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ABSTRACT

Based on the premise that multiple choice tests can be used as diagnostic tools for teachers in identifying and remedying student misconceptions, this study focused on the development of an instrument for diagnosing secondary students' understanding of photosynthesis and respiration. Information is presented on: (1) procedures of development of the two-tier instrument for assessing students' understandings of photosynthesis and respiration in plants; (2) test results based on administration to students of secondary schools from Perth, Western Australia; and (3) application possibilities for teachers in a classroom setting. Propositional statements representing the knowledge required to comprehend the mechanisms of photosynthesis and respiration are listed and sample questions from the instrument are included. Also identified are representative students' misconceptions from a series of pilot studies on photosynthesis and respiration in plants. (ML)

EVALUATING SECONDARY STUDENTS' MISCONCEPTIONS OF PHOTOSYNTHESIS AND RESPIRATION IN PLANTS USING A TWO-TIER DIAGNOSTIC INSTRUMENT

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INTRODUCTION

For the past decade there has been considerable interest in science misconceptions held by students. Initially this interest lead to research in science education which has resulted in a large body of phenomenological data which only recently has been more firmly supported by one or more theoretical foundations (see for example, Driver & Erickson, 1983; Osborne & Gilbert, 1984). The work reported in this study fits into the constructivist framework where the development of the items is based on actual student reasoning (see Treagust, 1985).

In most misconceptions research, the usual means for obtaining information about students' misconceptions has been through individual student interviews and/or open-ended response questions on specific science topics. Osborne and Gilbert (1980) and Watts (1981) have described a variety of interview formats or procedures for conducting these interviews. The two most commonly used procedures by researchers are interviews - about - instances and interviews - about - events. Some researchers such as Mitchell and Gunstone (1984) have used an interview format which is a mixture of these procedures.

Notable exceptions to this line of research have been multiple choice tests described by several authors such as Tamir (1971), Linke and Venz (1978, 1979), Helm (1980), Trembath (1984) and most recently by Halloun and Hestenes (1985). Only in the case of Tamir (1971) and Linke and Venz (1978) and Halloun and Hestenes (1985) were the tests related to any specified and limited content structure. The multiple choice tests by Helm (1980) covered a semester's work in college physics while that of Trembath (1984) covered a wide range of subject content areas in a variety of disciplines at the college level. In general, the methodology presented by these latter two authors who used a multiple choice test format appears to have been related to general subject matter taught and does not appear to have been pursued with any rigor in terms of the underlying conceptual knowledge of the subject matter.

The work by Tamir (1971) on an alternative approach to construction of multiple choice test items was innovative in that the distractors for the multiple choice items were based on students' answers to essay questions and other open-ended questions and addressed underlying conceptual knowledge related to a limited content area. As Tamir (1971, p.306) states "these alternative [responses] being representative of typical conceptions and misconceptions of students have a distinctive advantage as compared to regular test items for which professional test writers provide the alternatives." To these authors, it is surprising that Tamir's approach has not been pursued more actively in the past decade as interest in students' misconceptions has expanded.

In their multiple choice items, Linke and Venz (1978) dealt with the principles of structure of matter, changes of state and solubility and the basic principles of electricity. In their later study Linke and Venz (1979) examined students misconceptions of electromagnetic waves: light and heat, chemical reactions and motion and forces using multiple choice and free response items. The items, which contained distractors based on students identified misconceptions, were administered to non-science students in Years 11 and 12 and the general conclusion was that students completing secondary studies hold identifiable misconceptions or confused ideas.

In order to objectively evaluate first year college physics instruction, Halloun and Hestenes (1985) developed a physics diagnostic test which assessed students' basic knowledge of mechanics. The items were initially selected to assess the students' qualitative conceptions of motion and its causes and to identify common misconceptions already noted by previous investigators. Item distractors were chosen from students' responses identified as misconceptions on earlier tests.

The development of multiple choice tests on students' misconceptions has the potential to make a valuable contribution, not only to the body of work in the area of misconceptions, but also to assist in the process of science teachers more readily using the findings of research in their classrooms. It is well documented that research findings in science education take considerable time to be applied in the classroom. Further, if teachers decide to interview their own students to identify misconceptions, this practice itself is fraught with problems since not only is interviewing time consuming, it also requires substantial training.

One way for a teacher to more easily identify misconceptions held by a group of students would be to administer a pencil and paper multiple choice test which has items specifically designed to identify misconceptions and misunderstandings in a limited and clearly defined content area. Such a test could be used as a diagnostic tool and help the teacher to begin to remedy the misconceptions that exist based on earlier teaching and learning prior to commencing the topic or that have occurred following the teaching of the topic. It is, however, well documented that the task of changing misconceptions will not be easy since misconceptions have often been incorporated securely into cognitive structure (see for example, Ausubel, 1978; Driver, 1981; Gunstone, Champagne & Klopfer, 1981). Nevertheless, a teacher needs a starting place for addressing known misconceptions and a reliable and valid multiple choice diagnostic test incorporating students' reasoning in selecting responses would appear to provide a relatively straight forward method.

In examining related literature for this study, it was observed that the majority of research on students misconceptions has investigated physical science phenomena, fewer studies have reported research dealing with biological science phenomena. In the area dealing with students understanding of photosynthesis and respiration only four directly relevant research investigations were identified in the literature (Bell, 1984; Bishop, Roth & Anderson, 1985; Roth, Smith & Anderson, 1983; Wandersee, 1983). However, the first and third of these studies emphasised students' understanding of plant nutrition at the secondary level (aged 15 years) and fifth grade level respectively. In their work, Bishop et al. (1985) designed a teaching module to address misconceptions in photosynthesis and respiration of non-science college students who had an average of 1.5 years of previous high school and college courses. Wandersee (1983) reported on a cross-age study from elementary to college level where students were administered twelve tasks, each involving an experiment, a phenomenon or a situation that calls for a student response.

THE PURPOSE

The purpose of this paper is to (i) describe the development of a two-tier instrument to reliably and validly diagnose secondary students' understanding of photosynthesis and respiration in plants; (ii) discuss the findings when this instrument was administered to several classes of students in each of Years 8 - 12 from secondary schools in metropolitan Perth, Western Australia; (iii) describe implications from this research and illustrate how classroom teachers can use this instrument to improve the quality of and the approach taken to this area of science teaching.

PROCEDURES AND INSTRUMENTATION

Development

The development of the instrument to measure students' misconceptions about photosynthesis and respiration in plants was based on the procedure described by Treagust (1985). This procedure involved (i) the development of boundary conditions, to define the science content, in terms of propositional statements and concept maps, (ii) the development of items based on interviews, examination of the related literature, and open-ended pencil and paper measures, and (iii) the development of a two-tier diagnostic test. The first tier of each item is a multiple choice content question which relates to propositional statements and parts of the concept map. The second tier of each item consists of a multiple choice set of reasons for the answer given in the first tier. The set of reasons, which are based on students' responses to interviews, open-ended questions and/or previous research, consist of identified misconceptions and the scientifially acceptable answer.

Identification of Propositional Statements

Propositions were identified for students' understanding of the mechanism of photosynthesis (see Figure 1), the mechanism of respiration (see Figure 2) and the relationships between photosynthesis and respiration (see Figure 3). The level of understanding was as expected of students having studied the science syllabus described by the Education Department of Western Australia, which includes biological topics, in Years 8 - 10 (aged 13 - 15 years). All propositional statements were independently content validated by five experienced secondary biology teachers, two science educators and two tertiary biology lecturers. As a consequence, some propositional statements were eliminated and others changed to those shown in Figures 1-3. Certain propositions were retained which were part of the school syllabus to be taught even though these propositional statements were not addressed in this study.

Subjects

The administration of the instrument was conducted in regular class periods and was supervised by the authors. Four hundred and thirty eight students, -- 137 from Year 8, 88 from Year 9, 99 from Year 10, 68 from Year 11 and 49 from Year 12 -- completed the instrument. Students in Years 8 - 10 came from the same school, students in Years 11 and 12 came from three neighbouring schools with a similar socioeconomic background. In Western Australia, all students take science in Years 8 - 10. At the end of Year 10, only those students with average to above average grades are allowed to take science subjects in Years 11 and 12. Hence, students entering Years 11 and 12 are, on the average, more capable than those in Years 8 - 10. However, no data on intelligence or formal reasoning ability were collected to document this.

Instrumentation

In developing the final instrument, a series of five pilot studies about photosynthesis and respiration in plants were conducted by Haslam (1986) with secondary students from a range of grade levels. The pilot studies consisted of both an open discussion interview format and pencil and paper responses requiring an explanation for a given answer. Questions were of the type, "Explain what happens when plants respire?", "When do plants respire?", "How does a plant obtain food?", "When do plants photosynthesise"? Each pilot study was used to cross reference the types of student responses with the questions asked in the previous pilot studies. The students' misconceptions (or in some cases naive conceptions) are presented in Table 1 under eight categories; plant's use of light energy, function and nature of chlorophyll, role of water and stomates, role of carbon dioxide, role of oxygen, how plants obtain food, photosynthesis and respiration. Student responses to interview and paper and pencil pilot study questions highlighted the general false awareness of plants respiring only during the hours of darkness and photosynthesising during the day. Subsequently, these responses provided the focus for the development and refinement of the thirteen item, two-tier, multiple choice instrument, "What do you know about photosynthesis and respiration in plants?"

The first part of each two-tier diagnostic test item consists of a content question usually having two or three choices. The second part of each question contains a set of up to four possible reasons for the answer given in the first part. The reasons consist of the correct answer, and any identified misconceptions. This second part of each item in the test is developed from the students' responses on the reasons given in the pilot studies. Students are required to make one choice from the multiple choice response section and one choice from the multiple choice reason section for each question. Space is also provided for the student to give her/his own reason, when she/he has ideas different from the reasons provided in each of the 13 items. This opportunity for providing their own reason for a response minimises guessing and can illustrate how strongly a misconception is ingrained in the mind of the student.

The final instrument was content validated against the propositional statements, identified as being necessary for defining the science content, by means of a specification grid (see Table 2). The instrument reliability as measured by Cronbach's coefficient alpha was measured at 0.72 when both parts of the items were analysed. Difficulty indices ranged from 0.12 to 0.78, with a mean of 0.38, providing a wide range of difficulty in the items. Discrimination indices ranged from 0.36 to 0.60 with a mean of 0.48; most experts consider a discrimination index greater than 0.40 to be acceptable without need for further revision (Whitney, 1977). The reading age of the instrument, examined using Fry's Readibility Graph, was found to be between Years 7-8 level. Hence the diagnostic instrument is considered appropriate for any high school student from Years 8 to 12. Figure 4 summarizes the test characteristics.

RESULTS AND DISCUSSION

Student responses on each item were analysed by grade level and gender for the possible combinations of answer plus reason. Based on the total number of correct answers for both parts of each item there was a statistically significant difference between grades ($F=74.13$, $p<0.0001$). There were no gender differences and no interaction effects between gender and grade.

Each item was analysed as shown in Figures 5, 6 and 7 which illustrate items 2, 5 and 12. The percentage of responses is shown for each combination of content choice and reason for each grade level. For the purpose of this study attention was given to those responses selected by more than 10% of student groups (see Gilbert, 1977). Some items proved to be less effective than others in soliciting misconceptions in that many alternative reason responses were selected by less than 10% of students. Nevertheless consistency of misconceptions are identified throughout Years 8 to 11 particularly. Since a number of responses were selected by less than 10% of students in this sample, it is the authors' intention to omit these alternate responses from the next version of the diagnostic instrument. Few students used the opportunity to formulate their own response rather than use the alternatives provided.

In item 2 (see Figure 5), the concept investigated is the gas being taken in by plants when there is no light energy. The reasons here are as given by students in interviews and in open-ended pencil and paper questions. When the first part of the item only is taken into consideration (end column), the results show that there is decreasing, yet significant (>10%), response choice from Years 8-12 about which gas is taken in large amounts when there is no light energy at all. However, with each higher grade level there is less selection of the whole range of alternative choices in the second part of the item, though the correct selection remains a low selection until grade 12. These results together with those of other responses to items 3 and 8 (see Table 3) illustrate students' misconceptions and lack of understanding that respiration is an ongoing continuous process during both light and dark conditions.

During interviews with students and from responses on pencil and paper instruments in the pilot students, students gave a variety of answers for where they believed that respiration took place in the plant; some students said in all cells of the plant but others limited this to only in the leaves or only in the roots. As can be seen from Figure 6, more than 10% of the total students in Years 8 and 10 (end column) selected respiration taking place only in the roots. However, when the data in this item are examined more closely, there is some anomaly for say Year 8 where of the 10.2% of students who selected respiration of the roots only, half of the students (5.1%) gave a reason that all living cells need energy to live.

In Year 8, respiration is taught as an identified topic and the concept is used throughout the biology units in Years 9 and 10. It is hence somewhat surprising that more students in Year 8 (51%) believe that respiration takes place in every plant cell than is the case for Year 9 (38.6%) and Year 10 (41.1%). Even in Year 11, 38.2% of all students believed that respiration took place in the cells of the leaves only and gave a consistent reason (only leaves have special pores to exchange gas) for doing so. Only a small number of students retained this misconception in Year 12. While this item was designed based on students' responses to questions about location of respiration in plants, in a later version of this test, the item will be rewritten since a number of alternative responses are not attracting responses in the manner anticipated from interviews and from responses to pilot study pencil and paper items.

Item 12 (see figure 7) was designed to examine students' understanding of the process of photosynthesis with regard to the benefit for the plant. Three major ideas were put forward by students in the interviews and pilot studies, namely that photosynthesis was beneficial to plants since it removes carbon dioxide from the air, converts light energy to chemical energy and for the production of energy. Up until Year 12 (see end column) all three content choices were selected by at least 10% of the year: students in Year 8 (40.1%), Year 9 (38.6%), Year 10 (35.4%) and Year 11 (14.7%) selected the response that a benefit for the plant was removing carbon dioxide from the air. In our view this is a misconception which in this sample is being retained up until Year 11. Also even up to Year 12 (30.6%) a high percentage of students selected the restricted reason of photosynthesis providing energy for plant growth as the correct answer. By selecting such a response, students are overlooking other living processes of the plant that require energy.

The major misconceptions relating to students' understanding of photosynthesis and respiration in plants which were identified by the two-tier diagnostic test are shown in Table 3. The results illustrate how students' misconceptions about photosynthesis and respiration in plants are retained throughout secondary school years despite these concepts being taught each year as a topic, or as related to, or incorporated within, other topics. Further, the results highlight the consistency of students' thinking across year levels. For example, in item 2, of this sample of students, 27% in Year 8, 23.9% in Year 9, and 19.1% in Year 10 choose the response indicating that they believed that photosynthesis can occur when there is no light energy at all. In item 5, 29.2% of students in Year 8, 46.6% in Year 9, 41.4% in year 10 and 33.8% in Year 11 selected responses indicating their belief that respiration in plants takes place in the cells of the leaves only, since only leaves have special pores to exchange gases. Similarly, for item 12, students' selected that the most important benefit to green plants when they photosynthesise was the production of energy for plant growth (Year 8, 21.9%; Year 9, 28.4%; Year 10, 30.3%; Year 11, 33.8%; Year 12, 33.6%) and the removal of carbon dioxide from the air (Year 8, 21.9%; Year 9, 22.7%; Year 10, 25.3% Year 11, 11.8%; Year 12, 2%).

CONCLUSION

In making conclusions from this study, the two-tier multiple choice diagnostic test has provided data which show that across year levels 8 through 11, and in some cases in Year 12 as well, a high percentage of students: (1) do not comprehend the nature and function of respiration in plants, (2) do not comprehend that respiration in plants is an energy conversion process, (3) view photosynthesis as an energy providing process, (4) consider respiration to be synonomous with breathing, and (5) have little comprehension of the relationship between photosynthesis and respiration in plants.

Certain student responses in the pilot studies and the results from the diagnostic test indicate that the two most consistent misconceptions held by students in Year 8 - 11 relate to a lack of understanding of the relationship between photosynthesis and respiration and a lack of understanding <u>when</u> a plant respires. It would appear from this study that these two misconceptions are related to most other misconceptions about photosynthesis and respiration in plants.

As can be seen by the numbers in brackets after the identified misconceptions in Tables 1 and 3, the findings of this study are in agreement with many of the findings in studies reported by Bell (1984), Roth et al (1983) and Wandersee (1983). For example, in summarizing the work of Bell and Brook (1984), Bell (1984) reported that only a third to a fifth of 15 year old students used scientifically accepted ideas on plant nutrition in written responses to three questions. While many of the students' responses dealt specifically with plant nutrition, the focus of the study, Bell (1984) stated that

"There appeared to be confusion or little understanding of the relationship of the process of photosynthesis with other physical and chemical processes carried out by plants, for example, water up-take and respiration. The students appeared not to have linked together in a meaningful and in a scientifically acceptable way, the different aspects of plant functioning that they had learned about (p.14).

The results of this study would appear to lend support to Bell's claim.

IMPLICATIONS FOR TEACHING SCIENCE

While reported research on students' misconceptions, in this case dealing with photosynthesis and respiration, are inherently interesting and are illustrative of students' thinking and perhaps the failings of the implemented curricula, the results are not easily used by classroom practitioners. Consequently, there are two major implications from this study.

The first implication is that in order to improve student learning it is evident that the teaching approach to this topic should be modified in order to address identified misconceptions. Such an approach has been used successfully by Bishop et al. (1985) where they designed a teaching module for non-science college biology students. The second implication is that the existance of reliable and valid pencil and paper, easy-to-score, instruments will enable science teachers to better assess students' understanding of science, in this case photosynthesis and respiration in plants, upon which improved teaching can be based. When a diagnostic test as described in this paper is used by classroom teachers, the additional student reasons can be added to a later version of the test.

Using a diagnostic test at the beginning of a biology topic involving photosynthesis and respiration in plants, a science teacher can obtain clear ideas about the nature of the students' knowledge in the area. Once misconceptions are identified a science teacher will be more inclined to remedy the problem by developing alternative teaching approaches which address students' misconceptions and/or naive conceptions. The approach described by Bishop el at. (1985) and the suggestions made for teaching and learning by Bell (1984) are viable starting points.

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P 1. Chlorophyll gives green colour to the leaves and to the stems.

P 2. Chloroplasts are found in plant cells containing chlorophyll.

P 3. Photosynthesis takes place only in the presence of light energy.

P 4. Photosynthesis takes place mainly in the leaves (but green stems make food too).

P 5. Carbon dioxide is taken in by the green leaf (or green stem) during the process of photosynthesis.

P 6. Water is absorbed through the roots of the plant.

P 7. The four essential factors for photosynthesis in plant cells are: light energy, chlorophyll, carbon dioxide and water.

P 8. Glucose and oxygen are produced during photosynthesis.

P 9. Oxygen gas is given off by the green leaves (or green stems) during the process of photosynthesis.

P10. Plants use glucose molecules to derive energy for growth, transport, reproduction, etc.

P11. Glucose molecules that are not used immediately by the plant to form starch.

P12. Glucose is converted to starch for storage in the cells.

P13. Starch is converted back to glucose to supply energy for the plant's growth, etc.

P14. Photosynthesis may be represented by the equations:

. Carbon dioxide + water $\xrightarrow[\text{Chlorophyll}]{\text{high energy}}$ Glucose + oxygen gas

or . $CO_2 + H_2O \xrightarrow[\text{Chlorophyll}]{\text{light energy}} C_6H_{12}O_6 + O_2$

or . $6CO_2 + 6H_2O \xrightarrow[\text{Chlorophyll}]{\text{light energy}} C_6H_{12}O_6 + 6O_2$

P15. Photosynthesis is the process by which green plants containing chlorophyll, are able to trap light energy, and use it to combine carbon dioxide and water to make simple sugars (plant food) called glucose and to produce oxygen gas.

P16. In some simple plants (some seaweed) brown and red chloroplasts (other types of chlorophyll) are present, which absorb the light for photo-synthesis. This is to make better use of the light, mainly blue, available in deep water.

P17. Green plants use some of the oxygen produced during photosynthesis. The extra oxygen goes into the air.

P18. The rate of photosynthesis increases when light intensity increases.

Figure 1: Propositional statements representing knowledge required to comprehend the mechanism of photosynthesis at the lower secondary level.

R 1. Every living cell respires.

R 2. All organisms, plants and animals, respire continually.

R 3. Respiration is a chemical process in which chemical energy, stored in food, is released using oxygen so that cells can use it in other ways.

R 4. Plants need energy to live and grow.

R 5. During respiration plants derive energy from glucose.

R 6. Glucose is used up during respiration.

R 7. The end products of respiration are energy, carbon dioxide and water. This process may be represented by the equation:

Glucose + oxygen -> Energy + Carbon Dioxide + Water.

R 8. Carbon dioxide is present in the atmosphere.

R 9. Oxygen is present in the atmosphere.

R10. Oxygen is taken in during respiration.

R11. Roots of plants obtain oxygen from the soil air.

R12. The oxygen dissolved in soil water diffuses into the root cells while carbon dioxide produced from the root cells diffuses out.

R13. Oxygen molecules enter the leaf through the stomata (holes).

R14. Carbon dioxide produced during respiration diffuses out through the stomata.

R15. Stomata (holes) are present on the leaf surface. Gases diffuse in and out of the stomata.

R16. The symbol for oxygen gas is O_2. The symbol for carbon dioxide is CO_2.

R17. Both plants and animals release carbon dioxide during respiration.

R18. Carbon dioxide is the only gas which will react with clear lime water to turn it chalky.

R19. Carbon dioxide is the only gas which will react with Bromothymol Blue (BTB) solution to change its colour from Blue to Green - when there is a small amount of CO_2 and from Blue to Yellow - when there is much CO_2.

R20. All living things derive their energy from glucose molecules by a process of respiration in which oxygen is used.

R21. If an organism cannot obtain energy it will die.

R22. Breathing is a method of taking air into the body to provide the important oxygen which the body needs to carry out the process of respiration in cells. Breathing is a physical process while respiration is a chemical process.

Figure 2: Propositional statements representing knowledge required to comprehend the mechanism of respiration in plants at the lower secondary level.

PR 1. In bright daylight photosynthesis occurs at a much greater rate than respiration.

PR 2. At night if there is no light energy at all, photosynthesis ceases while respiration continues.

PR 3. During the day when photosynthesis is occurring more oxygen is produced than is used by respiration.

PR 4. Photosynthesis is a constructive process which may lead to increase in weight.

PR 5. Respiration is a destructive process which may lead to decrease in weight.

PR 6. Respiration and photosynthesis in terms of products and reactants are reverse reactions of each other, the products of one are used as reactants of the other.

Figure 3: Propositional statements representing knowledge required to comprehend the basic relationships between the mechanisms of photosynthesis and respiration in plants at the lower secondary level.

Areas Evaluated	:	Respiration in plants - Items 2, 3, 5, 6, 7, 8, 9. Photosynthesis - Items 1, 4, 10, 11, 12. Photosynthesis and Respiration - Item 13.
Content based on	:	Validated Propositional statements (see Tables 1-3)
Number of items	:	13
Response Format	:	Two-tier multiple choice First tier - content knowledge Second tier - reasons + space for students' own reasons
Recommended grade level	:	8 - 12
Time to complete test	:	15 - 25 minutes
Test Readability (Fry)	:	7 - 8 Level
Discrimination Indices	:	<u>Mean</u> 0.48 <u>Range</u> .30 - .40 (2 items) .40 - .60 (10 items) .60 - .80 (1 item)
Difficulty Indices	:	<u>Mean</u> 0.38 <u>Range</u> 0 - .20 (3 items) .20 - .40 (4 items) .40 - .60 (4 items) .60 - .80 (2 items)
Reliability (Cronbach's alpha)	:	.72

Figure 4: Characteristics of "What do you know about photosynthesis and respiration in plants?"

QUESTION 2

Which gas is taken by green plants in large amounts when there is no light energy at all?

1) carbon dioxide gas
2) oxygen gas.

The reason for my answer is because:

a) This gas is used in photosynthesis which occurs in green plants all the time.

b) This gas is used in photosynthesis which occurs in green plants when there is no light energy at all.

c) This gas is used in respiration which only occurs in green plants when there is no light energy to photosynthesise.

d) This gas is used in respiration which takes place continuously in green plants.

e) ______________________________

Grade	N	Choice	Reason						Total
			A	B	C	D	E	No Reason	
8	137	1	14.6	16.8	10.9	16.1	-	2.9	61.3
		2	7.3	10.2	11.7	8.8*	-	0.7	38.7
9	88	1	11.4	5.7	20.5	17.0	-	1.1	55.7
		2	3.4	18.2	11.4	11.4*	-	-	44.3
10	99	1	8.1	11.1	11.2	24.2	4.0	-	58.6
		2	3.0	8.1	23.2	7.1*	-	-	41.4
11	68	1	7.4	1.5	8.8	17.6	-	-	35.3
		2	1.5	1.5	33.8	27.9*	-	-	64.7
12	49	1	-	-	6.1	6.1	-	-	12.2
		2	-	-	14.3	65.3*	4.1	4.1	87.8

Figure 5: Item number 2 and percentage of students selecting alternate responses.

* the correct choice and reason response
\- no responses in this category

QUESTION 5

Respiration in plants takes place in:

1) the cells of the roots only,
2) in every plant cell,
3) in the cells of the leaves only.

The reason for my answer is because:

a) All living cells need energy to live.

b) Only leaves have special pores (stomates) to exchange gas.

c) Only roots have small pores to breathe.

d) Only roots need energy to absorb water.

e) ______

Grade	N	Choice	Reason						Total
			A	B	C	D	E	No Reason	
8	137	1	5.1	0.7	–	4.4	–	–	10.2
		2	42.3*	3.6	0.7	2.9	–	1.5	51.1
		3	6.6	29.2	1.5	0.7	–	0.7	38.7
9	88	1	–	–	–	1.1	–	2.3	3.4
		2	38.6*	–	–	–	–	–	38.6
		3	8.0	46.6	3.4	–	–	–	58.0
10	99	1	2.0	–	3.0	5.1	–	2.0	10.1
		2	37.4*	3.0	1.0	–	–	–	41.4
		3	3.0	41.4	3.0	1.0	–	–	48.5
11	68	1	–	1.5	–	–	–	–	1.5
		2	58.8*	–	–	1.5	–	–	60.3
		3	4.4	33.8	–	–	–	–	38.2
12	49	1	–	–	–	–	–	–	0.0
		2	87.8*	–	–	–	2.0	–	89.8
		3	–	8.2	–	–	2.0	–	10.2

Figure 6: Item number 5 and percentage of students selecting alternative responses.

* the correct choice and reason response.
– no responses in this category

QUESTION 12

The most important benefit to green plants when they photosynthesis is:

1) removal of carbon dioxide from the air
2) conversion of light energy to chemical energy
3) production of energy.

The reason for my answer is because:

a) Photosynthesis provides energy for plant growth.

b) During photosynthesis energy from the Sun is converted and stored in glucose molecules.

c) Carbon dioxide is taken in by the leaf through the stomates during photosynthesis.

d) ______________________________

Grade	N	Choice	Reason					Total
			A	B	C	D	No Reason	
8	137	1	9.5	5.1	21.9	-	3.6	40.1
		2	5.1	18.2*	3.6	1.5	0.7	29.2
		3	21.9	3.6	4.4	0.7	-	30.7
9	88	1	5.7	4.5	22.7	1.1	4.6	38.6
		2	6.8	10.2*	2.3	-	-	19.4
		3	28.4	10.2	2.3	1.1	-	42.0
10	99	1	7.1	1.0	25.3	1.0	1.0	35.4
		2	6.1	19.2*	2.0	1.0	-	28.2
		3	30.3	7.4	-	-	-	36.4
11	68	1	1.5	-	11.8	-	1.5	14.7
		2	2.9	36.8*	1.5	1.5	1.5	42.7
		3	33.8	7.4	-	-	-	42.6
12	49	1	-	-	2.0	-	-	2.0
		2	2.0	55.1*	-	-	-	57.1
		3	30.6	6.2	-	-	4.1	40.9

Figure 7: Item number 12 and percentage of students selecting alternative responses.

* the correct choice plus reason response.
- no responses in this category

Table 1

Students' misconceptions and/or naive conceptions identified by Haslam (1986) in a series of pilot studies on photosynthesis and respiration in plants.

Responses related to:	Misconceptions and/or naive conceptions
Plant's use of light energy	Solar rays feed leaves with energy Plants change solar energy into food (2, 3) Plants need heat to grow (3) Plants produce energy from the Sun Plants burn energy during photosynthesis to produce starch The heat from the Sun is absorbed by the leaves during photosynthesis Energy intake does not take place at night; plants make their energy at night
Function and nature of chlorophyll	Chlorophyll turns into starch Chlorophyll is plants' food (3) Chlorophyll is produced during the process of photosynthesis Chlorophyll mixes with water and carbon dioxide to produce food Chlorophyll is a fluid The cell wall is green in colour Cellulose is green in colour
Role of water and stomates	Water is absorbed through the leaves during photosynthesis (3) Water is produced during photosynthesis Water enters the leaf through the stomata (3) Stomata absorb water when roots cannot do so (reverse of transpiration) (3) Stomata store food When rain water is being absorbed through the stomate, the plant stops breathing
Role of Carbon Dioxide	Plants take in carbon dioxide since humans breathe it out Plants never give off carbon dioxide, they only use it. Plants do not respire, they do not need oxygen as they make it from carbon dioxide and water (1)
Role of Oxygen	Plants get the oxygen they need from carbon dioxide (1, 3) Oxygen is produced by the plants Photosynthesis stops and respiration begins when there is no light energy Plants cannot respire and photosynthesise at the same time Green plants always take in carbon dioxide and give out oxygen, whereas animals always take in oxygen Animals respire through their lungs and plants through their leaves

Students' misconceptions and/or naive conceptions identified by Haslam (1986) in a series of pilot studies on photosynthesis and respiration in plants.

How Plants obtain Food	Animals hunt for food, plants get their's from soil and rain Plants absorb food through their roots (2, 3) Roots absorb minerals and water as food (2, 3) Plant's food is starch which is stored in the leaves Plants take in oxygen gas in the presence of light to make food
Photo-synthesis	Photosynthesis provides energy for plant growth (2) Plants only photosynthesise Plants photosynthesise during the day and respire only at night Non green plants like fungi can also photosynthesise Carbon dioxide gas is given off during photosynthesis Photosynthesis can occur when there is no light energy The products of photosynthesis are sugars and water Starch is produced during photosynthesis
Respiration	Plants do not respire in the presence of light energy Plants respire only during the day Plants respire only at night, when there is no light energy Photosynthesis is the same as respiration in plants Plants do not respire, they photosynthesise Respiration is the same as breathing (1, 2) Respiration only occurs in the leaves of plants Only animals respire, plants do not respire at all Plants photosynthesise and animals respire (1) Glucose is broken down during respiration and oxygen released into the cells Respiration in green plants is a chemical process by which plants manufacture food from water and carbon dioxide Respiration is the taking in of carbon dioxide and giving off oxygen through plant stomates

Note: Numbers in brackets refer to misconceptions consistent with the work of (1) Bishop, et al. (1985), (2) Roth et al. (1983) and (3) Wandersee (1983).

Table 2

Specification grid showing the propositional statements addressed by each of the items in the two tier test "What do you know about photosynthesis and respiration in plants?"

	Propositional Statements		
Item	Photosynthesis	Respiration	Relationship between photosynthesis and respiration in plants
1	P3 P5 P15	(R2)	(PR3)
2	(P3) (P9)	R2 R10	
3	(P3)	R2 R10 R14	
4	(P3) (P5)	R17	(PR1)
5		R1 R2 R4	
6		R1 R4 R22	
7	(P3)	R4 R5 R7	
8	(P3)	R2 R4 R20	
9	(P14)	R5 R6 R7 R10	(PR6)
10	P8 P9 P14 P15	(R7)	(PR6)
11	P7 P14 P15 P18		
12	P5 P15		(PR1) (PR4)
13	P3	R2 R20 R21	PR2

Note: Propositional statements in parentheses indicate that this statement is also implicitly being addressed by the item.

Table 3

Secondary students' misconceptions[a] of photosynthesis and respiration of plants identified by the two tiered diagnostic test

Item	Misconceptions Identified	Percentage of students with misconceptions				
		Year 8 n =137	Year 9 n = 88	Year 10 n = 99	Year 11 n = 68	Year 12 n = 49
1	Respiration in green plants takes place only during the day.	21.1	11.3	17.2	0.0	0.0
	Respiration does not take place in the presence of light energy.	13.9	12.5	18.1	11.8	0.0
	Carbon dioxide gas is given off in largest amounts by green plants in the presence of sunlight. (2)	27.7	21.6	18.2	10.3	0.0
2	Photosynthesis occurs in green plants all the time.	21.9	14.8	11.1	8.9	0.0
	Photosynthesis can occur when there is no light energy.	27.0	23.9	19.1	3.0	0.0
	Carbon dioxide is used in respiration when there is no light energy to photosynthesise.	10.9	20.5	11.1	8.8	6.1
	Oxygen gas is used in respiration which only occurs in green plants when there is no light energy to photosynthesise.	11.7	11.4	23.2	33.8	14.3
3	Green plants stop photosynthesising when there is no light energy at all so they continue to respire and give off oxygen gas.	21.2	34.1	20.2	16.2	4.1
	Green plants respire only when there is no light energy.	17.5	20.5	25.3	20.5	10.2
4	Green plants make their food from oxygen gas in the presence of light energy.	24.8	13.4	18.2	10.3	2.0
5	Respiration in plants takes place in the cells of the leaves only since only leaves have special pores to exchange gases. (1, 2)	29.2	46.6	41.4	33.8	8.2
6	Respiration in green plants is a chemical process to obtain energy which occurs in plant cells but not in animal cells.	5.8	17.0	5.1	2.9	2.0
7	Respiration in green plants provides energy to live and is a chemical process by which plants manufacture food from water and carbon dioxide.	10.9	9.1	12.1	8.8	2.0
	Respiration in green plants is the taking in of carbon dioxide and giving off of oxygen gases through plant stomates. (1, 2)	18.2	9.1	24.2	16.2	0.0

Table 3 (continued)

Secondary students' misconceptions[a] of photosynthesis and respiration of plants identified by the two tiered diagnostic test

Item	Misconceptions Identified	Percentage of students with misconceptions				
		Year 8 n =137	Year 9 n = 88	Year 10 n = 99	Year 11 n = 68	Year 12 n = 49
8	Green plants respire only at night (when there is no light energy).	24.1	42.0	34.3	23.5	12.2
9	In the process of respiration carbon dioxide and water are used by the green plant to produce energy during which time glucose and oxygen waste are produced.	15.3	20.5	25.3	19.1	6.1
10	The green pigment called chlorophyll combines with the carbon dioxide in the presence of light energy and produces glucose and water. (1, 2)	4.4	12.5	12.1	10.3	4.1
11	Non green plants like fungi which do not contain chlorophyll or similar pigments can also photosynthesise.	17.5	12.5	19.2	7.4	0.0
12	The most important benefit to green plants when they photosynthesise is the production of energy for plant growth. (1, 2)	21.9	28.4	30.3	33.8	30.6
	The most important benefit to plants when they photosynthesise is the removal of carbon dioxide from the air through the leaf's stomates. (1, 2)	21.9	22.7	25.3	11.8	2.0
13	Respiration takes place in all plants only when there is no light energy and in all animals all the time.	22.6	31.8	28.3	23.5	16.3

Note: [a]Misconceptions presented here are generally based on >10% of students holding that misconception at each year level.

Numbers in brackets refer to misconceptions consistent with the work of (1) Roth et al. (1983) and (2) Wandersee (1983).