistry and physics. The quantitative part would investigate the frequency and time spent on teaching. The results would be compared with a survey similar to the one undertaken here.

Other areas for future investigation would be deeper quantitative analysis of the pupil's language and cultural background, including parent's socio-economic status. It would be of interest to discover if poorer understanding of science of correlated more to language or socio-economic status.

Similarly, the variables of interest have not been examined thoroughly here. These results show that interest is factor in learning natural science. What the interest or lack of interest depends upon is not part of the study. A further qualitative and quantitative survey including analysis of reasons for interest and lack of interest for science and nature, education in general, the degree of difficulty in learning the subject would be of interest.

In summary, the study indicates that the majority of 9$^{th}$ grade lack some aspects of an understanding of the wider implications of photosynthesis. This may have some effect on the pupil's ability to make informed judgments on and to participate in democratic debates on important ecological and environmental issues that impact society. In addition, a significant difference in understanding has been shown to exist between pupils uninterested and pupils interested in science and nature. This supports results of earlier studies. On the other hand, the indication from previous studies that significant differences in understanding exist between pupils who only speak Swedish at home and pupils who also speak other languages at home, as well as Swedish, has not been demonstrated by the pupils surveyed in this study.

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Appendix 1

# Enkät om elevernas insikt om FOTOSYNTES, EKOLOGI och MILJÖ

Hej, jag heter Tim Yates och utbildar mig till lärare. Som en del av min utbildning genomför jag ett självständigt projektarbete som handlar om högstadieelevers förståelse av några biologiska förklaringar. Jag är intresserad av att veta vad **du** kan om dem. Jag skulle uppskatta om du tar dig tid att svara på följande frågor i den här enkäten.

Undersökningen är helt frivillig och anonym. Dina svar kommer bara att behandlas av mig och ingen annan kommer att få veta hur du har svarat. Du har även rätt att avbryta enkäten när du vill.

Tack för din hjälp!

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Välj det svar som du tycker passar bäst för varje fråga genom att ringa in bokstaven.

DEL 1: Om dig själv

1. Jag pratar:

   A: bara svenska hemma
   B: pratar både svenska och ett annat språk hemma
   C: pratar bara ett annat språk hemma

2. Hur stort är ditt allmänna intresse för biologi, miljö och natur?

   A: Jag är intresserad
   B: Jag är varken intresserad eller ointresserad
   C: Jag är ointresserad

DEL 2

1. Utsläpp av koldioxid ökar växthuseffekten vilket kanske ledar till global uppvärmning. Vad händer med mängden koldioxid i luften om vi planterar mera träd och växter?

   A. Koldioxid minskar
   B. Koldioxid ökar
   C. Ingen förändring

2. När tas koldioxid upp från luften?

   A. Ved eldas
   B. En svamp växer
   C. En biogas bil körs
   D. En gran växer

3. Mängden syre i luften är mer eller mindre densamma hela tiden trots att de flesta organismer behöver använda syre för att leva. Var kommer allt syre ifrån?

   A: Havet
   B: Växter
   C: Rymden
   D: Marken

4. Alla växter på en stor ö dör. Vad beskriver bäst det som händer med djuren på ön?

   A. Många djur dör, men en del djur som inte äter växter klarar sig
   B. All djur dör så småningom
   C. En del djur som brukar äta växter börjar istället äta annan mat och klarar sig
   D. Bara de starkaste djuren överlever

5. Under våren planterade en bonde potatis på en åker. Vikten på potatis när de planterades var 40 gram. Vikten på potatisplantorna vid skörden på hösten var ungefär 1000 gram. Varifrån har den mesta av viktökningen kommit?

   A. Jord och vatten
   B. Vatten och luft
   C. Vatten och näringsämnen
   D. Jord och näringsämnen

6. Alla organismer behöver energi. I potatis finns mycket energi. Varifrån kommer energin som finns i potatisar från början?

   A. Vatten
   B. Koldioxid
   C. Solen
   D. Syre

7. Till frukost äter Lisa ägg, sill och filmjölk så att hon får tillräckligt med energi för att spela fotboll på förmiddagen. Varifrån kommer den här energin från början?

A. Koldioxid
B. Hönan, fisken och kon
C. Solen
D. Syre
E. Vatten

8. Vad betyder fotosyntes för människan?

A. Den ger oss syre som vi andas
B. Den ger oss energi i all mat som vi äter
C. Den tar upp koldioxiden som kommer från användningen av fossila bränslen
D. Både A och B
E. Både B och C
F. De tre första alternativen A, B och C
G. Fotosyntes är bara viktig för växter. Den har ingen betydelse för människan

Appendix 2

***Frequency of correct answer alternative in descending order***

| *Question* | *Correct answer* | *Tot* | *%* | *SW* | *%* | *OL* | *%* | *U* | *%* | *N* | *%* | *I* | *%* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Q3: The amount of oxygen in the air is more or less the same despite that most organisms need oxygen to live. Where does all the oxygen come from?* | *B: Plants* | *151* | *88,3* | *100* | *86,2* | *51* | *92,7* | *20* | *71,4* | *71* | *89,9* | *60* | *93,8* |
| *Q4: All the plants on a large island die. Which describes best what happens to the animals on the island?* | *B: All the animals die eventually* | *104* | *60,8* | *76* | *65,5* | *28* | *50,9* | *20* | *71,4* | *44* | *55,7* | *40* | *62,5* |
| *Q6: All organisms need energy. There is a lot of energy in potatoes. Where does the energy in potatoes originally come from?* | *C: The sun* | *96* | *56,1* | *58* | *50,0* | *38* | *69,1* | *11* | *39,3* | *46* | *58,2* | *39* | *60,9* |
| *Q1: Carbon dioxide emissions increase the greenhouse effect which can lead to global warming. What would happen to the amount of carbon dioxide in the air if we plant more trees and plants?* | *A: Carbon dioxide decreases* | *94* | *55,0* | *64* | *55,2* | *30* | *54,5* | *13* | *46,4* | *42* | *53,2* | *39* | *60,9* |
| *Q2: When is carbon dioxide in the air taken up?* | *D: A spruce tree grows* | *71* | *41,5* | *49* | *42,2* | *22* | *40,0* | *7* | *25,0* | *33* | *41,8* | *31* | *48,4* |
| *Q7: Lisa eats egg, herring and sour milk for breakfast so that she has enough energy to play football this morning. Where does this energy come from originally?* | *C: The sun* | *38* | *22,2* | *26* | *22,4* | *12* | *21,8* | *4* | *14,3* | *17* | *21,5* | *17* | *26,6* |
| *Q8: What's the importance of photosynthesis for Humans?* | *F: The first three alternatives A, B & C* | *30* | *17,5* | *19* | *16,4* | *11* | *20,0* | *4* | *14,3* | *11* | *13,9* | *15* | *23,4* |
| *Q5: A farmer plants potatoes in a field in the spring. The potato plants weigh about 40 grams when they are planted. When they are harvested in the autumn they weigh about 1000 grams. Where has most of the weight increase come from?* | *B: Water & air* | *20* | *11,7* | *18* | *15,5* | *2* | *3,6* | *4* | *14,3* | *10* | *12,7* | *6* | *9,4* |

*Appendix 2: The frequency of correct answer alternatives in ascending order by quantity and percent. Tot = the whole sample (n = 171), SW = pupils speaking only Swedish at home (n = 116), OL = pupils speaking both Swedish and another language at home (n = 55), U = pupils uninterested in science and nature (n = 28), N = pupils neither uninterested nor interested in science and nature (n = 79), I = pupils interested in science and nature (n = 64).*