STUDENTS' MISCONCEPTIONS ABOUT RESPIRATION: A CROSS-AGE STUDY

ÖĞRENCİLERİN SOLUNUM KONUSUNDAKİ KAVRAM YANILGILARI: KARŞILAŞTIRMALI BİR ÇALIŞMA

Zuhal AŞCI, Şule ÖZKAN, Yrd. Doç. Dr. Ceren TEKKAYA
Middle East Technical University
Faculty of Education
Department of Primary Education

ABSTRACT

Misconceptions of 10th grade and freshman level students regarding respiration were investigated. Students' understanding of respiration was assessed using an instrument requiring the students to write a brief essay concerning the process of respiration. Most of the students had misconceptions, especially about the purpose, function, process, chemical formula of respiration and respiration in plants. Some of the common misconceptions among students were that respiration takes place in lungs, the purpose of respiration is to provide oxygen and to remove carbon dioxide, respiration is a gas exchange process, that plant respire during night only, and that plants do not respire but photosynthesize instead.

ÖZ

Bu çalışmada lise 2. sınıf ve üniversite birinci sınıf düzeyinde biyoloji dersi alan öğrencilerin solunum konusundaki kavram yanılgıları, konu hakkında yazdıkları kısa bir metnin değerlendirilmesi sonucunda saptanmıştır. Analizler, öğrencilerin özellikle solunumun amacı, nerede gerçekleştiği, kimyasal formülü ve bitkilerde solunum konularında birçok kavram yanılgısına sahip olduğunu göstermektedir. Çalışmaya katılan öğrencilerde saptanan ortak kavram yanılgıları "solunum akciğerlerde gerçekleşir", "solunumun amacı oksijen alıp karbon dioksit vermektir", "solunum bir gaz değişim işlemidir", "bitkiler yalnızca geceleri solunum yapar" ve "bitkiler solunum yapmaz, onun yerine fotosentez yapar" olmuştur.

1. INTRODUCTION

Students construct sets of ideas, expectations and explanations about natural phenomena to make meaning of their everyday experiences. The ideas and explanations that students generate from a complex framework for thinking about the world are frequently different from the views of scientists. These differing frameworks have been described as misconceptions (Fisher, 1985), alternative views (Stewart et al. 1990), alternative conceptions (Arnaudin and Mintzes, 1985), erroneous ideas (Sanders, 1993), childrens' ideas (Braund, 1991), and childrens' conceptions (Teixeira, 2000). For the sake of simplicity of description, this article will use the term 'misconception' to denote any ideas held by students that are inconsistent or in conflict with those generally accepted by scientists. Misconceptions tend to be pervasive, stable and often resistant to change through traditional teaching methods. Several studies revealed that misconceptions may arise as a result of both in- and out-of –school experiences (Fisher, 1985; Sanders, 1993). Table 1 summarizes the sources of misconceptions.

Table 1

Sources of Misconceptions

Students' factors:

- Lack of prerequisite knowledge
- Informal preconceptions
- Lack of motivation and interest
- Using everyday language in a scientific context

Teachers' factors

- Inadequate subject matter
- Teaching strategies
- Compartmantalization of concepts
- Emphasis on excessive details (rote memory vs. understanding)

Textbooks' factors

- The teaching sequence
- Contain many errors/incorrect information
- Lack of figures and examples
- Lack of integration among topics

During the past two decades, a significant body of research in many countries has investigated students' understanding of different biological concepts: photosynthesis (Waheed and Lucas, 1992), amino acid and translation (Fisher, 1985), genetic issues (Pashley, 1994), reproduction (Yah Yip, 1998), ecology (Adeniyi, 1985), vertebrates and invertebrates (Braund, 1998), the digestive system (Teixeira, 2000). In Turkey, in recent years there also has been an interest in determining students' misconceptions concerning biological concepts (Yılmaz, 1998; Tekkaya, Şen, Özden, 1999; Çapa 2000; Sungur, 2000; Tekkaya, Çapa, Yılmaz, in press).

Respiration has long been recognized as one of the most important and difficult to learn concepts of the basic biology curriculum (Bahar et al. 1999; Lazarowitz and Penso, 1992). Difficulties in the meaningful learning of this concept lead to formation of misconceptions in the cognitive structure of students (Seymour and Longden, 1991; Songer and Mintzes, 1994; Sanders and Cramer, 1992). Sanders, in 1993, also studied the erroneous ideas present in biology teachers concerning respiration. Results of all these studies revealed that students as well as teachers have difficulty in understanding the process of respiration. Up to now no similar study has been done on Turkish students. In this study, we aimed to conduct a cross-age study determining high school and university students' understanding of respiration, since cross-age studies provide an opportunity to observe the shifts in concept development that occur as students mature, increase in intellectual development, and experience additional work (Westbrook and Marek, 1991).

2. METHOD

2.1 Sample and Instrument

101 tenth grade students from two different high schools and 90 university students participated in the study. This study was conducted at the end of the spring semester of 2000. The clinical interview (Nussbaum and Novak, 1976) is one way of eliciting cognitive structures, but it is time consuming and not easily implemented with large groups of students. Therefore, an instrument based on one used by Sanders 1993 is utilized in this study. In this instrument, the students were required to write a brief essay concerning the process of respiration, its purpose, function, place and chemical formula and respiration in plants.

2.2 Analysis of data

From the students' written responses, a set of categories was identified and analysis was performed accordingly. Categories were complete understanding, partial understanding with specific misconceptions, specific misconceptions, complete misunderstandings and contradictions. An explanation of each category is given below:

Complete understanding: Responses which were expressed by the students in a scientifically acceptable manner.

Partial understanding with specific misconceptions: These types of responses showed some understanding of the concepts but also contained information which indicates misconceptions.

Complete misunderstanding: None of the responses indicating understanding were demonstrated.

Contradictions: The students' responses were in contradiction with their own apparant knowledge.

3. RESULTS

High school and university students' misconceptions related to respiration were identified. The results showed that students had difficulty in understanding mainly the purpose of respiration, chemical reaction of respiration, place of respiration and respiration in plants. Therefore, the results are reviewed in terms of these four conceptual areas.

3.1 Purpose of Respiration

Sixteen misconceptions held by university and high school students about the purpose of respiration were identified (Table 2). The purposes offered by most students were quite different from the biological meaning.

Table 2

Students' Misconceptions Concerning Purpose of Respiration

The purpose of respiration is:

a. to exchange O2 between blood and tissue
b. to exchange gases
c. to provide O2 to the organism
d. to live
e. to take air inside us
f. to expell waste materials from cell s
g. to obtain respiratory gas for burning foods
h. to produce water
i. to clean blood
j. to provide oxygen and to remove carbon dioxide
k. to remove CO2
l. to convert oxygen to carbon dioxide
m. to convert glucose into starch
n. to obtain O2 from glucose
o. to burn vitamins and minerals in the body
p. to breath
q. to replac dirty air present in lung with fresh air
r. transportation of gases
s. transfer of nutrient
t. taking CO2 from the blood and giving O2 to Hb in the blood

The majority of students have difficulty in grasping respiration as a chemical process rather than physical one involving exchange of gases. These students provide a common language definition for respiration, in which the term is used as a synonym for breathing. They fail to realize that purpose of respiration is not taking in oxygen and releasing carbon dioxide but proving energy to the organism. About 24 % of university and 51% of high school students had a complete understanding of the concept.

Table 3

Percentages of Students' Responses Concerning the Purpose of Respiration

	University	High school
Providing energy	24.3	51.5
Taking O2 and giving CO2	13.5	12.1
Exchanging of Gases	21.6	–
Proving O2	22.5	11.1
Living	5.4	12.1
Cleaning of blood	4.5	2.0
Getting fresh air	1	5.1

It is understood from the responses that several students assumed that oxygen is converted to carbon dioxide in the process of respiration.

3.2 Where Respiration Takes Place

Misconceptions of university and high school students concerning this concept are summarized in Table 4. These are Students' responses which were markedly different from those generally accepted by biologist. Only 34% of the university and 32% of high school students clearly understood where respiration takes place. However, more than 70% of students had difficulty in understanding that respiration occurs in cells.

Table 4

Students' Misconceptions Concerning Place of Respiration

a. Lung /alveoli
b. Respiratory system
c. Chest cavity
d. Trachea
e. Skin
f. Gill
g. Capillary
h. Centrosome
i. Heart
j. Mouth
k. Between alveoli and cell
l. Between lung and outside
m. Between alveoli and lung vessels
n. Stomata/leaves/chloroplast.

A majority of students hold the idea that respiration occurs in different places in animals and plants. Responses of some students given below:

Respiration occurs in respiratory systems, such as nose-pharynx-larynx-trachea-lung

Respiration takes place in trachea in insects, in skin in amphibians, in lungs in humans, and in leaves/stomata in plants.

Table 5

Percentages of Students' Responses Concerning Place of Respiration

	University	High school
Cell	34.2	32.3
Lungs	29.7	41.4
Respiratory system	11.7	17.2
Gill	2.7	4.0
Skin	4.5	3.0
Trachea	2.7	2.0
Chloroplast	1	3.0
Leaves/stomata	1	5.0

3.3 Chemical Formula of Respiration

Most of the university and high school students accepted that the formula for respiration is C6H12O6 + O2 $\rightarrow$ $CO_2 + H_2O$. It is clearly seen that they ignore the energy released during the respiration process. This finding provides further evidence that students see respiration as a process of taking in oxygen and giving off carbon dioxide. It is also found that the students perceive respiration as a reverse of photosynthesis As it is seen clearly from the formula, $C_6H_{12}O_6 + O_2 \leftrightarrow CO_2 + H_2O$ + Energy, they used a double arrow and labeled the forward one as respiration and the reverse one as photosynthesis.

Table 6

Students' Understanding of Chemical Formula for Respiration

Glucose + O_2	$\rightarrow$	$CO_2 + H_2O$
$CO_2 + H_2O$	$\rightarrow$	O_2
O_2 + glucose	$\rightarrow$	CO_2 + energy
Glucose + O_2	$\leftrightarrow$	$CO_2 + H_2O$
H2O + CO_2	$\rightarrow$	H_2CO_3 + H
Glucose + O_2	$\leftrightarrow$	$CO_2 + H_2O$ + energy
Glucose + O_2	$\rightarrow$	CO_2 + small particles
Glucose + O_2	$\rightarrow$	$CO_2 + H_2O$ + heat energy
Glycogen + O_2	$\rightarrow$	$CO_2 + H_2O$+ glucose
Glucose + O_2	$\rightarrow$	CO_2
Glycogen+ O_2	$\rightarrow$	$CO_2 + H_2O$
CO_2	$\leftrightarrow$	O_2
2ATP + glucose + O_2	$\rightarrow$	$H_2O + CO_2$ + 40 ATP

Table 7

Percentages of Students' Responses Concerning the Chemical Formula of Respiration

	N	Always	Day	Night	No response
University	90	21.1	6.3	38.7	6.3
High school	101	62.6	1	31.3	1

3.4 Respiration in Plants

In this part, students' understanding of respiration in plants was investigated. As it is seen from the Table 8, most students believed that plants respire at night. Of 90 university students, approximately 21% of them gave the correct reponse that "plants respire all the time". On the other hand, out of 21%, only 5% explained the desired reason : "to produce energy". Hence, we can say that of 90 university students, only 5% demonstrated complete understanding. Although 63% of high school students demonstrated the correct response, most of them failed to explain the reason. Only 20% gave the desired response.

About 45% of university and 32% of high school students' responses demonstrated complete misunderstanding of the concept. They realized that plants respire either during day or during night. The most common misconception among the students was that " plants respire during the night". A few students thought, wrongly, that "plants respire during the day" (Table 8).

Table 8

Percentages of Students' Responses to 'When do Plants Respire'

	N	Always	Day	Night	No response
University	90	21.1	6.3	38.7	6.3
High school	101	62.6	1	31.3	1

The majority of students' responses showed some understanding of the concepts but also contained information which indicates misconceptions, catagorized as partial understanding with specific misconceptions (Table 9).

Table 9

Students' Responses Demonstrating Partial Understanding with Specific Misconceptions

Plants respire all the time;

a. but at night respiration increases to compensate photosynthesis
b. but at night their respiration can be seen
c. to produce food
d. to feed themselves by photosynthesis
e. to live/to survive
f. to get rid of CO2 and take O2
g. because in sunlight they do photosynthesis
h. because they are living organisms
i. because they need energy to do photosynthesis
j. because they always need to exchange gases
k. because they have to breath and get rid of CO2

Some students thought that respiration is a visible, tangible process. They did not realized that respiration is an internal process and cannot be seen. Students' misconceptions about respiration in plants are demonstrated in Table 10.

Table 10

Students' Responses Demonstrating Complete Misunderstanding

Plants respire during day time

a. to produce food by photosynthesis
b. to store glucogen in their body
c. because light is required for the enzyme present in chloroplast
d. because they can not produce energy at night.
e. because plants respire through photosynthesis. Therefore sunlight is required
f. because chloroplast needs light to produce energy

Plants respire during night

a. because, they make photosynthesis in the sunlight.
b. because plants use sunlight to make photosynthesis
c. because there is no light for photosynthesis
d. because they can not produce energy by photosynthesis when there is no light
e. because they cannot make photosynthesis during night therefore they have to respire
f. because no energy is required for photosynthesis
g. because they produce O2 with photosynthesis in the sunlight
h. because during the day, they obtain their energy by photosynthesis. This energy is used in food production.
i. because during the day glucose is synthesized and at night O2 is taken to burn glucose.
j. because they cannot produce C6H12O6 because of lessened sunlight, instead they produce CO2, H2O
k. because they need H2O and give O2 to the environment.

l. because plants need CO2 to produce their food.
m. because at night they use glucose produced by photosynthesis during the day
n. because this reaction, C6H12O6 + O2 → CO2 + H2O occurs in the absence of light
o. because the rate of photosynthesis is less than respiration rate
p. because plants take oxygen in only at night
q. because plants take oxygen and give carbon dioxide
r. to give out CO2
s. to produce energy for photosynthesis, excretion etc.
t. to produce energy
u. to obtain energy used by photosynthesis
v. to use energy stored during day
w. to get energy by taking O2
x. to use their prepared food by burning it with O2
y. To use O2 and produce CO2 for energy
z. there is no sunlight and they need energy to live

Some students attributed additional ideas concerning respiration in plants, catagorized as specific misconceptions (Table 11).

Table 11

Specific Misconceptions Concerning Respiration in Plants

Plants respire

a. to carry sufficient O2 to the lungs
b. to release O2, because plants use CO2 during respiration.
c. to do photosynthesis
d. to produce food
e. to take CO2
f. to produce ATP to do photosynthesis
g. to get CO2 and give O2 to the atmosphere because they do photosynthesis
h. to maintain their body temparature during hot weather
i. when they need food which is ATP
j. when light is not enough for them to produce energy
k. when there is no light for photosynthesis
l. when they can not do photosynthesis
m. when O2 saturation in blood is insufficient to carry sufficient O2 to lungs
n. when they need O2
o. through photosynthesis
p. through stomata /leaves
q. during photosynthesis to produce glucose

It can be understood from the responses of students that they see respiration and photosynthesis as mutually exclusive processes that do not occur simultaneously in plants. In other words, they thought plants can not respire and photosynthesize at the same time. This is implied by 35% of university and 20% of high school students who indicated that "plants respire only at night" because, "they make photosynthesis in the sunlight". It is also found that the students perceive respiration as a reverse of photosynthesis which provides further evidence that students see these two processes as mutually exclusive, one occuring during day and the other at night.

Many of these misconceptions are typical misconceptions identified by other studies (Sanders 1993; Sanders and Cramer, 1992; Seymour and Longden, 1991).

Findings of our study supported the idea that misconceptions concerning one concept can also impede understanding of another. For example, students who accepted the purpose of respiration is taking in oxygen and giving off carbon dioxide also indicated that respiration takes place in lungs/respiratory systems (40% of university and 30% of high school students). Percentages of students ignoring energy release in the formula in addition to these two concepts were 23% in the university and 17% in high school students. Only 10% of university and 21% of high school students explained these three concepts correctly. Among students, very few (3% of university and 6% of high school) showed a complete understanding of all the four concept areas investigated in this study. The results indicated that the lack of understanding of concepts such as chemical nature of respiration hampered clear explanations of the process of respiration.

A considerable degree of students expressed ideas, contradictory ideas. For example, they indicated that purpose of respiration is to produce energy but they failed to include energy at the end of formula. Similarly, students who believed that the purpose of respiration is taking in oxygen and giving off carbon dioxide, added energy at the end of formula. Furthermore, students knowing that energy is produced in the cell, on the other hand wrote that respiration occurs in lungs. All of these responses indicate inconsistent use of knowledge. The same situations were also observed in the case of respiration in plants: "Plants always respire but at dark they do respiration to get energy"; "plants respire at night, because they cannot produce energy at night".

4. DISCUSSION

The results of the study revealed that regardless of the age of the students or the level of schooling, misconceptions about respiration were prevalent and persistant. The responses of university students seemed to be more com-

plicated, consisting of more scientific terminology than those of high school students. Although the university students had been exposed to more information, the increased exposure to concepts and vocabulary evidently did not lead to increased understanding of the concept. Previous biology, chemistry as well as physics courses seemed neither to improve students' performance nor to prepare them to master these concepts during the course. This observation indicates that misconceptions are strongly held views which persist throughout the student's education and which are not easily remedied. Consequently, misconceptions seriously affect the students' understanding and subsequently, when failing to grasp the basic concept, they tend to employ a rote learning strategy in studying biology in order to pass examinations. As a result, students may have learned concepts which are not retained in their minds, but forgotten after some time. This means that concepts could not have been learnt meaningfully. The students may not have assimilated the prerequsite ideas into their cognitive structure, which is necessary for a meaningful understanding of the new topic. Teachers can be astonished to learn that desite their best efforts, students do not grasp fundamental ideas covered in class. Even if some students give the right responses they may only be using correctly memorized words. When questioned more closely, these students reveal their failure to understand fully the underlying concepts.

Respiration and gas exchange are topics which many students fail to understand completely. Numerous misconceptions propose that commonsense ideas and everyday experience outside of the school influence students' understanding of the scientific concept of respiration. The responses of several students indicated a persistent belief that respiration, gas exchange and breathing all have same meaning. Therefore it would be reasonable to expect students to conclude that respiration takes place in lungs. On the other hand, respiration is a term that is used in the biological contexts with a different meaning from everyday language. Misconceptions like 'respiration is the same as breathing' and 'respiration occurs in lung' are already implemented tightly in the minds of the students and show resistance to change over time.

Barras (1984) criticises the imprecise use of language in teaching. The use of more than one term for a concept, such as, "internal respiration"; "external respiration"; "cellular respiration"; "general respiration"; "aerobic respiration" ; "respiration" create confusion in students' minds. He claims these terms are misleading, implying that respiration can occur outside of cells. On the other hand respiration is a chemical process occuring in all organisms all the time to breakdown energy-rich compounds to provide energy for metabolism.

The majority of students believed that photosynthesis and respiration function in an opposite and contrasting manner. Some textbooks, used in Turkish high schools and university, encourage this view by presenting tables that compare and contrast the reactants, products, and equations of photosynthesis and respiration, (Bulut, Sağdıç and Korkmaz, 1999: 83; Solomon et al. 1993: 203) others (Bernstein and Bernstein, 1996:106) include statements such as "in some ways, photosynthesis is opposite of respiration". Bernstein and Bernstein stated that "when aerobic respiration burns glucose as a fuel, the overall reaction is the reverse of photosynthesis"... "the two reactions complement each other; photosynthesis uses the products of cellular respiration (carbon dioxide and water), and cellular respiration uses the products of photosynthesis (sugar and oxygen gas). p 106". Schraer and Stoltze (1987), stated that "photosynthesis is in fact, the reverse of cellular respiration. In respiration, glucose and oxygen are used to produce carbon dioxide, water and energy. In photosynthesis, carbon dioxide, water and energy of light are used to produce glucose and oxygen." (p. 289).

Textbook errors related to respiration can be summarized as follows: Starr and Taggart (1992) emphasis that "...aerobic respiration produces the most ATP for each glucose molecule being dismantled..." (p.120). However, they did not include energy in the formula of respiration.

Sequencing may be another important point, which causes difficulty understanding the concept. In many curricula, the topic of respiration is introduced relatively early in the course and inserted somewhere between osmosis and mitotic cell division (Songer and Mintzes, 1994). They suggested that "respiration and photosynthesis are better understood within the context of energy flow in natural ecosystems, following a consideration of important physiological topics such as gas exchange, digestion and transport mechanism". Similarly, in some of the textbooks taught in Turkey, respiration is embedded between transport of materials across cell membrane and photosynthesis which is followed by mitosis (Barret et al. 1986; Starr and Taggert, 1992; Bernstein and Bernstein, 1996) and between photosynthesis and genetics (Bulut et al., 1999).

Certain prerequisite concepts are necessary for learn-

ers to develop understanding of a certain concept. If these do not exist, it would be difficult for the learner to understand the new concept. Students' misconceptions arise when they combine a newly learned concept (respiration occurs in cell), with their previously held, primitive ideas (respiration occurs in lungs). Many biological concepts have their foundation both in the chemical and the physical sciences. Students' understanding of biological processes breaks down because of physical and chemical science misconceptions. Some of the prerequisite concepts require knowledge of chemistry and physics. In order to understand the chemical nature of respiration, students should have mastered the concept of chemical reaction, organic and inorganic compounds, and energy transformation in chemistry course before being introduced to respiration / photosynthesis in their biology course.

5. CONCLUSION

In the teaching and learning of biology, concepts do not exist in isolation. Each concept is closely related to others (Novak, 1970; Fisher, 1985). However, students tend to memorize the concepts without thinking about the reason behind them. As a result of rote-memorization, they could not make any connection between the concepts. Thus, they show a wide range of difficulties in understanding the basic biological concepts. If these misconceptions are not detected and corrected immediately, they will adversely affect the students' subsequent learning. This is a major source of learning problems in schools. Therefore, there is a need to identify the causes of such misconceptions and to find ways to rectify them.

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