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Comprehension Levels on Photosynthesis and Cellular Respiration among First Year College Students in a State University: A Two-tier Diagnostic Analysis

Ervin C. Malones

Senior High School Department, Santa Barbara National Comprehensive High School,

Iloilo, Philippines

ervin.malones@gmail.com

Abstract

This descriptive study aimed to determine the comprehension levels and alternative conceptions on photosynthesis and cellular respiration among first year college students. The respondents consisted of 147 first year college students from a state university in Iloilo City, Philippines. The sample was made up of one hundred thirteen BS Biological Science and thirty four BSEd Science major students. The instrument for collecting data was a 20-item validated researcher-made two-tier diagnostic test. Results revealed that the comprehension level of first year college students was average. Common alternative conceptions were identified in eleven categories. These were: Source of oxygen for photosynthesis, Comparing photosynthesis and cellular respiration, Gas Exchange, Stages of cellular respiration, Electron transport chain, Purpose of photosynthesis, When do green plants respire, Cell respiration in plants, Electron flow in photosynthesis, and Krebs cycle. Two sample proposals were made to eliminate alternative conceptions. In photosynthesis, teachers could use graphic explanation of the correct chemical equation focusing on the sources of reactants and products of photosynthesis, while for cellular respiration; it might help if teachers could check prior learning and integrate the topic to other disciplines for contextualized learning.

Keywords: comprehension levels, alternative conceptions, two-tier diagnostic analysis, photosynthesis, cellular respiration

INTRODUCTION

Biology contains lots of abstract concepts which may cause students‘ difficulty in constructing knowledge. In the recent implementation of the K to 12 Program in the Philippines, senior high school students learn photosynthesis and cellular respiration as part of a specialized or a core subject. For students in the STEM (Science, Technology, Engineering, and Mathematics) strand,

Biology I is a specialized subject taken in the 2nd Quarter of Grade 12. However, for non-STEM majors, Earth and Life Science is a core subject taken in the 2nd Quarter of Grade 11.

It has been observed that there are a lot of abstract concepts concerning photosynthesis and cellular respiration in the senior high school science curriculum. These concepts include the functional definition, reactants and products, importance of pigments, oxygen, ATP, and the major stages of photosynthesis and cellular respiration. The results of the summative exam yield a lot of satisfactory results and only a few got outstanding results. It concerned the researcher as to what alternative conceptions concerning photosynthesis and cellular respiration the senior high school students still have despite remediation were given.

Admission to college, including those who plan to specialize in biological science, does not require the student a specific strand graduated in their senior high school as long as they passed the college admission process. Do the first senior high school graduates possess enough foundation knowledge of photosynthesis and cellular respiration? Because no two students are the same, they come to biology classes having a wide variety of alternative conceptions based on their prior experiences that are incompatible with established scientific theories (Brown & Clement, 1987). Kurt, Ekici, Aktas, and Aksu, (2013) prefer the term alternative conception which refers to experience-based explanations constructed by a learner to make a range of natural phenomena and objects intelligible. Alternative conceptions are also called misconceptions (Fayer, 2010). Science educators have come to use the term alternative conception, rather than misconception and other defensibly acceptable term, because the latter emphasizes the learner‘s knowledge is incorrect with respect to scientifically correct ideas. On the other hand, the former ―confers intellectual respect on the learner who holds those ideas because it implies that alternative conceptions are contextually valid and rational and can lead to even more fruitful conceptions (scientific conceptions) (Wandersee et al., 1994). Thus, the term alternative conceptions was used in this study.

As of this time, there were very few empirical data about Filipino students‘ alternative conceptions on these topics. Thus, the aim of this study was to determine the comprehension levels and alternative conceptions of biology concepts: photosynthesis and cellular respiration among first-year college students using the researcher-made two-tier diagnostic test.

MATERIALS AND METHODS

Purpose of the Study

This study was conducted to determine the comprehension levels and alternative conceptions on photosynthesis and cellular respiration among first-year college students of a state university using a two-tier diagnostic test during the 1st semester of the academic year 2018-2019.

Specifically, the study aimed at finding answers to the following questions:

1. What is the comprehension level and conceptions on photosynthesis and cellular respiration among first-year college students when grouped according to their chosen undergraduate degree?

2. What are the common alternative conceptions on photosynthesis and cellular respiration among first-year college students when grouped according to their chosen undergraduate degree?

3. What sample proposals can be made to correct the alternative conceptions on photosynthesis and cellular respiration?

Research Design

This study employed a descriptive survey as the key method in determining the comprehension levels and identifying alternative conceptions on photosynthesis and cellular respiration among first-year college students. The survey method gathers data from a relatively large number of cases at a particular time. It is concerned with the statistics that result when data are abstracted from a number of individual cases‖ (Best and Kahn, 2006).

Research Locale and Respondents

The study was conducted in a state-owned university in Iloilo City, Philippines. The respondents included in this study were the first year BS Biological Science and BSEd Science major students of the said state university enrolled during the 1st semester in the school year 2018-2019. The respondents were chosen because it was assumed that they had acquired the topics during their senior high school.

Since the study includes the development process of a two-tier test and its application, two different sample groups were chosen from the pool of the respondents. The first sample group for the first phase was composed of thirty (30) first-year college students; twenty (20) BS Biological Science and ten (10) Bachelor of Secondary Education major in Science students of a state university helped identify the least mastered competencies covering the topics on photosynthesis and cellular respiration.

Instrumentation

In this study, the researcher-made two-tier diagnostic test was used to gather data. The test was adapted based on the procedure described by Treagust (cited in Tüysüz, 2009) that involved 2 phases. (1) Obtaining information about students' alternative conceptions and (2) Constructing a two-tier diagnostic test.

Phase One: Obtaining Information about Students' Alternative Conceptions

Phase one aimed to identify the least mastered competencies as well as obtaining information about students‘ alternative conceptions by constructing a multiple-choice diagnostic test (MCDT) with open responses. The target concepts were based on the different competencies on the topic photosynthesis and cellular respiration in the Grade 12 General Biology 1 – K to 12 Senior High School Science Curriculum.

The topics include the role of adenosine triphosphate (ATP), the major features and chemical events in photosynthesis and cellular respiration, the importance of chlorophyll and other pigments, the light reaction events, the Calvin cycle, the differences between aerobic and anaerobic respiration, and the major features of glycolysis, Krebs cycle, electron transport system, and chemiosmosis. A

table of specification was made to guide the researcher as to the total number of items, the number of items per topic, and what topics need more emphasis and which ones need less emphasis in the construction of the test questionnaire. The multiple choice diagnostic test (MCDT) which composed of forty (40) items had four choices and with an open-ended part, in where students are required to explain their reason for their answers to the first part, was constructed. The MCDT was subjected to face and content validation by a panel of Biology experts and administered to (30) first year BS Biological Science and Bachelor of Secondary Education major in Science students. A list of students‘ responses was constructed from their justifications that they provided to the 40 multiple-choice items. Distracters (alternative conceptions) to be considered in the next phase were constructed according to this list.

Phase Two: Constructing a two-tier diagnostic test

Phase two aimed to develop the two-tier diagnostic test which was the main instrument for this study be used to determine the first year college students‘ comprehension level and alternative conceptions on photosynthesis and cellular respiration. A two-tier test is a two-level multiple choice question that diagnoses students‘ alternative conceptions in science. The first tier which represents the least mastered competencies identified in phase one is in the multiple-choice format asking the conceptual knowledge of the students with four choices. The second tier is again in the multiple-choice format containing a set of four justifications asking the reason for the response given in the first tier (Odom and Barrow, 1995). Included in these justifications are the correct answer and three distracters that collected from the students‘ responses from the first phase. Alternative conceptions from the related literature were considered if the students if insufficient reasoning is given during the first phase. These items were considered to be student-oriented items that were different from traditional multiple-choice test items. Once the items were constructed, the students were asked to select the most appropriate answer to each question and then select the explanations for their choices.

The 20-item instrument was subjected to face and content validation by a panel of experts in Biology and administered for pilot testing to 31 first year BSEd Science major students of another public university who were not respondents of this study. The answer to an item is considered to be correct only if both content and reason parts are correctly answered. The result was statistically treated using Kuder-Richardson 20 using Statistical Package for Social Sciences (SPSS) software version twenty (20). The output resulted in a reliability coefficient of 0.788 in the first run of the statistical test. The 20-item two-tier multiple choice test was considered manageable for students to answer in a 60-minute time frame. An assessment instrument whose KR-20 reliability coefficient is 0.70 or higher is acknowledged as reliable (Fraenkel and Wallen, 2006). The validated two-tier diagnostic test instrument was administered to 147 first-year BS Biological Science and Bachelor of Secondary Education major in Science students to assess the alternative conceptions of the said respondents.

The 20-item test includes 9 items of photosynthesis-related questions, 10 items of cellular respiration-related questions and an item for comparing both processes. Nine (9) items were taken

from Haslam and Treagust (1987). Two-tiered questions have an advantage over conventional one-tiered questions, a decrease in the measurement error. In a one-tiered multiple choice question with 4 possible choices, there is a 25% chance of correctly guessing the answer. These random correct guesses must be accounted for in the measurement error. A two-tiered question is considered correct only if both tiers are answered correctly. As a result, a student responding to a question with 4 choices in the first tier and 4 in the second has only a 6.25 % chance of randomly correct guessing (Haslam and Treagust, 1987).

Data Collection Procedure

Preliminary Activities. The researcher secured a permit to conduct the study from the Office of the University President. The deans of the College of Arts and Sciences and the College of Education were informed through written communication for the approval of the conduct of the study. The researcher arranged with the Bachelor of Science in Biological Science and Bachelor of Secondary Education major in Science advisers the most convenient schedule for the administration of the instrument.

*Data Collection Proper***.** Upon approval of requests, the instrument was administered to the respondents. The respondents were given 60 minutes to answer the 20-item test. Necessary instructions were given to the students to ensure the correct procedure in answering the instrument was observed. Results of the gathered data were tallied, tabulated, computer-processed, analyzed and interpreted.

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Data Analysis Procedure

Proper sorting and classification of the completed instrument according to the respondents‘ undergraduate course was done immediately after retrieval from the respondents. For the purpose of the study, the data collected in this study was encoded using the Microsoft Excel program and Statistical Package for Social Sciences (SPSS).

The descriptive statistics used to determine the comprehension levels of first-year college students on photosynthesis and cellular respiration were their mean scores and standard deviations on the two-tier test. The answer to an item was considered correct only if both content and reason parts were correctly answered. Common alternative conceptions on photosynthesis and cellular respiration among BS Biological Science and BSEd Science major students on the other hand was determined by assessing incorrect responses selected on the second tier of the test using frequency count, percentage ,mean percentage and ranking of these responses. Sample proposals to correct alternative conceptions on photosynthesis and cellular respiration were based on the results of the two-tier diagnostic analysis focusing on the categories that incurred a lot of alternative conceptions. Alternative conceptions related to the mentioned topics were evaluated as to its complexity and possible sources of these alternative conceptions as supported by the literature.

RESULTS AND DISCUSSION

Comprehension Levels in Photosynthesis and Cellular Respiration

Table 1 shows the comprehension levels using the mean scores and standard deviation of BS Biological Science and BSEd Science students selecting the desired content choice and reason on the two-tier diagnostic test on photosynthesis and cellular respiration.

Results revealed that the comprehension level of first-year BS Biological Science students on the 20-item two-tier diagnostic test was low (M=6.64) and was performing below expectations. This is quite alarming for these students because soon they will be facing specialized or advanced subjects and prior knowledge with these two topics is quite needed. Photosynthesis and cell respiration were the last two topics in General Biology 1 subject and the target concepts may not be taught well due to lack of time. As Shtulman and Valcarel (2012) found, people experienced in science and under time-pressure are slow to verify their alternative conceptions. The researcher made two-tier diagnostic test can be used to identify student‘s prior knowledge by the teachers before instruction to adopt the ideal instructional methods which save time to ensure conceptual change.

Table 1

Comprehension Levels among First-Year College Students

Undergraduate Course	n	SD	M	Descriptive Rating
BS Biological Science	114	2.60	6.64	Low
BSEd Science	33	2.18	7.39	Average
Entire Group	147	2.53	7.02	Average

Also, it revealed that the comprehension level of first-year BSEd Science major students was average (M=7.39) and interpreted as having met expectations. Having an average comprehension level on both topics might sound good to some but as pre-service service teachers they should master the topics and have high content knowledge as required for soon to be teachers. Remediation needs to be given for them to achieve exceeds expectations. Carlson (2002) describes teachers as teaching according to their own conceptual understanding which can differ from a scientifically correct one. Thus, students‘ alternative conceptions just echo a teachers‘ understanding. Teacher training programs should be designed in a way to facilitate pre-service teachers‘ conceptual developments, to improve their professional skills and to enable them to determine their students‘ learning difficulties. This is very important especially in a field like biology, in which the emphasis is on drawings and visualizations in order to concretize subjects.

When taken as a group, the first year BS Biological Science and BSEd Science major students comprehension level was average (M=7.02) and interpreted as having met expectations. The researcher was able to identify that none of the undergraduate courses was able to get at least half of the total number of items on the topics included on the two-tier test. The respondents on average only

answered at least six to seven items (of the 20) correctly. This means that they did not pass the diagnostic test.

Common Alternative Conceptions among BS Biological Science and BSEd Science Students.

Alternative conceptions are one of the major factors affecting students' understanding of science at the secondary school level that is carried onwards to university studies (Coll and Treagust, 2003). This study focused on two biological processes, photosynthesis and cell respiration, which were rated as the most difficult topics for students to master due to contradicting and prior knowledge about plants and biological functions of living things (Marmaroti and Galanopolou, 2006).

Figure 1 shows the top categories of alternative conceptions using the mean percentages of responses by BS Biological Science and BSEd Science major students detected by the 20-item Two-tier Diagnostic Test. These ten categories were: (1) Source of oxygen for photosynthesis, (2) Comparing photosynthesis and cellular respiration, (3) Gas Exchange, (4) Stages of cellular respiration, (5) Electron transport chain, (6) Purpose of photosynthesis, (7) When do green plants respire, (8) Cell respiration in plants, (9) Electron flow in photosynthesis, and (10) Krebs cycle.

The most common alternative conception among first-year college students was under the category: Source of oxygen produced during photosynthesis, the statement *was "Plants take in CO_2 and change it to O_2."* selected by 72.93% of the respondents (BS Biological Science = 64.04%; BSEd Science= 81.82%). The correct conception on this item was "*Oxygen is produced after the splitting of water molecules."*, which was only selected by 25.44% of the BS Biological Science and 15.15% of BSEd Science students. In a study by Keleş and Kefeli (2010) among grade 6 and 7 students using computer-assisted instruction (CAI) material, students also agreed that carbon dioxide is converted into oxygen in photosynthesis. We should clarify that green plants DO NOT convert carbon dioxide (CO_2) into oxygen (O_2). The oxygen produced during photosynthesis comes from water. During photosynthesis, green plants DO, however, convert atmospheric CO_2 into sugars.

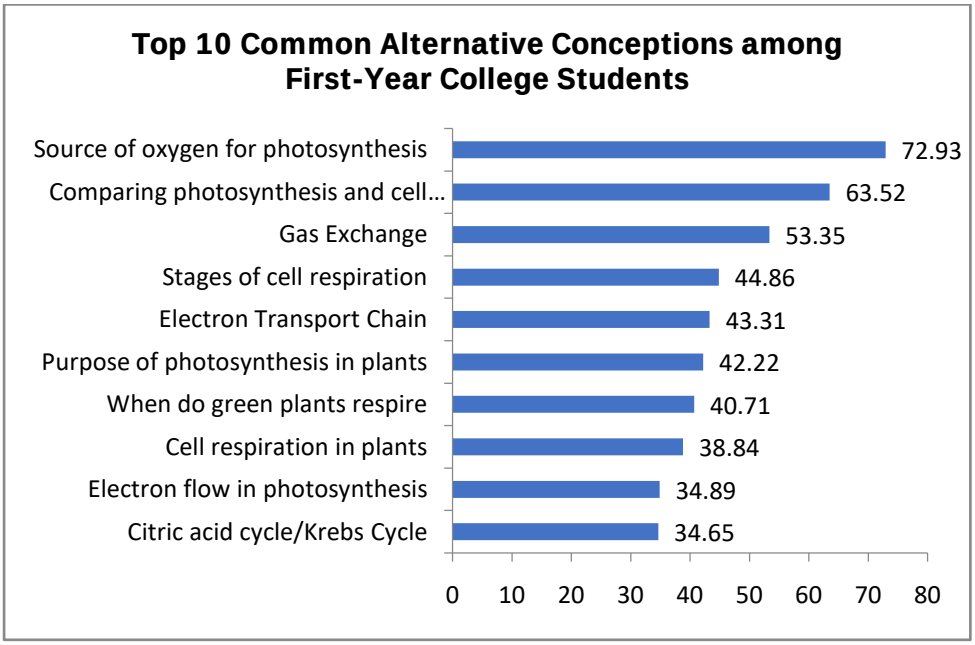

Figure 1. Common Alternative Conceptions among First Year College Students

Second. Comparing photosynthesis and cell respiration, "*Plants respire when they cannot obtain enough energy from photosynthesis (e.g. at night) and animals respire continuously because they cannot photosynthesize.*" selected by 63.52% of the respondents (BS Biological Science = 48.25%; BSEd Science= 78.79%). The correct conception on this item was "*Because respiration is continuous in all living things. Photosynthesis occurs only when light energy is available*.", which was only selected by 21.93% of the BS Biological Science and 9.09 % of BSEd Science students. In an interview by Kose (2008) among university students, students also believed that when plants carry out photosynthesis, they do not respire.

Third. Gas exchange, the statement was "*Only leaves have special pores (stomates) for exchange gas.*", selected by 53.35% of the respondents (BS Biological Science = 49.12%; BSEd Science= 57.58%). The correct conception on this item was "*All living cells need the energy to live.*", which was only selected by 35.96% of the BS Biological Science and 30.3 % of BSEd Science students. Tuysuz (2009) and Kose (2008) found out that students believed that green plants respired at night and thought that respiration in plants takes place in the cells of the leaves only since they believed that only leaves have special pores for the exchange of gasses. Many primary school textbooks, as well as higher biology textbooks, show photosynthesis in a simplified picture of a plant leaf (Dimec and Strgar, 2017).

Fourth. Stages of cell respiration, "*Glycolysis is a part of cellular respiration and uses oxygen to generate ATP, NADH, and* $FADH_{2.}$*"*, selected by 44.86% of the respondents (BS Biological Science = 41.23%; BSEd Science= 48.48%). Glycolysis is the first step in the breakdown of glucose to extract energy for cellular metabolism. Nearly all living organisms carry out glycolysis as part of their metabolism. The process does not use oxygen and is therefore anaerobic. Glycolysis begins with the six carbon ring-shaped structure of a single glucose molecule and ends with two molecules of a three-carbon sugar called pyruvate. Glycolysis consists of two distinct phases. The first part of the glycolysis pathway traps the glucose molecule in the cell and uses energy to modify it so that the six-carbon sugar molecule can be split evenly into the two three-carbon molecules. The second part of glycolysis extracts energy from the molecules and stores it in the form of ATP and NADH, the reduced form of NAD, not including $FADH_{2.}$ (OpenStax College, *Biology*, 2013). The correct conception on this item was "*NADH and* $FADH_2$ *is converted to ATP with oxygen as the terminal electron acceptor*.", which was only selected by 11.40% of the BS Biological Science and 9.09 % of BSEd Science students.

Fifth, two alternative conceptions on the list were under the category: Electron transport chain, "*NADPH oxidizes water in order to remove electrons.*", selected by 43.30% of the respondents (BS Biological Science = 35.09%; BSEd Science= 51.52%). NADPH is considered as an electron carrier, a reduced form of NADP, created during the Krebs cycle after accepting electrons. An enzyme NADH dehydrogenase has high affinity to NADH and receives its electron and passes it down the

electron transport chain. And "*ADP accepts electrons to create ATP.*", selected by 29.91% of the respondents (BS Biological Science = 38.60%; BSEd Science= 21.21%). Adenosine diphosphate (ADP) is converted to Adenosine triphosphate (ATP) for the storing of energy by the addition of a high-energy phosphate group, not electrons. The correct conception on this item was *"Oxygen accepts electrons and forms water."*, which was only selected by 15.79% of the BS Biological Science and 21.21 % of BSEd Science students. The electron transport chain is the last component of aerobic respiration and is the only part of glucose metabolism that uses atmospheric oxygen. Electron transport is a series of redox reactions that resemble a relay race or bucket brigade in that electrons are passed rapidly from one component to the next, to the endpoint of the chain where the electrons reduce molecular oxygen, producing water (OpenStax College, *Biology*, 2013).

Sample Proposals to Correct Alternative Conceptions

Based on the results of the two-tier diagnostic test, it was confirmed that students come to school with plenty knowledge about physical world based on their daily experiences and these alternative conceptions were not challenged even after instruction. Two sample proposals were made to address the concern, one for photosynthesis, and the other for cellular respiration. Photosynthesis. The most consistent alternative conception was in the category: Source of oxygen for photosynthesis. During the light-dependent reaction of photosynthesis water is broken down into hydrogen ions and oxygen with the help of sunlight. This is the process of photolysis of water. The chemical equation of photosynthesis is described in this formula, $CO_2 + H_2O \rightarrow O_2 + C_6H_{12}O_6$. The respondents believed that plants take in CO_2 and change it to O_2. Alternative conceptions might have arisen because the chemical formula of carbon dioxide (CO_2) shows the chemical formula of oxygen (O_2). In connection to this, the researcher proposed that to eliminate alternative conceptions in photosynthesis, teachers could use graphic explanation of the correct chemical equation focusing on the sources of reactants and products of photosynthesis. Cellular Respiration. The most consistent alternative conception was in the category: Stages of cellular respiration. There are three stages of cellular respiration: glycolysis, Krebs cycle and the electron transport chain. The respondents believed that glycolysis is a part of cellular respiration and uses oxygen to generate ATP, NADH, and $FADH_2$. Glycolysis is a series of reactions that extract energy from glucose by splitting it into two three-carbon molecule called pyruvates and is considered an anaerobic process so it doesn't need oxygen to occur. Meanwhile, Flavin-adenine dinucleotide ($FADH_2$) is a redox cofactor that is created during the Krebs cycle and utilized during the last part of cell respiration, the electron transport chain. While it is true that oxygen is a reactant of cellular respiration it does not participate in glycolysis. Glycolysis is considered as an anaerobic process. The next stage of cellular respiration after glycolysis is the Krebs' cycle and for it to takes place this time oxygen must be present and is considered an aerobic process.

The K to 12 curriculum mandates contextualization among its different subjects and integration between these subjects for meaningful learning. Teachers may contextualize using fermentation of vinegar or ginamos-making done by bacteria for example to explain that glycolysis can still take place even without oxygen. According to Tsui and Treagust (2013), teachers should

guide prerequisite concepts for students as the bridging between students‘ existing ideas and the understanding of the concept being learned. In connection to this, the researcher proposed that to eliminate alternative conceptions in cellular respiration, it might help if teachers could check prior learning and integrate the topic to other disciplines for contextualized learning.

CONCLUSIONS

Based on the findings of the study that first-year college students held low to average comprehension levels and notable alternative conceptions on photosynthesis and cellular respiration, the following conclusions were drawn: Concept learning is one of the primary requirements for obtaining information on a subject. First year college students need to master the least understood concepts to be learned in photosynthesis and cell respiration while in senior high school Biology subject. Despite instruction, there were a number of alternative conceptions identified in this study which should have been corrected. The two processes (photosynthesis and cellular respiration) have a lot of abstract concepts which was a challenge for teachers to teach them well. Relying on simple diagrams (which is often misleading) does not ensure concept mastery but detailing each step of the process and guiding the students with the appropriate teaching and assessment strategies. Sample proposals to correct alternative conceptions call for teachers to carefully monitor alternative conceptions, which may emerge at all educational levels and they should carry out effective teaching activities (like conceptual change text and concept mapping) in order not only to prevent their emergence but also to alter existing ones. These alternative conceptions resulted from the confusion in understanding of reactants and products in the chemical equations of the two processes and the poor integration of these topics to other disciplines.

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