Understanding photosynthesis and respiration – is it a problem? Eighth graders’ written and oral reasoning about photosynthesis and respiration.

1. Introduction
At the senior level of nine-year compulsory school in Sweden, photosynthesis and respiration play an important part in biology instruction and curricula. One important objective is that the student at the end of year nine should “have an insight into photosynthesis and combustion, as well as the importance of water for life on earth” (The Swedish National Agency for Education, 2009). Another objective to strive towards is to develop knowledge about organisms and their interplay with the environment. In the understanding of cell and life processes, knowledge about photosynthesis and respiration is described as essential (ibid).

Students at almost all school levels, from 9 to 19 years of age, show difficulties in understanding photosynthesis and respiration, and there seems to be a fundamental lack of understanding of basic ecological concepts, e.g. energy flow in ecosystems, including the role of photosynthesis and respiration for life on earth (Canal 1999; Marmaroti & Galanopoulou 2006; Wood-Robinson 1991). Reports from three different decades show the persistence of the intuitive explanation that plants get their food from their environment specifically from the soil, where the roots are the organs of feeding (Andersson 2008; Driver et al. 1994, Smith & Anderson 1984). Understanding photosynthesis depends on concepts of particle theory, changes of phase and transformation that students have difficulty grasping (Carlsson 1999). But according to Barak (1999), the process is not learnt properly if the teaching does not go beyond learning just words and concepts. When photosynthesis is not truly understood, the students tend to use rote learning as a strategy and their knowledge about photosynthesis is not meaningful (Canal 1999). Understanding complex topics in ecosystems requires knowledge about concepts and how to relate them to the whole system (Helldén 2005; Hogan & Fisherkeller 1996 and Magntorn 2007). Ecology teaching gives an opportunity to relate photosynthesis and respiration to the whole system. Even so, results from Özay & Öztas (2003) show that students aged fifteen did not understand photosynthesis after ecology teaching.

Many of the above mentioned difficulties are demonstrated in results from different written tests. Written tests are the most common way to evaluate students’ knowledge both in school and in national (NE, 1992; 2003) and international surveys (TIMSS and PISA). These evaluations have a high impact in media, and one question is whether they fairly reflect the knowledge of the students. Schoultz et al. (2001) showed how students’ difficulties in understanding two items from a TIMSS’ test were easily solved in an interactive setting and they found it doubtful if these items could test conceptual knowledge.

According to Andersson (2008) both every-day language/thinking and scientific language/thinking have an important role in understanding science. It is important for the students to learn how to move between every-day and scientific thinking. Andersson’s work is based upon large empirical material and Piaget’s and Vygotskij’s theoretical descriptions about every-day and scientific knowledge. Using living plant material as artefacts in teaching is important to obtain an ecological understanding and to provide good learning opportunities about photosynthesis in early grades (Helldén 1992; Näs & Ottander 2008; Vikström 2005). Vikström worked with the lifecycles of plants, seeds and angiosperms. She showed how seven to twelve year old students developed complex understanding of photosynthesis when their teachers used a language including metaphors, and when they pointed out critical aspects for the students’ learning. Magntorn & Helldén (2007) described a ‘bottom-up’ perspective in

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teaching primary students about ecosystems which took its starting point in one common key organism. By connecting the effecting environment and other organisms’ dependence upon the key organism, the students acquired a better understanding of the ecological concepts.

Teenagers’ lack of interest in describing and understanding ecological concepts like food webs, recycling and energy transformations tells us that new ways of teaching ecology are needed (Barker & Slingsby 1998; Delpech 2002; Driver et al. 1994; Feinsinger et al. 1997). Slingsby & Barker (2003) claimed that biology teaching needs ethical and emotional aspects to practice the skills. A group task about survival on a Space Shuttle, used as an ecology introduction, allowed the students to discuss and use ethical and emotional aspects and the student interest increased (Näs & Ottander 2009). Delpech pointed out that it is important for the teacher to give the students opportunities to express other knowledge than memorised facts. Teaching, such as process teaching, group work, outdoor education, and ethical and emotional discussions, really needs supportive, experienced and instructing teachers if the students are to learn and understand difficult science concepts (Delpech 2002; Näs & Ottander 2008; Vikström 2008).

Knowledge about students’ reasoning gives the teacher interesting insights into student understanding and thoughts (Driver et al. 1996; Mortimer & Scott 2003; Schoultz et al. 2001). Driver et al. listened to students reasoning during work with different scientific problems outside the classroom. In their analyses they tried to describe the learning process of the students. Schoultz used items from TIMSS and could therefore compare the understanding the students showed in a communicative format to the understanding measured in TIMSS’s assessment. Mortimer and Scott studied science talk in the classroom by applying a prepared framework and they found that students’ understanding and interest increased when the teacher used their framework. Research in science education often focuses on designed teaching sessions or at special parts of the classroom activity. Only few studies present the real classroom atmosphere. We would like to contribute to this field of enquiry with students’ knowledge originating from ordinary science classrooms.

We studied ecology lessons in three eighth grade classes for ten weeks (the ecology unit) in a Swedish school where the teachers used their usual teaching. The first author had an ethnographic approach (Bogdan & Biklen 2003; Erickson 1986). She observed in the classrooms, studied the tests from all students and conducted 23 individual interviews (Table 1). This paper focuses on students’ written and oral reasoning about photosynthesis and respiration, and we investigate their knowledge before and after ecology instruction. We address the following questions:

- What knowledge about photosynthesis and respiration do the students show in written tests and in a guided interview?
- How does the reasoning of students differ in a written test and in a guided interview?

2. Method

2.1 The ecology unit
The ecology unit consisted of ten weeks with 33 hours in each class. Table 1 presents the activities during the ecology unit and results from the parts, written in bold, are presented in this paper.
Table 1. The teachers’ lesson plan, data acquisition and time used at each part

<table>
<thead>
<tr>
<th>Week and time used</th>
<th>Activities carried out in each of the three classes.</th>
<th>Data acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2, six hours</td>
<td>Introduction to ecology with cultivation and group work about leaving earth and the survival on a space shuttle.</td>
<td>Observation notes in all the three classes</td>
</tr>
<tr>
<td>3, three hours</td>
<td>Theory lessons in ecology and group work as a preparation for the excursion to the forest biotope. <strong>Pre-test questionnaire</strong> (Andersson et al., 2005). n=69.</td>
<td>Observation notes and 69 collected questionnaires</td>
</tr>
<tr>
<td>4, six hours</td>
<td>The excursion and supplementary group work.</td>
<td>Observation notes</td>
</tr>
<tr>
<td>5, three hours</td>
<td>Supplementary work with excursion material and theory lessons.</td>
<td>None</td>
</tr>
<tr>
<td>6-8, nine hours</td>
<td>Theory lessons with ecology, photosynthesis and respiration content carried out both as lectures, group work and individual work with questions from the textbook interspersed with demonstrations and laboratory work.</td>
<td>Observation notes and audiotaped discussions partly transcribed</td>
</tr>
<tr>
<td>9</td>
<td>Autumn holiday</td>
<td>None</td>
</tr>
<tr>
<td>10, three hours</td>
<td>Go through/repeat the ecology content.</td>
<td>Observation notes</td>
</tr>
<tr>
<td>11, three hours</td>
<td>Repetition lessons before test and one lesson’s <strong>written test (Appendix 1) as an examination of the whole ecology unit.</strong></td>
<td>Observation notes, collected and copied tests</td>
</tr>
<tr>
<td>14-16, twelve hours</td>
<td><strong>Interviews with 23 students</strong></td>
<td>Audiotaped interviews fully transcribed</td>
</tr>
</tbody>
</table>

2.2 Students and teachers involved

Three eighth grade classes and their two teachers participated in this study. The teachers had more than ten years of experience and they managed all lesson plans and the teaching. The teachers described the classes as two normal and one problematic class. Many students in the problematic class were restless and disruptive, and they spoiled two thirds of the lessons. One teacher taught the problematic class (18 students) and the other teacher the other two classes (24 and 27 students respectively). The students had joined the present classes from the sixth grade and had two years left at senior level of the nine-year compulsory school. During the four years together, all the students had science lessons in the three subjects biology, chemistry and physics. They had been taught about photosynthesis and respiration in sixth and seventh grade, but the teachers wanted to repeat the content in the ecology unit.

All students and their parents were asked for acceptance of the attendance of the researcher during the lessons and for the follow-up interviews. The Swedish ethical principals in research were followed (The Swedish Research Council 2002).

2.3 The ecology test and analysing strategies
The students completed the ecology unit by taking a final test with 20 questions (Appendix 1), designed by the two teachers. The teachers decided the scoring strategies and they scored their students’ tests. I collected tests from 66 students and specifically scrutinised questions with photosynthesis and respiration content. The analysis was made when the tests had been scored, which gave an opportunity to look at both the answers and the teachers’ scoring.

In this paper I report the results of three essay questions (questions 9, 17 and 20, Appendix 1). The answers to these questions were analysed and categorised with three aims: (1) to examine the written reasoning of the 66 students, (2) to allow to compare their reasoning with a large national evaluation (3100 Swedish students in 1992 and 620 students in 2003), and (3) to use the written answers in comparison of the 23 interviewed students oral statements.

Three answer categories were constructed: (1) correct, (2) not comprehensive and (3) no or an irrelevant answers (cf. Table 3, 4 and 5). These three categories were an amalgamation of the National Evaluation’s nine categories used on the essay question ‘Growing tree’ (question 9) in 1992 and 2003. The ‘correct’ category corresponds to the two categories of the National Evaluations (NE) for a passed and a passed with distinction grade. To get a passed grade, the NE required carbon dioxide in the answer, perhaps in any combination with nutrition, water and sun energy, and for the passed with distinction grade a more scientific explanation needed to be included in the answer. The NE used five categories including answers where the students tried to explain but used the science words and concepts both incorrectly and incompletely or fragmentarily, such as: the tree has grown and the sun, air or nutrition in diverse combinations. I united their five categories into one ‘not comprehensive’ category since these answers corresponded to attempts to give a correct answer. Our third category corresponded to the NE’s ‘no answer’ or ‘other’ categories where ‘no answer’ was the dominating answer in the material.

I categorised and analysed all three essay questions (the Growing tree, the Polar bear and the Terrarium) in the same way. These questions are part of a workshop on the Internet, NORDLAB-SE, (Andersson et al. 2009), and the teachers used these questions in the ecology test.

2.4 The interviews
23 students were interviewed. The students were informed about the interviews in the beginning of the teaching unit and were asked to participate after the last lesson. An interest in learning something about both their lack of knowledge and their actual knowledge was made clear. The students applied on a voluntary basis but some were denied participation as all of them could not be interviewed. The previous observations had given some knowledge about the reasoning capacity of the students, and I wanted to interview as many students with varying levels of achievement as possible. The composition of the interviewed group was proportional to the three classes’ diversity and composition of strong and weak students.

The design of the interview was semi-structured with groups of questions about themselves, the teaching and photosynthesis and respiration. The specific subject content was introduced by means of questions and material (branches of trees, potato, apple and carrot). The interview guide is shown in Table 2. During the interview the students were challenged in their reasoning and the guide was not strictly followed. When the manner and contribution of the students changed the focus of the interview, they were encouraged to finish what they had to say so I could catch unexpected threads. The interview dealt, to a large extent, with photosynthesis and respiration content.
<table>
<thead>
<tr>
<th>Question</th>
<th>My aim</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tell me something about yourself!</td>
<td>Get to know and make them relax.</td>
</tr>
<tr>
<td>Tell me something about the unit you just have finished. Do you remember anything in particular?</td>
<td>To talk about the ecology unit by letting the students mention the science words, processes or concepts.</td>
</tr>
<tr>
<td>Do you remember the space shuttle? If you were told to do it now, would you change your equipment and plans?</td>
<td>To mention an actual part of the teaching like the space shuttle and to investigate their knowledge about that part.</td>
</tr>
<tr>
<td>What do you think about photosynthesis? Is it important? Where is oxygen used? What is respiration?</td>
<td>To make them start reasoning about photosynthesis and respiration.</td>
</tr>
<tr>
<td>Branches of pine and spruce, a potato, a carrot and an apple were used. How does this become a pine, potato, etc.? What is it made up of?</td>
<td>To see if they could use their knowledge about photosynthesis and respiration with a plant or a fruit in their hands.</td>
</tr>
</tbody>
</table>

### 2.4.1 Analysis of the interviews

The interview design made the questions partly leading and also allowed the interviewer to gain insight into the students’ thoughts and knowledge. During the interviews the students were encouraged to elaborate on their explanations, applications and guesses about plant life and other organisms’ dependence on plant life. The reasoning capacity of the students was continuously interpreted (Bogdan & Biklen 2003; Erickson 1986). This first analysis during the interview (Table 2) corresponds to Kvale’s (1996) first three steps in the analysis of qualitative interviews (pp.189-190). The real interpretation of the students’ reasoning (Kvale’s fourth step), started with the transcription of the audiotaped interviews. Directly after the transcription of each interview, the main issues were summarised and the feeling about the students’ skills were commented on.

The transcripts were read many times and I tried to develop the meanings of the students’ reasoning. This eventually resulted the defining of three types of reasoning representing the way students described, explained and just talk about ecology, photosynthesis and respiration. In the beginning boys and girls were separated. More gender similarities than differences appeared in the analysis and three reasoning types were united:

1. The ‘linking-together’ reasoning: The students mainly linked scientific concepts and words to form a whole description by using more everyday language rather than scientific language.

2. The ‘memory’ reasoning: The students mainly presented their knowledge by using memorised formulations and correctly articulated scientific concepts.

3. The ‘school-weary’ reasoning: The students mainly maintained that they did not know anything and that it was boring.

The interviews of five students will be presented to demonstrate the reasoning types and the different ways of expressing knowledge in the guided interview.

### 3. Results
3.1 Written knowledge
Table 3 shows how the 66 students managed to answer the essay questions. The questions dealt with photosynthesis (the Growing tree) and carbon recycling (the Polar bear and the Terrarium). Below we show an example of an answer to the Growing tree question categorised as correct.

The tree absorbs solar energy and carbon dioxide through the stomata and water from the soil. In the photosynthesis the tree uses the energy to put the carbon dioxide and the water together to get carbohydrates and oxygen. The oxygen is released through the stomata and the carbohydrates build up the tree.

An example of an answer categorised as not comprehensive was:

The weight is a lot of water, nutrients and the tree itself. When it’s raining the tree eagerly sucks up the water with its roots and the water evaporates and the nutrients too. It gets big and heavy because of the branches, the stem and the leaves. Everything weighs.

Over all the answers in the Growing tree and the Terrarium questions were better formulated than in the Polar bear question. There were more than three times as many students that had no or an irrelevant answer in the Polar bear question compared to the other two questions.

<table>
<thead>
<tr>
<th>Category</th>
<th>The Growing tree</th>
<th>Polar bear</th>
<th>Terrarium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct</td>
<td>59%</td>
<td>34%</td>
<td>52%</td>
</tr>
<tr>
<td>Not comprehensive</td>
<td>29%</td>
<td>24%</td>
<td>33%</td>
</tr>
<tr>
<td>No or irrelevant answer</td>
<td>12%</td>
<td>42%</td>
<td>15%</td>
</tr>
</tbody>
</table>

Table 4. The 59 students’ pre-test and 66 students’ post-test answers in two essay questions (9 and 17 in Appendix).

<table>
<thead>
<tr>
<th>Category</th>
<th>The growing tree pre- and post-test</th>
<th>The polar bear pre- and post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct</td>
<td>22%; 59%</td>
<td>16%; 34%</td>
</tr>
<tr>
<td>Not comprehensive</td>
<td>56%; 29%</td>
<td>25%; 24%</td>
</tr>
<tr>
<td>No or irrelevant answer</td>
<td>22%; 12%</td>
<td>59%; 42%</td>
</tr>
</tbody>
</table>

In a pre-test and in the final ecology test (post-test), the students answered three essay questions (Appendix 1) dealing with photosynthesis (the growing tree) and carbon recycling (the polar bear and the terrarium). The comparison of pre- and post-test of the growing tree and the polar bear question is shown in Table 4. The pre-test was accomplished in the third week just before the ecology and photosynthesis/respiration lessons started and the post-test questions were included in the final ecology test.

In the growing tree question, the students showed a prominent improvement after teaching with an increase from 22 % to 59 % in the correct category. The polar bear question did not produce the same increase, but the increase was evident (from 16 % to 34 %). In the not comprehensive category, there was a sharp decrease in the growing tree question, whereas the polar bear question did not alter. In the post-test about the polar bear, 42 % of the students were categorised in the no answer or irrelevant answer category, whereas the results in the same category for both the growing tree and the terrarium questions were about 12 % and 15
% (Table 3). The figures indicate that the teaching gave the students better knowledge about both photosynthesis and respiration, but the respiration (polar bear) question was more difficult to explain or understand.

In the post-test, the answers in the growing tree and the terrarium questions were better formulated than in the polar bear question. There were more than three times as many students that had no or an irrelevant answer in the polar bear question compared to the other two questions. 59% of the growing tree questions were answered correctly; only 34% of the polar bear questions were answered correctly.

The students’ answers to the growing tree question (in both pre- and post-test) differed substantially from the results of the National Evaluation (NE). The correct answer category was three to four times higher in the pre-test and seven to ten times higher in the post-test compared to the results of the same question on the NE (table 3 and 5).

More than 50% of the students had correct answers on the Growing tree and the Terrarium questions, where the Polar bear question only had half as many correct answers.

The students’ answers to the Growing tree question differed substantially (cf. Table 3 and 5) from the results of the National Evaluation (NE). The correct answer category was seven to ten times higher in our material. The high percentage in the no or irrelevant category in the NE of 2003 is also worth noting.

<table>
<thead>
<tr>
<th>Category</th>
<th>1992 (n= 3103)</th>
<th>2003 (n=620)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct</td>
<td>5%</td>
<td>8%</td>
</tr>
<tr>
<td>Not comprehensive</td>
<td>73%</td>
<td>47%</td>
</tr>
<tr>
<td>No or irrelevant answer</td>
<td>23%</td>
<td>45%</td>
</tr>
</tbody>
</table>

The students in the NE had not necessarily been taught about ecology, plants and photosynthesis recently, so the results from the two studies cannot be easily compared. The students in the NE were, however, in the same age as our students and most of them must have been taught about these topics. Since we used the same correct criteria, we can make the conclusion that our students learnt something from their teaching and it is evident that the students in the NE had forgotten, did not understand or just did not want to answer the questions. Of course, we do not know if our students would also soon forget what they had learnt about photosynthesis. Even so, Näs and Ottander (2008) showed that 11-12 year old students remembered what they had learnt about photosynthesis six months after teaching.

3.1.1 Written answers to the three essay questions

Jonas, Sara, Sune, Evelina and Timon will exemplify the written reasoning of the whole group and in section 3.2.1-4 we will discuss their oral reasoning. Below we show their answers to the three essay questions.

The Growing tree (“Where does the biomass come from?” question 9, Appendix 1)

Jonas: *Carbon by means of taking in carbon dioxide and using the carbon to build up itself and then it gets nutrients from the soil that it also uses to build up itself.*

Sara: *It comes from the air. The tree needs carbon dioxide to grow and the bigger it gets it will need more carbon dioxide… so the air and the sun’s energy is the tree’s ‘food’.*
Sune: The 250 kilos come from the plant’s photosynthesis. The glucose that is caught is partly used by the plant to build itself up.

Evelina: Energy from the sun.

Timon: The tree has picked up energy and carbon dioxide and formed it into glucose and oxygen. The plant eats of the glucose and transforms it into building blocks so the tree can grow.

All answers except Evelina’s was categorised as correct to this question. Her answer was categorised as not comprehensive. The not comprehensive answers could in the test sometimes render points by the teacher, but never up to a passing level. Timon had the most comprehensive scientific explanation and he also showed a willingness to explain in a holistic way.

The Polar bear (“Describe the journey of carbon atoms.” question 17, Appendix 1)

Jonas: A polar bear swam to Norway and found a wolverine that it bit in the leg. This passed the carbon atom to the wolverine and he started to migrate to Sweden where he found a female that he mated with and then it has been passed on through generations.

Sara: When the polar bear breathed out, the carbon atom flew away and in the end the wolverine breathed in the atom and the atom entered into the blood circulation and went to the paw.

Sune: The carbon atoms are spread in the wind and come to a flower in the Swedish mountains. Then a field mouse eats the plant and gets the carbon atom. The wolverine then eats the mouse and gets the atom.

Evelina: The polar bear breathed out it and the wolverine, later on, breathed it in.

Timon: No answer.

Timon did not answer this question but all the others tried to make a scientific answer. Sune was the only one who combined photosynthesis and respiration and explained it in a nearly correct way. Jonas had a long answer that was not comprehensive. His answer describes population ecology theories and not carbon recycling. It is possible that he did not understand the question but he tried (like in the Growing tree) to put the carbon atom in a meaningful context. Students that knew something about molecules and the transformation from one form to another, but did not fully explain, were categorised as not comprehensive (e.g. Sara). A correct answer, out of the 66 students, was: “the plant picks up the carbon atom → is eaten by the bird → the bird flies to Sweden → and the wolverine eats the bird → the wolverine gets the atom → it goes to the front paw”

The Terrarium (“What will happen in the jar if you do not open the lid?” question 20, Appendix 1)

Jonas: The plant dies.
Sara: *The plants die as they need carbon dioxide to live and when you put a lid on, there will be no carbon dioxide. That is why the plants die because they need carbon dioxide to make glucose and without carbon dioxide everything stops.*

Sune: *The plants grow slowly but surely since the oxygen and carbohydrates, made in the photosynthesis, are used in the respiration and there it’ll form carbon dioxide, water and energy that are used in the next photosynthesis and like that it goes on. Photosynthesis = Carbon dioxide + water + energy = oxygen + glucose.*

Evelina: *There will still be plants in it after five years.*

Timon: *It will get misty because they breathe out oxygen but it will not get out of the jar. There will be photosynthesis because there is…*

The answers of the students in the terrarium question were hard to categorise since the formulation “What will happen” did not insist upon any scientific explanation. An answer like “It will grow” or “It will stay the same” therefore generated a correct answer. Evelina’s answer was categorised as correct. Sara was categorised as not comprehensive though she tried to explain with the use of carbon dioxide. Sune was again categorised as correct, but his answer shows that he had difficulties in explaining and formulating an answer. Several students showed difficulties in explaining and understanding the questions with an essay character.

3.2 The reasoning during the interview

One third of the students taking the ecology unit were interviewed. At the start some of the students did not want to say anything or only said they knew nothing. They needed to be encouraged. They often started to talk about plants and photosynthesis and, unexpectedly, ecology was mentioned more seldomly.

The reluctant students started their reasoning about plants/photosynthesis during the third question and those who already had lost their thread were directed back to the subject with this question. When the students realised that they were allowed to use every-day knowledge, their must-give-the-right-answer-tendency was abandoned and new explanations that showed a broader understanding were used.

The explanations used were often a mix of school science and of their every-day experiences. Branches of pine and potatoes helped the theoretically weak students to find explanations often from a practical angle. For the theoretically competent students a potato in the hand gave an aha-reaction and satisfaction when he/she realised that photosynthesis and respiration were something more than a formula. The pedagogical experience and content knowledge of the interviewer helped the students to broaden and deepen their reasoning (cf. Schoultz et al. 2001).

The five interviews below show the reasoning and how the students often used two and sometimes three types of reasoning.

3.2.1 Linking together reasoning

The interview with Jonas was easy to accomplish since he was confident, easy to talk to, thoughtful and reflecting in his reasoning. He thought that the ecology unit had been interesting and he highly commended the practical parts with the excursion and the
experiments with plants. When he got a potato in his hand he directly connected the photosynthesis of the potato plant with the production of potatoes beneath the soil. Jonas connected scientific words and concepts to his every-day language and he only used linking-together reasoning.

J: It gets like a photosynthesis…
I: Yes what is that?
J: It’s like… when the plant mixes sunlight, water and air into energy… or not air, carbon dioxide and then transforms these into air and energy… I mean glucose.
I: Exactly, if you say that you have carbon dioxide in the mixture from start… what do you get afterwards?
J: Then it will only be oxygen. Because it makes use of the carbon dioxide, there, together with the energy…
I: Yes, what happens to the carbon dioxide?
J: I don’t know… it stores it?
I: Now you say that you got water, carbon dioxide and energy and then glucose and … is made…
J: Oxygen… then the carbon dioxide must go into the glucose.
I: Yes, why?
J: Because it is needed… in the glucose or otherwise in wont be glucose.

His explanation below of how a plant generates dextrose\(^1\) pastilles was easy and logically explained:

No, but it is like this… chemically… it is like made up of… like the scientists have…it’s like synthesised glucose… it’s not like an apple that is taken directly from the tree…they have used the apple and made pastilles from the apples.

Jonas reasoning sprawled but at the same time helped him progress in his understanding. His explanations were elaborated on during the guided interview and he needed help in his learning process.

Sara mostly used linking-together but also memory reasoning. Her knowledge about photosynthesis and respiration was well developed. She was self-confident and went on talking in a way that sometimes got things wrong. She used scientific language and wanted to explain difficult processes. During the interview there was only a need to ask about her statements and to split some of her "big" theories into smaller parts. She constantly tried to connect concepts to a context and she tried to create consistency.

I: Why are the plants important?
S: I mean, the plants create oxygen and humans need that… we need oxygen to live and if the plants wouldn’t be there we probably would have been created differently.
I: How is the oxygen made?
S: Hmm… that’s photosynthesis in these spruces and inside the vessels it’s created with like water and air and energy from the sun. Photosynthesis is created and the glucose comes out and at the same time oxygen comes too.
I: Hmm when you say comes out what do you mean?

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\(^1\) During the lessons the teachers mostly used the word grape sugar. Grape sugar and dextrose is the same word in Swedish and the students starts to think about the dextrose pastilles when grape sugar is mentioned. Glucose, carbohydrates, sugar, grape sugar, fruit sugar, dextrose etc. are words used during the lessons. In this paper we consistently use the word glucose when it is of little consequence for the context.
S: Eh... actually we have talked about oxygen coming through the stomata on the leaves but I am not sure about the pine-needles and I really don’t know at all how the glucose comes out. Actually it could not come just like this out in the air, could it? I don’t know... we haven’t talked about that.

I: Does the glucose come through the plants? Why do you think like that?
S: But, I have seen those dextrose pastilles... and then I thought that you could not possibly saw out them from the tree... or I do not know. In some way I think that it comes out.

Sara was interested and learned easily. The next excerpt, with her explanation of respiration about the glucose in the plant, shows that she relied on her memory.

It burns...or it solves oxygen and carbon dioxide and water again so it gets like three different parts again. And the water the tree drinks up... no like... and then... I think that it has something to do with the bark/cortex and that it goes out through the bark or something... evaporates through the leaves or something maybe?

This excerpt shows the difficulty in connecting and understanding all facts that are presented in textbooks and by the teacher. Sara seems to have mixed up things but follow-up questions showed that she could explain the concepts and how they were connected to the context. Sara was more confident than Jonas with the scientific concepts and could easily recall the formula for photosynthesis or respiration (memory reasoning) if she was asked to do so. She also got stuck to a greater extent than Jonas since she was more bound to what the books and the teacher had said. Sara’s concept knowledge and reliance on the words of books and teachers characterizes memory reasoning, as described in the next passage.

Of all 23 interviewed students there were eleven that mostly used linking-together reasoning. One memory and four school-weary reasoning students also partly used linking-together reasoning.

3.2.2 Memory reasoning
Sune used memory reasoning and only with guidance he realised that he had missed some crucial connections between concepts. He was seen as the cleverest boy in the class by both students and teachers. He was a bit bullied because of his proper and adult way of talking. He had, as he said, a good memory and his reasoning was characterised by telling correctly memorised formulas and concepts. He learnt during the interview. The next excerpt shows his reasoning:

I: How can photosynthesis help to become this spruce twig?
S: The spruce takes in CO₂ and H₂O and energy from the sun and transforms it into oxygen and glucose, where the glucose mostly is used to build up the trunk.
I: Could you tell me more... it doesn’t matter if you say something wrong.
S: But it’s like... water comes up through the roots and is transported in the trunk and the CO₂ gets in at the needles... at the stomata.

I: If you were to describe a potato... how does it become a potato?
S: Yes... I have no idea where the potato comes from, but I have heard that there is starch in it.
I: What is that?
S: It’s like long glucose molecules that take a longer time to combust than usual glucose.
I: How can it become starch in the potato?
S: Could it be like… that it takes in CO\textsubscript{2} and the sun’s energy into the plant above the soil and that the… the law of gravity takes it down to the potato?

When Sune got the question where in the body you need glucose he tried to come to the point, but after a while he came to the conclusion that he did not know. On the question “What is respiration?” he gave a perfect account for the formula, but then he claimed that he did not know where the respiration process takes place. When he was told to think about the word cellular respiration, genuinely surprised he said: Is it in the cells? It is notably that Sune did not know that respiration is a cellular process. He also encountered problems when he was told to put his knowledge into practice with, for example, the potato.

Of all the 23 interviewed students there were only four that mostly used memory reasoning (Figure 1). Another boy, the “most fluent ecology speaker”, used memory reasoning together with linking-together reasoning and one used it together with a great deal of school-weary reasoning (Figure 1). Four students mostly using linking-together and two mostly using school-weary reasoning, also partly used memory reasoning.

### 3.2.3 School-weary reasoning

Evelina said that she had no interest in science and that she had not understood the point in knowing or learning something about ecology. Evelina was a weak performer in school and without self-confidence. She said: I don’t know what to say … I know practically nothing. When she was asked to say something about what she remembered from the whole ecology unit she mentioned the stomata that she had looked at in the microscope, and seeds and ecosystems were also mentioned. The interviewer asked her what she meant by food and she answered:

Green houses and things… and animals like… that we had… then you always got food… if you let them breed and such … then it’ll get more and more.

A switch back to the stomata track tried to make her talk about plants and what they need. Five times she answered that she did not know, but the stubborn interviewer did not give up and then she suddenly just said: you mean carbon dioxide and water that the plants need followed by an explanation about the products. She forgot the oxygen but easily and directly complemented her answer when she was asked about it. An urgent ongoing reasoning made Evelina talk and she partly showed understanding of both photosynthesis and respiration. The next excerpt shows a “competition dialogue” often used in the interviews with the school-weary students:

I: Where is the sugar made before it comes to the apple?
E: I don’t know.
I: Yes you do.
E: Yeah, but from the tree then….
I: And where in the tree is it made?
E: Is it in the roots?
I: It is stored in the roots but in this case it is stored in the apple. Where is the glucose made?
E: I don’t know…
I: But you have told me before.
E: No not where it is made, no…
I: Where is the photosynthesis happening?
E: But, in the plant.
I: And… where about in the plant?
E: I don’t know…
I: Where did you say that the stomata were located?
E: In the leaves. …is the sugar made in the leaves too?

Evelina’s question of whether the sugar is made in the leaves shows how important it is to connect photosynthesis to living matter and to something concrete as an apple. Evelina, just like Sune, had missed where photosynthesis and respiration take place. They used two totally different ways of reasoning but both of them needed a discussion to better understand the processes.

Eight students mostly and three partly used school-weary reasoning (Figure 1). Evelina and five more students that did not pass the test showed understanding during the interview. It was difficult to interview these students but during the interview they displayed knowledge they did not know they were capable of.

3.2.4 Timon used all three reasoning types
Timon used his concept knowledge (memory) and he connected the concepts correctly (linking-together), but he answered a question only when he wanted to (school-weary). Many of the students that used school-weary reasoning required a wheedling and enticing way of interviewing not to get bored and tired of the whole thing. Timon was restless and in the interview he was bored after five minutes. His fast and often correct answers made the short fifteen-minute interview substantial. Timon’s behaviour during the lessons had made me believe that he knew and learned very little. I was incorrect because he was a quick learner. When asked to tell me something about the unit in the second question, he directly answered:

T: Carbon dioxide and water and energy from the sun give glucose and oxygen.
I: Was that what you remembered?
T: That’s just it. Photosynthesis…
I: What is the glucose used for?
T: Fruit, resin, cones and to give food. Because the plants eat it and then they grow. They grow because of the glucose but they also make cellulose, starch that is in bread, potatoes and trunks.

3.3 A comparison of the written and oral reasoning knowledge
Figure 1 shows how the three reasoning types were used by the 23 interviewed students. Each student is categorised according to final test (Appendix 1) results and to the most dominating oral reasoning type. The arrows mark the other types of oral reasoning that the students used. The boys are marked with a square and a Y and the girls are marked with a circle and a X. For example, Timon, the only student named in the table, used mostly linking-together reasoning and he received a passing grade. His use of both memory and school-weary reasoning are marked with two arrows. The figure is meant to show the diversity of the reasoning types used by the interviewed students.
The students often used two reasoning types during the interview. All students who used school-weary reasoning also used either linking-together or memory reasoning. Only one of the school-weary students passed the test. Students who used linking-together reasoning often showed better understanding during the interview than in test. These students tried to put everything in a context and they wanted to explain everything. This strategy often made them speculate and develop their own theories, a strategy that was not successful when taking the test. The students who used linking-together reasoning and succeeded well in the test reasoned sparingly and did not speculate. Some students, who used memory reasoning, scored high and could give correct definitions, showed surprising gaps when they orally tried to explain the consistency of concepts. School-weary students who used memory reasoning succeeded better than those who used their own explanations and made efforts to link together ideas. The students revealed much more understanding about photosynthesis and respiration during the interviews than in the written test.

All 23 interviewed students managed to explain the process of how photosynthesis works, but many of them needed some guidance to explain the process of respiration. Half of all interviewed students claimed that science is boring and all but one of those students used linking-together and school-weary reasoning.

Jonas used linking-together reasoning and his knowledge served him better in the interview than in the test. Sara’s oral explanation about what happens to the dextrose pastille showed a knowledge that she did not use in the written Terrarium question, for example. Sara’s oral reasoning was characterised by high concept knowledge that she always tried to put in a
context. Sara only got a passing grade in the test. Linking-together reasoning often generated lower grades than memory reasoning. Even so, there were students who only used linking-together reasoning and succeeded well in the test e.g. the female student who succeeded best of all in the test (Figure 1). She reasoned more sparingly than Sara and did not speculate. This girl’s closest male equivalent was the most fluent ecology speaker. He used more memory than linking-together reasoning. Sune’s memory reasoning with short and correct answers (often written formulas) was rewarded in the test and he received a pass with distinction grade. Evelina’s sun energy answer in the Growing tree scored zero and she did not pass the test, but in the interview she showed that she had more knowledge and understood better. There were only two students who, from their oral reasoning, could be categorised as weak achievers, and they partly used memory reasoning.

Timon’s answers in the three essay questions showed that he had understood photosynthesis. Why did Timon not answer the Polar bear question and why did not he elaborate his answer in the Terrarium question? Was it because he was stubborn and bored? In the interview he clearly explained that respiration happens in humans. In his written answer in question 10 (Fig. 2), the respiration process is correctly explained but, contradictory to his oral reasoning, he wrote that respiration only happens in plants. This answer also shows the danger with making respiration the inverse formula to photosynthesis (cf. Canal 1999).

| Describe respiration. Please draw to support your writing. (2p). |
| Oxygen + glucose → water + energy + carbon dioxide. Respiration is like photosynthesis backwards. |
| Does respiration take place in both plants and animals? Explain. (2p) |
| No, only in plants because they've got chlorophyll. |

Figure 2 Timon’s answer to question 10 (cf. Appendix 1). Answer in Swedish to the left.

4. Discussion

According to the literature, learning and understanding photosynthesis and respiration is difficult (Andersson 2008; Driver et al. 1994; Smith & Anderson 1984). An essential question is if it is possible to judge the understanding of a student from an answer in a written test? The students in this study took part in an ecology unit for about ten weeks. Their written tests showed more knowledge about photosynthesis and respiration than expected from Özay’s & Öztas’ (2003) study. The students, however, also showed more knowledge about both concepts than in the National Evaluation (NE) and in Driver et al.’s study 1994. Both the oral and the written reasoning of the students confirm better knowledge in photosynthesis than in respiration. The teachers’ greater focus on plants than animals during the ecology unit was probably one of the reasons for more knowledge in photosynthesis.

In the comparison with the NE (1992 & 2003), I found that 66 students had much better knowledge about photosynthesis than the students in the NE. I think that the large national and international evaluations (NE, PISA and TIMSS), which present students’ understanding about photosynthesis and respiration without any oral reasoning or connection to teaching and classroom context, underestimate students’ knowledge. Of course I do not know how motivated the students are to answer correctly in these big surveys.
Most of the students presented more knowledge in the guided interview compared to the written test. In the interview most of the school-weary students showed a will to link the concepts and they would have passed in an oral test. All of the 23 interviewed students showed ‘good’ oral qualifications in photosynthesis. But I also met students with good memory and high grades in the test that showed surprising gaps in understanding when they orally had to explain the formulas and put them in a context. There were also students who had succeeded quite well in the test and remembered nothing in the interview one or two weeks later. The students who succeeded best in the interview tried to put everything in a context and they wanted to explain everything. Unfortunately, this often made them speculate and develop their own theories that naturally were not successful in the test. This corresponds with the results from Schoultz et al. (2001). These students emphasised the importance of the communicative format. The traditional test situation in schools does not include the presence of a conversational partner and without that, the text of the problem can, for example, be difficult for the students to understand. The conversational partner can also help the students to resolve difficulties of a conceptual nature. Schoultz et al. concluded that the low performance on written tests appears to be a product of the absence of the communicative format. The results show the importance of a communicative partner for students’ understanding.

The low achieving students asked for emotional aspects, like ethical and practical dilemmas in the teaching to make it more interesting and the lack of such a discussion was probably one of the reasons for both their written and oral answering strategies. Slingsby & Barker (2003) claimed that biology teaching need to equip the students with ethical and emotional aspects to practice the social and scientific skills. I also found that a more complex reasoning in the interview made both high and low achieving students more interested, i.e. a formula interested a few students but the more complex explanation about how a carrot, potato or an apple ‘comes out of’ photosynthesis interested all 23 teenagers. This corresponds with Delpech (2002), who asked for more practical fieldwork and to allow more flexibility in the students’ answers. Magntorn and Helldén (2007) mentioned the importance of taking primary students out to engage them and acquire better understanding. Teenagers also need to get out, but the opportunity to discuss authentic matter in the classroom and thereby interest students more and allow them to gain deeper understanding could be even more important.

One conclusion is that learning and understanding photosynthesis and respiration is not as big problem as concluded from big surveys. If the students are given the opportunity to reason with their teachers and classmates, to use fewer formulas, and, when using formulas, to connect them to concrete material, such as branches and fruits, they will achieve better understanding. This corresponds to learning theories that present both every-day language and scientific language as essential for a deeper understanding.

5. References


Appendix 1

**Ecology test in the 8th grade**

1. In the textbook the word ecology is described as "the theory about the house". Explain what the word ecology means. 1p

2. Karin fills up a plastic bag with usual air (air is a mixture of gases). Then she puts the plastic bag over the potted plant and ties it round the stem as shown in the figure below. The seal is fully airtight. The plant is put in darkness for a whole night. The following are some statements about what happens to the air mixture in the plastic bag. You are going to put an R after a right statement and an F after a false statement. 1p

   i. The amount of oxygen increases  
   ii. The amount of oxygen decreases  
   iii. The amount of oxygen stays the same  
   iv. The amount of carbon dioxide increases  
   v. The amount of carbon dioxide decreases  
   vi. The amount of carbon dioxide stays the same

![Diagram of a plant in a plastic bag](image)

3. Name two examples of eco systems. 1p

4. Mention two things that, besides animals and plants, have an effect on an ecosystem. 2p

5. Which one/ones of the following food chains are correct? 1p for right, and minus 1p for wrong, answer. The question generates minimum 0p.

   b) Pine --- bug --- woodpecker --- moose ---
   c) field-mouse --- fox --- golden eagle
   d) plant plankton --- zoo plankton --- dragon fly larva --- perch
   e) zoo plankton --- plant plankton --- fry --- pike
   f) birch --- plant-louse --- ladybird --- willow warbler

6. What is meant by a population? 1p

7. a) What is the process in which the green plants capture light called? 1p

   b) Why do raspberries that get more sun light taste sweeter than the ones that have been in the shade? 2p

   c) What is the green pigment in plants called? 1p
8. You have an elodea plant in a test tube beneath a shining lamp. What gas comes like bubbles from the plant? 1p

9. A small tree is planted on a meadow. Twenty years later it has grown into a big tree. The tree has grown taller, the trunk has grown thicker. The tree has many leaves, branches and big roots. The tree weighs 250 kilos more than when it was planted. Where do these 250 kilos come from? Explain your answer as fully as possible. 3p

10. a) Describe respiration. Please draw to support your explanation. 2p

   b) Does respiration take place in both plants and animals? Explain. 2p

11. a) What purpose do decomposers serve in the ecosystem? 2p

   b) Give two examples of decomposers. 2p

12. What is an animal on the last level of a food chain called? 1p

13. a) What is meant by symbiosis? 1p

   b) Name an example from the nature. 1p

14. a) Describe soil humidity in a biotope where almost only pine trees grow. 1p

   b) Name two examples of plants that you can find in a pine forest. 2p

   c) Name two examples of plants that you can find in a spruce forest. 2p

15. What do you know about the soil in the pine forest? 1p

16. a) Why do the lakes have a seasonal thermocline? 2p

   b) Which seasons is the lack of oxygen in the lakes a problem? 2p

17. In the exhalation air from a polar bear on Greenland there are molecules of carbon dioxide. We are interested in the carbon atom in one of these molecules. Many years later this special carbon atom is found again in the front paw muscle of a young wolverine in the Swedish mountains. Describe as carefully as possible the carbon atom’s journey from the polar bear to the wolverine’s paw. 4p

18. Why are there so few top-level predators in an ecosystem compared to plants? Explain as carefully as you can. 3p

19. Use the figure and explain the oxygen and carbon cycles in nature. Please draw arrows that elucidate your description. Use the following words: oxygen, fox, hare, water, carbon atom, grass, respiration, air, glucose, carbon dioxide and decomposers. 4p
20. You take a glass jar with a lid and put some soil in it. Soil usually has fungus and bacteria in it. You plant some green plants and add water to get humidity. Then you put on the lid and put the jar in a lit place. What will happen in the jar if it is standing there for five years without opening the lid. 4p