STUDENTS' CHEMICAL KNOWLEDGE IN PHOTOSYNTHESIS AND RESPIRATION IN PORT HARCOURT METROPOLIS OF RIVERS STATE OF NIGERIA

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ABSTRACT

The study investigated the amount of chemical knowledge students hold in their memory for understanding photosynthesis and respiration. Two hundred and three (203) students made up of 107 SS2 (mean age 15.8 years) and 96 US2 students (mean age 17.5 years) participated in the study. Three main instruments, namely, Photosynthesis - Respiration test (P-RT), Photosynthesis-Respiration Chemical Reaction Test (P-RCRT) and PLDRT-essay test on light and dark reactions of photosynthesis and fate of glucose in animal and plant systems, were used in the study. Overall findings of the study revealed that the students' answers contained deficient chemistry content of photosynthetic and respiratory reactions. Students' answers also lacked integration. Although there was no significant difference between the mean scores of University Students (US2) and that of the secondary students (SS2) in both photosynthesis and respiration, higher percentage (over 8%) of the answers of university students contained relevant chemical information than those of the secondary students. *[AJCE 4(4), July 2014]*

INTRODUCTION

An important purpose of education is for students to learn how to use the information they acquire to interpret events and experiences. It has been noted [1] that a valid measure of understanding of a concept involves eliciting the full set of elements the person has in memory about it.

Good science teachers ensure their students' mastery of scientific concepts. The usefulness of such mastery of concepts is in its application in scientific explanations. In broad fields curriculum design such as in biochemistry, chemical concepts, principles, theories and laws are used in explaining issues associated with biological phenomenon. Biology deals with related matters of plants and animals. What are plants and animals? They are packs of chemical substances arising from deoxyribonucleic acid (DNA), an important component of the gene responsible for hereditary.

In this sense, we can see the link between biology and chemistry. Well drawn up science curriculum where biology is properly married to chemistry will help students to understand such biological concepts like photosynthesis and respiration. After all chemical processes are the bases for gaining knowledge into what happens in photosynthesis and respiration.

Photosynthesis is a process that takes place in green parts of the plant whereby carbon dioxide (CO_2) gas reacts with water (H_2O) in the presence of chlorophyll, enzymes and solar energy to produce carbohydrate and oxygen (O_2). This process is generally represented by the equation;

$$6C0_2(g) + 6H_2O(g) \xrightarrow[\text{enzyme, chlorophyll}]{\text{light energy}} C_6H_{12}O_6(s) + 60_2(g) + \text{Energy}$$

This process is an important life process whereby too much carbon dioxide in our environment is absorbed and utilized by plants and the much needed oxygen by living things, including humans and animals, is produced and added to the environment. The reverse of the photosynthetic reaction is respiration, thus,

$$C_6H_{12}O_6(s) + 6O_2 + E \xrightarrow[\text{in cells tissues}]{\text{mitochondria}} 6CO_2(g) + 6H_2O(g)$$

Respiration is an oxidative reaction that provides energy required to do work in plants and animals. Students' understanding of the two processes – photosynthesis and respiration -is very important in their knowledge of the major biological processes, although students cannot differentiate between photosynthesis and respiration [2]. Students, perhaps reason that photosynthesis is the plant's equivalent of respiration. Behind the thorough understanding of the biological processes is the chemical process. For example, mere knowledge and recalling of the general equation of photosynthesis does not tell all that happens during photosynthesis. According to information in biology and biochemistry textbook [cf: 3], two main reactions are described in photosynthesis. These are the dark and light reactions which involve chemical processes. According to Roberts [4]:

> *the light stage involves the photochemical splitting of water. … But the light stage involves more than just the splitting of water. It has been shown that isolated chloroplasts, as well as splitting water into hydrogen and oxygen, are capable of producing ATP… The light stage is therefore two fold (1) by the photochemical splitting of water it provides hydrogen atoms for the reduction of carbon dioxide; and (2) by producing ATP it produces a source of chemical energy for the synthesis of carbohydrates… Essentially, the dark reactions involve the reduction of carbon dioxide to form carbohydrate. This is an endergonic process requiring energy. The energy is supplied by the splitting of the ATP formed in the light stage. The hydrogen for reducing the carbon dioxide is provided by the reduced NADP, also formed in the light stage.*

Major questions students need to answer are:

1. What is the source of carbon dioxide?
2. What is the source of water?

3. What is the source of the light energy?
4. What is the source of the chlorophyll?
5. What are the sources of the enzymes?
6. What is the role of carbon dioxide?
7. What is the role of water molecule? And
8. What is the fate of glucose (carbohydrate) produced during photosynthesis?

These and more questions should form the bases for teaching/learning photosynthesis and respiration in the schools. These are also requirements for preparation of students for Senior School Certificate Examination (SSCE) and National Examination Council (NECO) as observed in their syllabuses [cf: 5 and 6].

Dienier [7] has argued that science students are all familiar with plants and questioned their (students') familiarly with photosynthesis and the chemistry that plants routinely perform. On the basis of this doubt, it becomes necessary to find answers to the following questions, namely,

1. What chemical knowledge do the students hold about photosynthesis and respiration?
2. Is there any relationship between knowledge held by the students in photosynthesis/respiration and related knowledge in chemical reactions?
3. How is grade level related to the performance of the students in photosynthesis and respiration?

METHODOLOGY

The research is of the descriptive type. Year 2 Senior Secondary Students (SS2) and year 2 science University Students (US2) in Port Harcourt metropolis of Rivers State, Nigeria constituted the population of study. The sample was made up of 107 SS2 (age range 15-17, mean age: 15.8 years) and 96 US2 students (age range 17-21, mean age 17.5 years). These were students who were studying subjects or related courses in biology, chemistry, and physics in their schools. They (students) indicated interest to participate in the study and obtained 50% and above in the achievement test in photosynthesis and respiration.

The choice of SS2 and US2 in the study was deliberate. SS2 students were not preparing for any national or final examinations. They were readily available. US2 students were chosen for the purpose of comparison and considered to have advanced knowledge in the concepts investigated.

Three main data collecting instruments were used in the study. They are: a) Photosynthesis - Respiration Test (P- RT), b) Photosynthesis – Respiration chemical Reaction Test (P – RCRT) and c) Essay Test on Light and Dark reactions of photosynthesis and fate of glucose in animal and plant systems (PLDRT). P – RT was made up of sixty items of 30 items photosynthesis and 30 items respiration processes. Each item carries a stem which is a statement or a question requiring an answer. Four options were presented to the student in which one of the options represents the correct answer. Samples of the test items in P-RT are shown in fig.1 below:

1. In photosynthesis, one of these is given off as a waste product. Which one? (a) Oxygen (b) Glucose (c) Carbon dioxide (d) Sunlight.
2. Both respiration and Photosynthesis require _____ (a) Sunlight (b) Organic substrate (c) Cytochromes (d) Green cells

Fig.1: Sample test items in P – RT
(Ans: 1. A 2. C)

P – RT was drawn from past question papers from Secondary School Certificate Examination (SSCE) and Joint Admissions and Matriculation Board Examination (JAMB). These were given to a ten-years experienced biology teacher to determine face and content validity. The teacher confirmed that the test items were within the reach of the students.

P–RT was then administered to 50 SS1 students in a school in another Local Government Area of the state. Item analyses were carried out which revealed a mean facility value of 61% and mean discrimination index 0.38 for the test items. A reliability coefficient (r) computed was 0.69 using Pearson's Product Moment Correlation Coefficient formula on two sets of scores obtained after two administrations on the test on the students spaced by three weeks.

P – RCRT was a twenty item Multiple Choice Objectives test. The test items were purely on those chemical reactions that occur during photosynthesis and respiration. Each item is made up of a stem and four options in which an option represents the correct answer. The test items were presented to a chemistry teacher of ten years experience. The teacher indicated that the test items were within the reach of the students. The test was then administered to the 50 SS1 students in a school in another Local Government Area of Rivers State. Item analyses were carried out which showed a mean facility value of 52% and mean discrimination index of 0.31. Reliability coefficient (r) on two sets of the scores obtained after two administrations spanned by two weeks was 0.71 Samples of the test items in P – RCRT are shown in fig.2 below:

1. Chemical reaction of photosynthesis occurs in two phases called………………….. (a) Photolysis and chlorophyll (b) chloroplast and carbon fixation (c) Photolysis and carbon fixation (d) carbon dioxide and photolysis
2. Which of the following is correct of photosynthesis equation?
   (a) $6C0_{2(g)} + 12H_2 0(l) + \text{light energy} \longrightarrow C_6H_{12}06_{(s)} + 60_2 + H_20_{(g)}$
   (b) $6C0_2 + C_6H_{12}0^2 + \text{light energy} \longrightarrow H_20 + C_6H_{12}0_6 + 2H_20$
   (c) $6C0_2 + C_6H_{12}0 + \text{light energy} \longrightarrow C_6H_{12}0_6 + 60_2 + 6H_20$
   (d) $6C0_2 + 12H_20 + \text{light energy} \longrightarrow H_20 + C_6H_{12}0_6 + 2H_20$
3. In the light reaction, light energy combines with water to form…?
   (a) $ATP + NADPH_2H^+ + 0_2$
   (b) $ADP + NADPH + H + 0_2$
   (c) $ATP + NAD_2 + 0_2$
   (d) $ADP + NADPH + H_2 + 0_2$

Fig. 2: Sample Test items in P – RCRT

(Ans: 1.C 2. A 3. A)

PLDRT is an essay test that required the students to write all they knew about (i) light reaction, (ii) dark reaction in photosynthesis and (iii) fate of glucose in animals and plants. Students used for the study were from intact classes in a demonstration secondary school and a state-owned university. Researchers administered the instruments to the University students in a hall in the University while that of the secondary schools was in their school. Permission was sought from the authorities of the schools to administer the instruments. Six secondary school teachers and two University lecturers assisted in administering the tests.

P – RT was administered first to students numbered 001 to 399 (which served as identification numbers). Students brought pencils and erasers only and were given a special Multiple Choice Objective answer sheets carrying the letters A-D and requiring the students to shade completely the letters that represented their answers to the questions. It took the last student 50 minutes to complete the 60 items. Only students who obtained 50% and above were invited the next day to participate in the study.

P – RCRT was the second test administered. The method and order followed in the administration of P – RT was maintained. It took the last student 20 minutes to complete the 20 items.

PLDRT was the third and last test given to the student after 10 minutes of break. A student was given three sheets of paper to clearly write his/her number, date of birth and grade level on each sheet. They were requested to write on each sheet all they know about light reaction, dark reaction of photosynthesis and to describe the fate of glucose in either plant or animal system. Students were not timed.

Inter-scorer's Reliability of the Scoring of the Essay Tests

Two graduate assistants (GAs) independently scored the answers of the students to the essay portions of the instruments used for the study. The two GAs discussed with the researchers the scoring format of the answers. Answers relevant to the chemistry of photosynthesis and respiration were scored one point. Irrelevant answers were not scored. The scorers were advised not to directly score on the students' scripts but on provided sheets of paper with the identification numbers of the participants.

One GA completed scoring first and handed over scripts to the other. This was to ensure that scoring did not take place at the same time with the two GAs. Number of scripts that the scorings tallied (agreed) and the total number of scripts was used to compute the reliability co-efficient of the scorings. Thus:

$$\text{Reliability coefficient} = \left(\frac{\text{Number of tallied scorings}}{\text{Total number of scripts}}\right) \text{X} \; \frac{100}{1} \; \%$$

This gave an inter-scorer reliability of the students' essay answers to photosynthesis and respiration of 89% (0.89). Based on this coefficient, the researchers considered the scores of the students on photosynthesis and respiration reliable for the study.

ANALYSES OF DATA

Data were analyzed according to the research questions.

Students' chemical knowledge in photosynthesis

Students' answers in light and dark reactions of photosynthesis were analyzed according to the relevance of the chemical knowledge content related to photosynthesis. Identified chemical knowledge information in a students' script was scored one (1) point. Irrelevant information was not scored. Table 1 is a display of percentage of Senior Secondary two (SS2) students and year 2 University Students (US2) scored according to chemical knowledge content of their answers.

Table 1: SS2 and US2 Chemical Knowledge Content of Light and Dark Photosynthetic Reactions

Objectives	SS2		US2	
	(n = 107)		(n = 96)	
	(f)	%	(f)	%
(i) Ability to explain photolysis of water molecules $4H_2O \rightarrow 4H^+ + 4OH^-$	(15)	14.0	(26)	27.1
(ii) Ability to describe further reaction of the OH- component, thus $4OH^- \rightarrow 2H_2O + O_2$	(11)	10.3	(19)	19.8
(iii) Ability to explain the reduction of CO_2 by H+ component: $CO_2 + 4H^+ \rightarrow CH_2O + H_2O$	(04)	3.7	(26)	27.1
(iv) Writing down the overall reaction of photosynthesis $2H_2O + CO_2 \xrightarrow[chlorophyll]{energy, enzymes} CH_2O + H_2O + O_2$	(05)	4.7	(18)	18.8
Or $6H_2O + 6CO_2 \xrightarrow[chlorophyll]{energy, enzymes} C_6H_{12}O_6 + 6O_2$	(13)	12.1	(23)	24.0

(f = frequency)

It was observed in Table 1 that in all of the answers of students examined less than 28% of them contained relevant chemical information related to photosynthesis. More of the university students (over 18%) than the year 2 senior secondary students had photosynthesis chemical knowledge in their answers. SS2 and US2 students' mean scores in photosynthetic reactions were compared and t-test carried out. The result is shown in table 2.

Table 2: t-test between mean scores ($\overline{X}$) of SS2 and US2 in photosynthetic reactions

Group	N	$\overline{X}$	Sd	df	t-value
SS2	107	25.9	2.71	201	-1.05
US2	96	26.3	2.72		

It was found in Table 2 that "there is no significant difference between the mean score of the year 2 senior secondary students and that of year 2 university students in the photosynthetic reactions.

A correlation between the scores of the students in the essay test and the photosynthesis chemical knowledge test gave r=0.89 for SS2 students, r=0.90 for US2 students. This was used to corroborate the scoring of the light and dark reactions with the students' chemical knowledge as assessed with the achievement test.

Students' chemical knowledge in respiration

Students' answers in respiration were analyzed according to the relevance of the chemical knowledge content related to fate of glucose in plants and animal systems. Identified chemical knowledge recall in a student's answer was scored one (10) point. Irrelevant information was not scored. Table 3 shows the percentage of SS2 students and US2 students scored according to chemical knowledge content of their answers.

Table 3: SS2 and US2 chemical knowledge content in respiratory processes

Objectives	SS2 (n = 107)		US2 (n = 96)	
	(f)	%	(f)	%
(i) Ability to describe the enzymatic breakdown of carbohydrates to simple sugar e.g. glucose Carbohydrate $\xrightarrow{enzyme}$ glucose Cx $(H_2O)y$ $C_6H_{12}O_6$	(6)	5.6	(9)	9.4
(ii) Ability to trace the pathway of glucose to the tissues and cell's mitochondria	(15)	14.1	(40)	41.7
(iii) Ability to describe glycolysis in the cells (simple description), incomplete oxidation of glucose to pyruvic acid Glucose $\xrightarrow{enzymes}$ Pyruvic acid $C_6H_{12}0_6 \xrightarrow{enzymes} C_3H_4O_3 + ATP$	(4)	3.7	(9)	9.4
(iv) Ability to explain complete oxidation of the pyruvic acid to CO_2 and H_2O called krebs cycle $C_3H_4O_3 + O_2 \xrightarrow{enzymes} CO_2 + H2O$	(1)	0.9	(11)	11.4
(v) Ability to write such related equations as				
* $ATP + H_2O \xrightarrow{enzymes} ADP + H_3PO_4 + energy$	-	-	(8)	8.3
* $C_6H_{12}O_6 \longrightarrow 2CH_3CH_2OH + 2CO_2 + energy$	(2)	1.9	(13)	13.5
* $C_6H_{12}O_6 \longrightarrow 2CH_3CH (OH) COOH + energy$	(1)	0.9	(13)	13.5
* $C_6H_{12}O_6+6O_2 \xrightarrow{enzymes} 6CO_2 + 6H_2O + energy$	(31)	28.9	(52)	54.2

(f=frequency)

It was observed in Table 3 that less than 55% of the students' answers contained relevant chemical knowledge information. More university students (41.7%) than the secondary students (14.1%) were able to trace the pathway of glucose to the tissues and cell's mitochondria. More university students (28.9%) were able to write the overall oxidative reaction of the glucose molecule.

SS2 and US2 students mean scores in the respiratory processes were compared and t-value computed. The result of the computation is shown on table 4.

Table 4: t-test between Mean scores ($\bar{X}$) of SS2 and US2 in respiratory process

Group	N	$\bar{X}$	Sd	df	t-value
SS2	107	27.1	2.59	201	1.13
US2	96	23.1	2.69		

It was found in Table 4 that there is no significant difference between the mean score of the year 2 Senior Secondary students and that of year 2 University students in the respiratory processes.

A correlation between the scores of the students on the fate of glucose in plant and animal systems and that of their chemical knowledge gave r=0.71 for SS2 students, r=0.68 for US2 students. This was used to corroborate the scoring of the fate of glucose in plant and animal systems with the achievement test in chemical reactions in the respiratory processes.

DISCUSSION OF FINDINGS

Photosynthesis is one such concept that is studied at virtually all levels of schooling- preprimary, primary, secondary and tertiary, especially when plant nutrition is mentioned. One will therefore expect progressive understanding and performance of students from one level to another. At the tertiary level, a biological science student who has acquired higher knowledge than all other levels in chemistry should excel in the chemical knowledge of photosynthesis. This was so expressed in the result of the study (cf: Table 1) where the university students had higher chemical knowledge content in their answers than the secondary students. Although this was the observed trend in the study, this was rated poor because less than 27% of the scripts of the students contained relevant chemical knowledge.

What appears to have contributed to this is attributed to textbook factor and the teachers' presentation of the topic. Biology textbooks at the secondary school level present overall equation of photosynthesis, namely,

$$6CO_{2(g)} + 6H_2O_{(g)} \xrightarrow[chlorophyll/light]{Energy\ (E)} \underset{\text{glucose}}{C_6H_{12}O_6} + O_{2(g)} + \text{energy}$$

A secondary school student might think that everything about photosynthesis begins and stops with the overall equation. Teachers at this level appear to be emphasizing this overall equation thereby helping in the limitation of the students' chemistry of photosynthesis.

White and Gunstone [1] have noted that a concept is the total set of knowledge that a person associated with a label. Therefore, understanding of the concept is a function of the set of knowledge. They [1] also argued that understanding improves as the amount of knowledge increases. But with the university students who were considered to have sufficient knowledge of photosynthesis as demonstrated by their performance in the tests (photosynthesis test and the chemical knowledge test), why did they not outperform the secondary students? The results of the study clearly showed that there was no significant difference between their mean scores (Table 2).

It was observed that the secondary students were currently studying plant nutrition whereas the university students were studying other complex concepts or higher concepts that may be considered as "big ideas" other than photosynthesis. Would this have been possible explanation? But the overall scores of the students in the photosynthetic reactions (light and dark) and the chemical knowledge test correlated heavily with r being over +0.80. This will mean that acquiring the chemical knowledge in photosynthesis will not depend on the level of schooling or even age, rather will rest on the teachers' presentation. After all, "any subject can be taught effectively in some intellectually honest form to any child at any stage of development" [8].

It is believed that students will learn what they are taught by the teacher. For instance, if the teacher presents the photosynthetic reactions systematically, and ends with the overall equation, the students will learn knowing fully well that their knowledge will be tested on what the teacher has taught.

There are startling evidences that students tend to pay more attention to trivial information than the details. In the case of the issue associated with respiration, students were interested in the processes and not with the chemistry of the processes. This is so because the students chosen for the study obtained 50% and above in the photosynthesis/respiration test. So why did they not recall from their memories associated chemical processes?

For all the chemical knowledge content of the answers of the students, it was observed that more students (over 24%) were able to note the pathway of glucose to the tissues and the cells' mitochondria (see table 3). Tracing the pathway did not involve any chemical reaction, so it was easy for the students to recall.

It was also observed that generally more university students were able to recall more chemical information in respiration than the secondary students. Perhaps maturity, experience and advance studies may have been responsible for this. But it was further noted that "there was no significant different between the mean scores of the university students and that of the secondary students" (see table 4), in the students' performance in respiratory processes.

One other observation in the study was that there was high positive correlation between students' performance on the essay on the fate of glucose and chemical reactions associated with respiration. This finding, apart from validating the two tests, also revealed the chemistry contained in respiration. The overall equation of respiration which is the reverse for photosynthesis was easily written by the students although more university students than the secondary students did this. Again, maturity, experience and advanced foundation of the university students may have contributed to this. The university students also outperformed the secondary student in the recall of the chemical information related to glycolysis, aerobic and anaerobic respiration. Energy generation through adenosine triophosphate (ATP) and reduction were well noted in the higher chemical knowledge recall of the university students' answers than the secondary students.

CONCLUSIONS AND SUGGESTIONS

In conclusion, the study revealed student's deficiency in related chemical knowledge required to thoroughly understand photosynthesis and respiration processes. They (students) are also unable to integrate knowledge which is required to show understanding in photosynthesis and respiration. Sample answers of the students exhibit such deficiencies and lack of integration of knowledge.

For the secondary students:

> ***Light reaction****: This occurs in the reaction and can not be discussed.*
> ***Dark reaction****: this does not involve light in its reaction or experiment.*
> *CO_2 combines with hydrogen atom to form sugar.*

For the university students:

> ***Light reaction****: this is the stage that requires light in the reaction, at this state, oxygen is given out as a waste product. This is discussed in phases such as transfer of energy emersion effect etc.*
> ***Dark reaction****: At this stage, CO_2 is reduced by combining with atoms of hydrogen provided by the enzyme NADP to form sugar. This reaction does not need light in its reaction. This is also called light independent reaction because it does not involve light action.*

The ordinary level requirement stated that students should be able to understand the nature of photosynthesis which is more of grappling with the light and dark reactions. Availability is a measure of the ease with which knowledge is recalled and it is also a property of understanding [1]. Most of the students – both secondary and university - could not recall relevant knowledge in photosynthesis and respiration. There is no way the students can understand the process of photosynthesis and respiration without chemistry of the reactions because chemical substances/molecules are involved. Teachers should not only explain the processes but should also teach the students the chemistry associated with the processes.

It may also be necessary for a curriculum reform to focus on this aspect of plant nutrition especially now that studies are being conducted to see the possibility of artificial photosynthesis in the laboratory [9]. The initial problem was on the nature and distribution of chlorophyll molecules in precise positions in the chloroplast – at exactly the same angle and orientation in every chloroplast of the green parts. Without knowledge of chemistry, this will not be understood. Therefore there is the need to teach students the processes as well as the associated chemistry.

Textbook writers while trying to simplify the processes of photosynthesis and respiration should include relevant chemical reactions as is found in [3] and other advanced textbooks.
Overall chemical equation is not enough. Explanations of the splitting of water molecule, reduction of carbon dioxide and formation of carbon hydrate are needed for photosynthesis while glycolysis is essential for understanding respiration. All these demand students' expansion of their memory capacity for chemical knowledge. Bridging knowledge gap between chemistry and biology is important in students' understanding of some biological processes such as photosynthesis and respiration.

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