Chapter 6
Understanding Photosynthesis and Respiration: Is It a Problem? Eighth Graders' Written and Oral Reasoning About Photosynthesis and Respiration

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6.1 Introduction

At the senior level of the 9-year compulsory schooling in Sweden, photosynthesis and respiration play an important part in biology curricula. One important objective is that the student, at the end of year 9, 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). Other objectives are to develop knowledge about organisms and their interplay with the environment and to understand cell and life processes, so knowledge about photosynthesis and respiration is essential (ibid).

Students at almost all school levels, from 9 to 19 years of age, show difficulties in understanding photosynthesis and respiration, and there also seems to be a fundamental lack of understanding of basic ecological concepts, for example, energy flow in ecosystems, including the role of photosynthesis and respiration for life on earth (Canal 1999; Marmaroti and Galanopoulou 2006; Wood-Robinson 1991). Research 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 and Anderson 1984). Understanding of photosynthesis depends on understanding particle theory, changes of phase and transformation, concepts that students have difficulty grasping (Carlsson 1999). According to Barak (1999), teaching focuses mainly on learning words at the expense of the understanding of concepts and the life processes. When photosynthesis is not truly understood, the students tend to

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use rote memorization as a strategy, and their knowledge is not meaningful (Canal 1999). Understanding complex topics in ecosystems requires deep understanding of concepts like photosynthesis and respiration and how to relate them to the whole system (Helldén 2005; Hogan and Fisherkeller 1996; Magntorn 2007). Thus, learning about ecology provides an opportunity for students to relate photosynthesis and respiration to the whole system. Even so, results from Özay and Öztas (2003) show that students aged 15 did not understand photosynthesis after learning about ecology.

Many of the above-mentioned difficulties are demonstrated in results from high stakes testing. Written tests are a common way to evaluate students' knowledge both in school, National Evaluations (NE) (NE 1992, 2003), and international surveys (TIMSS and PISA). However, one question is whether these surveys accurately reflect the knowledge of the students. Schoultz et al. (2001) showed how students' difficulties in answering two items from a TIMSS' test were easily addressed in an interactive setting where the students discussed and answered the TIMSS' items together with the researcher, and they expressed doubts if these items actually tested conceptual knowledge.

According to Andersson (2008), both everyday language/thinking and scientific language/thinking play a crucial role in understanding science. It is important for students to learn how to move between everyday and scientific thinking. Andersson's assertion is based on empirical data and Piaget's and Vygotskij's theoretical descriptions about everyday and scientific knowledge. Using living plant material as artefacts in teaching is a way to attain an ecological interest and understanding and provides good learning opportunities about photosynthesis in early grades (Helldén 1992; Näs and Ottander 2008; Vikström 2005). Vikström used the life cycles of plants, seeds and angiosperms to demonstrate how 7- to 12-year-old students developed complex understanding of photosynthesis when their teachers used language that included metaphors and when they pointed out critical aspects, like how the sugar is needed and used in the plant. Magntorn and Helldén (2007) described a 'bottom-up' perspective in teaching primary students about ecosystems, which took, as a starting point, the freshwater shrimp, an organism in a river ecosystem near the children's school. By connecting the environment and other organisms' dependence on the freshwater shrimp, the students gained an interest in and acquired a better understanding of many ecological concepts and processes.

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 and Slingsby 1998; Delpech 2002; Driver et al. 1994; Feinsinger et al. 1997). Delpech pointed out that it is important for the teacher to give students opportunities to express their knowledge in ways beyond memorised facts. According to Slingsby and Barker (2003) biology teachers need to include ethical and emotional aspects in their practice to enhance new factual knowledge. They also suggested that 'once the students have been taught the science they need to be put in the place of someone who has just discovered they have cancer or they need to consider how climate change could effect them' (p. 5).

Enquiry-based teaching, group work, outdoor education and ethical and emotional discussions need supportive and experienced teachers if the students are to learn and understand difficult science concepts (Delpech 2002; Näs and Ottander 2009; Vikström 2008).

Probing students' reasoning gives a teacher interesting insights into their understanding and thoughts (Driver et al. 1996; Mortimer and 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 and colleagues used items from TIMSS and could therefore compare the understanding the students showed in a communicative format to the understanding measured in TIMSS' assessment.

This chapter focuses on students' written and oral knowledge and reasoning about photosynthesis and respiration before and after ecology instruction. The following questions are addressed:

What knowledge about photosynthesis and respiration do the students demonstrate in written tests and in a guided interview?

How does the reasoning of students differ in a written test and in a guided interview?

6.2 Method

6.2.1 The Ecology Unit

The ecology unit ran for 10 weeks with each class having 33 h of lessons. Table 6.1 presents the activities during the ecology unit, and results from the parts in bold are presented in this chapter.

6.2.2 Students and Teachers Involved

Three eighth grade classes and their two teachers participated in the study. The teachers managed all lesson plans and the teaching. The teachers described the classes as two normal classes and one problematic one. One teacher taught the problematic class (18 students) where most of the students were disruptive and not focused on the school work, while the other teacher taught the other two classes (24 and 27 students, respectively) where most of the students were interested in their school work. The students had been taught photosynthesis and respiration in sixth and seventh grades, but the teachers wanted to reinforce the content in the ecology unit. In line with Swedish ethical requirements (The Swedish Research Council 2002), all students and their parents were asked for permission to allow me to observe the lessons and for the follow-up interviews.

Table 6.1 Time used at each part, teachers' lesson plans and the researcher's data acquisition

Week and time used	Activities carried out in each of the three classes	Data acquisition
1–2, 6 h	Introduction to ecology with cultivation and group work about leaving earth and the survival on a space shuttle	Observation notes in all the three classes
3, 3 h	Theory lessons in ecology and group work as a preparation for the excursion to the forest biotope. **Pre-test questionnaire** (Andersson et al. 2009). $n=59$	Observation notes and 59 collected questionnaires
4, 6 h	The excursion and supplementary group work	Observation notes
5, 3 h	Supplementary work with excursion material and theory lessons	None
6–8, 9 h	Theory lessons with ecology, photosynthesis and respiration content carried out in lectures, group work and individual work with questions from the textbook interspersed with demonstrations and laboratory work	Observation notes and audiotaped discussions partly transcribed
9	Autumn holiday	None
10, 3 h	Review of the ecology content	Observation notes
11, 3 h	Repetition lessons before test and one lesson's **written test (post-test, mostly teacher constructed, Appendix) as an examination of the whole ecology unit**	Observation notes, 66 collected and copied tests
14–16, 12 h	**Interviews with 23 students**	Audiotaped interviews fully transcribed

6.2.3 The Pre- and Post-test and Analysing Strategies

This chapter reports the results of responses to three essay questions (questions 9, 17 and 20, Appendix) which were included in both pre- and post-tests. These questions are part of a workshop used in Swedish in-service training courses on the Internet, NORDLAB-SE (Andersson et al. 2009). The pre-test was given to 59 students in the third week just before the ecology and photosynthesis/respiration lessons started (Table 6.1). There were altogether 69 students, but non-attendance and illness were the reasons that 59 students did the pre-test and 66 did the post-test. The written answers were analysed and categorised with three aims:

– To examine the written reasoning of the students
– To compare the written answers with the results of two National Evaluations[1] (NE)
– To compare the written reasoning of 23 interviewed students with their oral reasoning

[1] Three thousand one hundred Swedish students in 1992 and 620 students in 2003. http://www.skolverket.se/

Table 6.2 The interview guide

Question	My aim
Tell me something about yourself!	To get to know and make them relax
Tell me something about the unit you just have finished. Do you remember anything in particular?	To talk about the ecology unit by letting the students mention the science words, processes or concepts
Do you remember the space shuttle? If you were told to do it now, would you change your equipment and plans?	To mention an actual part of the teaching like the space shuttle and to investigate their knowledge about that part
What do you think about photosynthesis? Is it important? Where is oxygen used? What is respiration?	To make them start reasoning about photosynthesis and respiration
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?	To see if they could use their knowledge about photosynthesis and respiration with a plant or a fruit in their hands

Three answer categories were constructed: (1) correct, (2) not comprehensive and (3) no or irrelevant answer (cf. Tables 6.3 and 6.4). These three categories were an amalgamation of the National Evaluation's (1992, 2003) nine categories used on the essay question 'the growing tree' (question 9, Appendix). This study's 'correct' category correspond to the two first categories of NE, where the passing grade required carbon dioxide in the answer, perhaps in any combination with nutrition, water and sun energy, and the pass with distinction grade required a more scientific explanation. The NE used five categories to differentiate answers where the students tried to explain but used the science words and concepts both incorrectly and incompletely or fragmentarily in diverse combinations. In this study, these five categories were united into one 'not comprehensive' category since these answers corresponded to attempts to give a correct answer. The third category used in this study was a 'no answer' or 'other' category, so the incorrect answers in this study are described by the 'not comprehensive' and 'no answer' or 'other' categories. All answers to the three essay questions (the growing tree, the polar bear and the terrarium) are categorised and analysed in the same way.

6.2.4 The Interviews

Twenty-three students were interviewed on their understanding of photosynthesis and respiration and how the ecology unit was taught, on a voluntary basis. The composition of the interviewed group corresponded to the three classes' diversity and composition of strong and weak students. 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 6.2. During the semi-structured interviews, the students were encouraged to explain their reasoning and deviation from the guide occurred when unexpected threads were pursued.

6.2.4.1 Analysis of the Interviews

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 to gain insights into the students' thoughts and knowledge. The reasoning capacity of the students was continuously interpreted (Bogdan and Biklen 2003; Erickson 1986). Kvale's (1996) first three steps in the analysis of qualitative interviews (pp. 189–190) were used: (1) the interviewee's short description of herself, (2) the interviewee finds out new ways of thinking or understanding connections and (3) the interviewer tries to help the interviewee to focus and elaborate on what they said during the interview (Table 6.2). The interpretation of the reasoning of the interviewee started with the transcription of the audiotaped interviews and then continued with its categorisation (i.e. Kvale's fourth step). The transcripts were read many times with an aim to understand each student's reasoning. Some of the interviews were also read and interpreted by another researcher to ensure similar interpretations. In the beginning, the interviews of the boys and girls were analysed separately. As more gender similarities than differences were noted, the interviews of the boys and girls were analysed together. The reasoning categories used in the analyses are:

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 the science content and lessons were boring.

6.3 Results

6.3.1 Written Knowledge

Table 6.3 displays how the students answered the essay questions in the pre- and post-tests. The questions dealt with photosynthesis (the growing tree) and carbon recycling (the polar bear and the terrarium). Overall, the written responses to the growing tree and the terrarium questions were better formulated than the polar bear question (cf. 6.3.1.1). More than three times as many students did not give an answer or gave an irrelevant answer in the polar bear question compared to the other two questions.

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 and the terrarium question did not produce the same steep increase, but the increases, 18% and 15%, respectively, were evident. The figures indicate that students enhanced

Table 6.3 The students' pre- and post-test answers in the questions 9, 17 and 20 (Appendix)

Category	Growing tree		Polar bear		Terrarium	
Pre and post	Pre	Post	Pre	Post	Pre	Post
Correct	22%	59%	16%	34%	37%	52%
Not comprehensive	56%	29%	25%	24%	33%	33%
No or irrelevant answer	22%	12%	59%	42%	30%	15%

Table 6.4 The results from the question about the growing tree in the NE (1992) and (2003)

Category	1992 ($n=3{,}103$)	2003 ($n=620$)
Correct	5%	8%
Not comprehensive	73%	47%
No or irrelevant answer	23%	45%

their knowledge of both photosynthesis and respiration, but respiration was more difficult to explain or understand. In the 'not comprehensive' category, there was a sharp decrease in the growing tree question, whereas the polar bear and the terrarium question did not alter. There were more than three times as many students that gave no or an irrelevant answer in the polar bear question (42%) in the post-test compared to the growing tree (12%) and the terrarium questions (15%).

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 (Table 6.3) compared to the results of the same question on the NE (Table 6.4). The high percentage in the no or irrelevant category in the NE of 2003 is also worth noting. The NE are distributed to the schools any time during the year, and the students are in the same age as the students in this study, but the topics (e.g. photosynthesis and respiration) have not necessarily been taught immediately before the NE so the results from the NE and this study may not be a fully fair comparison.

6.3.1.1 Written Answers to the Three Essay Questions

Five students' written answers in the post-test are shown below. In Sects. 6.3.2.1, 6.3.2.2, 6.3.2.3 and 6.3.2.4, these students' oral reasoning is reported.

The growing tree: 'Where does the biomass come from?' (question 9, Appendix)

To the growing tree question, all answers except Evelina's was categorised as 'correct'. Her answer was categorised as 'not comprehensive'. The 'not comprehensive' answers could be given points by the teacher but never up to a passing level.

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 k 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 off the glucose and transforms it into building blocks so the tree can grow.

The polar bear: 'Describe the journey of carbon atoms' (question 17, Appendix)

Timon did not answer the polar bear question, but the other students tried to give a scientific explanation. Sune was the only one who combined photosynthesis and respiration and gave a correct explanation. Jonas gave a long answer categorised as 'not comprehensive'. His answer described population ecology theories but 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. Student responses that indicated some knowledge of molecules and the transformation from one form to another, but did not correspond to a full explanation, were categorised as 'not comprehensive'.

Jonas: A polar bear swam to Norway and a wolverine there bit it 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.

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.

The terrarium: 'What will happen in the jar if you do not open the lid?' (question 20, Appendix)

The students' answers in the terrarium question were difficult to categorise since the formulation 'What will happen' did not depend upon any scientific explanation. Evelina's answer 'There will still be plants in it after five years' therefore was deemed as a correct answer although that answer did not describe any understanding of carbon recycling. Sara's answer was categorised as 'not comprehensive' though she tried to explain with the use of carbon dioxide. Sune's response was again categorised as correct.

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.

6.3.2 Reasoning During the Interviews

One third of the students taking the ecology unit were interviewed. At the start, some of the students did not want to say anything, and they needed encouragement to do so. However, when they realised that they were allowed to use everyday knowledge in their reasoning and explanations, using a mix of school science and everyday experiences, they started to show that they had an understanding of the concepts. Branches of pine and potatoes helped the weaker students to construct explanations, and the more competent students had 'aha' moments when they realised that photosynthesis and respiration were something more than just formulas. During the interview, the experience of the researcher helped the students to broaden and deepen their understanding (cf. Schoultz et al. 2001). Parts of the interviews below show how each student often used two types of reasoning (cf. Fig. 6.1) in their explanations.

6.3.2.1 Linking-Together Reasoning

The interview with Jonas was easy to conduct since he was confident, easy to talk to, thoughtful and reflective in his reasoning. He said that the ecology unit had been interesting and he highly commended the practical parts such as the ecology excursion in the woods and the experiments with plants. When he held a potato in his hand, he directly connected the photosynthesis of the potato plant with the production of potatoes beneath the soil. Jonas used both scientific and everyday language in his explanation.

In the excerpts, the interviewer (=I) and the student's first letter, for example, Jonas (=J)

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?*

His explanation below of how dextrose[2] pastilles were produced from plants was easily 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.*

[2] During the lessons, the teachers mostly used the word grape sugar. Grape sugar and dextrose are the same words in Swedish, and the students start 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 chapter, we consistently use the word glucose when it is of little consequence for the context.

Sara mostly used linking-together reasoning with some memory reasoning. Her knowledge about photosynthesis and respiration was well developed. She was confident but went on talking in a way that sometimes muddled things up. She used scientific language and wanted to explain difficult processes. During the interview, there was a need to ask her to elaborate on her statements and to split some of her ‘big’ theories, like the whole plant life cycle, into smaller parts:

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?
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.*

The next excerpt on how respiration is related to the glucose in the plant shows the difficulty that students have connecting and understanding all facts that are presented in textbooks and by the teacher:

> *It burns…or it dissolves 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?*

Sara seemed to be confused but her answers to the follow-up questions showed that she could explain the concepts and how they were connected to the context. Sara was more confident than Jonas in explaining the scientific concepts and could easily recall the formula for photosynthesis or respiration (memory reasoning). However, she also faced more problems clarifying her thoughts than Jonas, since she was more bound to what the books and the teacher had said. Sara’s conceptual knowledge and reliance on the words of books and teachers characterise memory reasoning, as described in the next section.

Of all 23 interviewed students, there were 11 that mostly used linking-together reasoning. One memory and four school-weary reasoning students also partly used linking-together reasoning (see Fig. 6.1).

6.3.2.2 Memory Reasoning

Sune used memory reasoning and only with guidance did he realise that he had missed some crucial connections between concepts. He had, as he said, a good

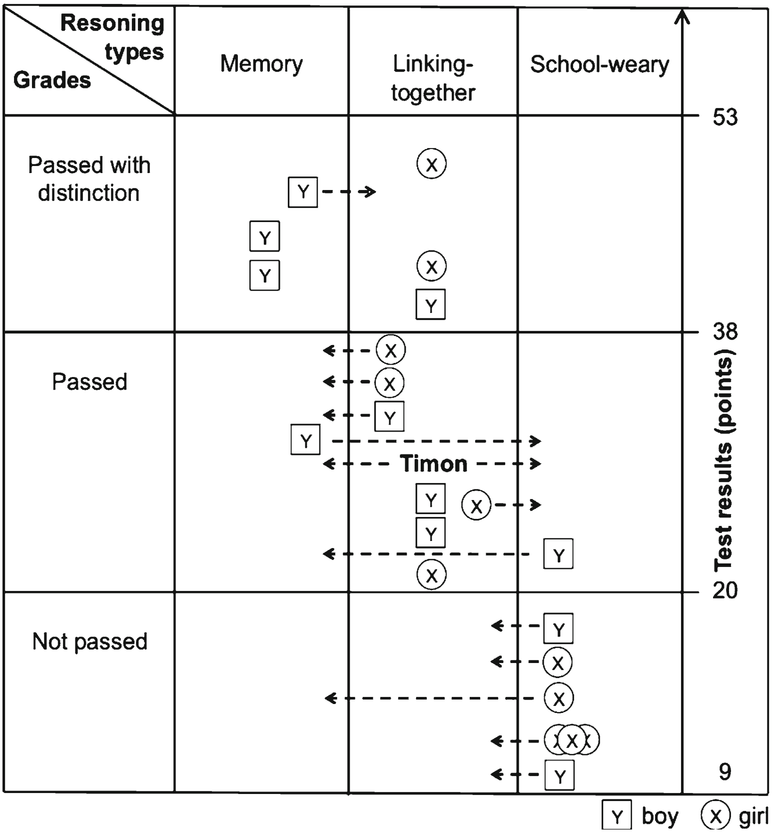

Fig. 6.1 Twenty-three students' use of reasoning types, their test results and grades

memory and his reasoning was characterised by memorised formulas and concepts. Nevertheless, he showed that he had understanding of processes involved in photosynthesis as illustrated by the following excerpt:

I: How can photosynthesis help to become this spruce twig?
S: *The spruce takes in* CO_2 *and* H_2O *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* CO_2 *gets in at the needles … at the stomata.*

Sune struggled with the question of where glucose was required in the body for a while before he concluded that he did not know. On the question 'What is respiration?', he gave a perfect account for the respiration formula but then claimed that he did not know where the respiration process took place. When he was told to think about the word, 'cellular respiration', genuinely surprised he said, 'Is it in the cells?' It is notable that Sune did not know that respiration is a cellular process. He also encountered problems when he was told to use his knowledge of photosynthesis to explain the creation of the potato. Of the 23 interviewed students, only four mostly used memory reasoning (see Fig. 6.1). Four students, who mostly used linking-together reasoning and two who mostly used school-weary reasoning, also partly used memory reasoning.

6.3.2.3 School-Weary Reasoning

Evelina said that she had no interest in science and that she had not understood the point in knowing or learning about ecology. Evelina was a weak performer in school and in the interview said that she did not know what to say as she knew 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 with the microscope, and seeds and ecosystems were also mentioned. The researcher tried to make her talk about plants and what they need. At least three times, she answered that she did not know, but then suddenly said 'You mean carbon dioxide and water that the plants need', followed by an explanation about the products. She forgot the oxygen produced initially but easily stated it when she was asked about it. The ongoing discussion encouraged Evelina to talk and she showed some understanding of both photosynthesis and respiration:

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 was made in the leaves showed how important it was to connect photosynthesis to living matter and to something concrete such as an apple or a branch. Evelina, just like Sune, did not realise where photosynthesis and respiration took place. Though they used two totally different ways of reasoning, they needed to engage in a discussion to better understand the processes.

Eight students mostly and three partly used school-weary reasoning (Fig. 6.1). It was difficult to interview these students as they constantly replied that they did not know the answer but during the interview they displayed some knowledge of the topics discussed.

6.3.2.4 Combination of All Three Reasoning Types

Timon was able to recall the concepts taught (memory) and he managed to link the concepts correctly (linking together), but he answered a question only when he wanted to (school weary). When he was asked to say something about the ecology unit, he skipped the ecology part and 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.*

Many of the students that used school-weary reasoning required a 'wheedling and enticing' way of interviewing to prevent them from getting bored; Timon was restless and bored after 5 min. His fast and often correct answers made the short 15-min interview substantial.

6.3.3 A Comparison of the Test Results and the Oral Reasoning

Figure 6.1 shows the diversity of the reasoning types used by the 23 interviewed students. Each student is categorised according to final test results and to the most dominant 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 an *X*. For example, Timon, the only student named in the figure, used mostly linking-together reasoning, and he received a passing grade. He also used memory and school-weary reasoning, and these are marked with two arrows.

Figure 6.1 shows that the students who used school-weary reasoning also used either linking-together or memory reasoning. Only one of the school-weary students passed the test. School-weary students who used memory reasoning, for example, the school-weary boy (*Y*) who passed the test, succeeded better in test than those who used their own explanations and made efforts to link together ideas. 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, could give correct definitions and scored high in the test. However, they showed surprising gaps when they tried to explain the relationship between concepts in the interviews.

The students revealed much more understanding about photosynthesis and respiration during the interviews than in the written test. All 23 students managed to orally explain the process of how photosynthesis works, but many of them needed some guidance to explain the process of respiration. Jonas used linking-together reasoning, and his knowledge served him better in the interview than in the test. Sara's oral explanation was characterised by high concept knowledge that she always tried to put into a context. Her reasoning lost focus in the written questions, and she only got a passing grade in the test. Even so, there were students who only used linking-together reasoning and succeeded well in the test, for example, the female student who obtained the highest marks in the test (Fig. 6.1). She reasoned more sparingly than Sara and did not speculate. This girl's closest male equivalent was the one who explained ecology processes most fluently but 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 did not pass the test, but in the interview she showed that she had more knowledge and understood better that what her test result indicated. There were only two students who, from their oral reasoning, could be categorised as weak achievers, and they partly used memory reasoning.

6.4 Discussion

According to the literature, learning and understanding photosynthesis and respiration is difficult (Andersson 2008; Driver et al. 1994; Smith and Anderson 1984). An essential question is whether it is possible to judge the understanding of a student from an answer in a written test. In this study, Timon's answers in the three essay questions indicated that he had understood photosynthesis. Why did Timon not answer the Polar bear question and why did he not elaborate his answer in the Terrarium question? In his written answer, the respiration process was correctly explained, but, contradictory to his oral reasoning, he wrote that respiration only happens in plants.

The students in this study took part in an ecology unit for about 10 weeks, and their written tests showed that they increased their knowledge of photosynthesis and respiration more than expected, when compared to results from the study by Özay and Öztas (2003). The students also showed greater knowledge of both concepts than students in the NE and in the study by Driver et al. (1994). Their written reasoning confirmed better knowledge in photosynthesis than in respiration which may be attributed to the two teachers' greater focus on plants than animals during the ecology unit.

In the comparison with the NE (1992, 2003), the pre-test results in this study also showed that the students had much better knowledge about photosynthesis than the students in the NE. The large national and international evaluations (NE, PISA and TIMSS) which present students' understanding about photosynthesis and respiration without any connection to the ongoing teaching and the classroom context may not adequately measure students' actual knowledge. A long time could have passed since the content was learned, students may have difficulties interpreting the questions or the students may not be motivated to answer adequately and correctly in these large surveys. Questions or tests connected to the ongoing teaching in the classrooms are a fairer way to evaluate students' knowledge.

Most of the students demonstrated deeper knowledge in the guided interview compared to the written test. The interviewed school-weary students managed to link the concepts, and they would have passed in an oral test. All of the 23 interviewed students showed adequate understanding of photosynthesis. But there were also students with good memory and high grades in the test that showed surprising gaps in understanding when they had to orally explain the formulas and put them in a context. One of the boys who used memory reasoning and succeeded quite well in the test did not remember anything in the interview 2 weeks later. The students who succeeded best in the interviews tried to put everything in a context, and they wanted to explain everything. Unfortunately, these students often speculated and developed their own theories that were not acceptable in the test. The traditional test situation in schools does not include the presence of a conversational partner, and without that, the text of the problem can be difficult for the students to understand. The conversational partner can help the students to resolve difficulties of a conceptual nature. Schoultz et al. (2001) concluded that the low performance on written tests appears to be a product of the absence of the oral communicative format. Results of this study add strength to the importance of a conversational partner to assess students' understanding.

A chemical formula of photosynthesis or respiration interested a few students, but the complex explanation about how a carrot, potato or an apple 'comes out of' photosynthesis made all 23 teenagers more interested in the difficult processes. This kind of more complex reasoning during the interview made both high and low achieving students more interested in knowing more about the life cycle of plants. This corresponds with the findings of Delpech (2002), who asked for more everyday examples to be included in teaching and to allow more flexibility in the students' reasoning, like speculations and wondering questions beyond the content of the lesson or the textbook. The low achieving students in this study asked for emotional aspects, like ethical and practical dilemmas, in the lessons, to make it more interesting. During the interview, these students started to show their actual knowledge about plants when they realised the importance of plants to life. This is in line with Slingsby and Barker (2003) who claimed that biology teaching need to equip the students with ethical and emotional aspects to learn social and scientific skills.

6.4.1 Conclusion

Written tests alone may not give an adequate indication of students' understanding of science; students need to be given opportunities to be assessed orally as well to clarify what the questions mean and explain their understandings. Developing a deep understanding of photosynthesis and respiration may not be as unattainable as indicated by international surveys if students are given the opportunity to reason with their teachers and classmates and, when using chemical formulas, to connect them to concrete material, such as branches and fruits. This corresponds to learning theories that argue for both everyday language and scientific language as essential for a deeper understanding of science.

Appendix

(*Ecology test in the eighth grade – only contains the questions with a content of photosynthesis and respiration)*

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. 1*p* (*p* = scores in the test):

(a) The amount of oxygen increases
(b) The amount of oxygen decreases
(c) The amount of oxygen stays the same
(d) The amount of carbon dioxide increases
(e) The amount of carbon dioxide decreases
(f) The amount of carbon dioxide stays the same

7. (a) What is the process in which the green plants capture light called? 1*p*
   (b) Why do raspberries that get more sun light taste sweeter than the ones that have been in the shade? 2*p*
   (c) What is the green pigment in plants called? 1*p*
8. You have an elodea plant in a test tube beneath a shining lamp. What gas comes like bubbles from the plant? 1*p*
9. A small tree is planted on a meadow. Twenty years later, it has grown into a big tree. The tree has grown taller and the trunk has grown thicker. The tree has many leaves, branches and big roots. The tree weighs 250 k more than when it was planted. Where do these 250 k come from? Explain your answer as fully as possible. 3*p*
10. (a) Describe respiration. Please draw to support your explanation. 2*p*
    (b) Does respiration take place in both plants and animals? Explain. 2*p*
11. What purpose do decomposers serve in the ecosystem? 2*p*
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. 4*p*
18. Why are there so few top-level predators in an ecosystem compared to plants? Explain as carefully as you can. 3*p*
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. 4*p*



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 5 years without opening the lid. 4*p*

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