JOURNAL OF BALTIC SCIENCE EDUCATION

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

THE COGNITIVE STRUCTURE OF PRE-SERVICE SCIENCE TEACHERS ABOUT ENERGY METABOLISM

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Abstract. *In this research word association test was used to explore the cognitive structure of Pre-service science teachers about biological energy metabolism. The participant group constitutes 67 Pre-service students at a university in Black Sea Region of Turkey. Ten key concepts in General Biology course were given as a stimulating word and a mind map was established by using the frequency values of valid response words. The results showed that the total number of different response words for the key word "enzyme" is the highest with "cell" and "energy" being higher than others and for the key word "photosynthesis" is the lowest. The mind map also showed that they based their cognitive perceptions of the biological energy mechanism mostly on scientific concepts that are emphasized in the lessons and are academically acknowledged and included in the concepts used in everyday life at the least. However, they were not able to see the key concept "enzymes" as a part of branched network and they had also problems regarding the respiratory event in the plants as well as realization process of photosynthesis in the cellular level. Implications of the results in terms of understanding the subject of biological energy metabolism are also discussed.*

Keywords: *biological energy metabolism, cognitive structure, mind map, pre-service science teacher, word association test.*

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Introduction

Energy is required for all biochemical reactions in living organisms. There are two components of the complementary biological energy mechanism that is photosynthesis and respiration. In photosynthesis the green plants and certain other organisms called photoautotrophs transform light energy into the chemical energy. During photosynthesis in photoautotrophs the light energy is captured by chlorophyll and used to convert water, carbon dioxide, and minerals into oxygen and energy rich organic substance called glucose. Then glucose can be converted into other organic compounds such as fat, protein and long chained carbohydrates. On the other hand, respiration is the process by which heterotroph organisms break down glucose in order to release energy. In autotroph organisms this process requires oxygen and is catalyzed by enzymes. Photosynthesis and respiration complement each other but occur almost inversely to each other. The end products of the respiratory reaction, carbon dioxide, and water, are the raw material of the photosynthesis reactions and the glucose occurring as a result of photosynthesis is broken down in order to obtain energy in respiratory reactions. Thus, while aerobic organisms provide carbon dioxide for photoautotrophs to be used in photosynthesis and to produce glucose, these photoautotrophs provide the oxygen needed for the respiration of all living organisms. Therefore, photosynthesis and respiration are two basic interrelated processes necessary for the living creatures in the world to continue their lives. It is necessary for people to understand the importance of these phenomena, which take such a great place in the life, in order to protect the environment and to healthily maintain the life. For teachers, who have a significant share in the learning lives of children and young people, to understand these issues and transfer them correctly to their students provide a great incontrovertible contribution to this requirement. The reason is that the basic aim of science educators is that the concepts that are intended to be taught are meaningfully understood by students and the knowledge learned is used in daily life (Köse, Coştu & Keser, 2003). Biological phenomena, including photosynthesis and respiration, involve too many abstract concepts, which makes it difficult for students to construct and structure the knowledge (Keleş & Kefeli, 2010).

The cognitive structure is a hypothetical construction showing relations held between concepts in a learner's long-term memory (Shavelson, 1974). According to Tsai (2001) it contains the learners' existing experiences and knowledge that will dominate their reconstruction and information processing of the incoming stimuli. There are variety of methods to explore the cognitive structure such as concept maps, tree construction, structural communication grid, diagnostic tree branching etc. The word association test (WAT) which shows how the knowledge of any subject is constructed and structured in mind and how the relationship between the concepts in these subjects is established, has also been used by many researchers to reveal the cognitive structure of students on the subject examined (Atabek-Yiğit, 2016; Bahar, Johnstone & Sutcliffe, 1999; Bahar & Özatlı, 2003; Kostova & Radoynovska, 2008; Ozata-Yücel & Ozkan, 2016; Tokcan & Yiter, 2017). The WAT is based on the assumption of responding with free stimulus words without limiting the ideas that come to mind (Bahar, Johnstone & Hansell., 1999; Sato & James, 1999). In other words, the WAT is based on the assumption that giving a stimulus word and asking the respondent to freely associate what ideas come to his or her mind gives relatively unrestricted access to mental representations of the key term (Hovardas & Korfiadis 2006). The order of the response retrieval from long term memory reflects at least a significant part of the structure within and between concepts (Shavelson, 1974). The smaller the distance between two concepts is, the more closely these concepts are related and the faster the response is (Bahar & Özatlı, 2003).

Research Problem

In this research, it is aimed to explore the Pre-service science teachers' cognitive structure related to biological energy mechanisms namely respiration and photosynthesis by using the WAT as the topics respiration and photosynthesis are perceived as difficult to learn by the students (Bahar, Johnstone & Hansell, 1999; Keleş & Kefeli, 2010; Tekkaya, Özkan & Sungur, 2001) and they are important in terms of understanding the energy mechanisms in biology. In accordance with this aim, the main problem of this research is "how the Pre-service science teachers' cognitive structure about energy mechanism is constructed?" On the basis of this main problem, the following sub-problems are tried to be answered;

- What are the differences between the total numbers of response words to each key word related to biological energy mechanism?
- How are the key concepts and their response words about the biological energy mechanisms linked in Pre-service science teachers' cognitive structure?
- What are the possible implications of the results related to the understanding the subject of biological energy metabolism?

Methodology of Research

Research Design

The research design is comprised of the phenomenology that focuses on phenomena, experiences, perceptions, orientations, concepts, or situations that are recognized but about which there is not an in-depth and detailed understanding (Yıldırım & Şimşek, 2008). In this research, the phenomenon, about which an in-depth opinion is wanted to be formed, is the perceptions of Pre-service science teachers of the biological energy mechanism.

Study Group

The study group Of the research consists of 67 Pre-service teachers in total studying in the second grade of the Department of Science Teaching, Faculty of Education at a university in the Western Black Sea region in the spring semester of the 2015-2016 academic year. The study group is made up of 9 male and 58 female participants whose ages are ranging from 19 to 21. In the formation of the study group, criterion sampling, one of the purposeful sampling methods, was used (Yıldırım & Şimşek, 2008). While the fact that the Pre-service science teachers took the courses of General Biology I and II was considered to be the main criterion, a study group was formed on the basis of volunteerism from the Pre-service teachers who fulfilled this criterion. Apart from this criterion the other Pre-service science teachers' demographic characteristics such as income levels, ethnic sub-structures, and family structures are not taken into consideration as they are not related to the aim being explored.

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Data Collection Tool and Application Period

The Word Association Test: In order to construct the WAT, 10 key concepts (i.e. cell, enzyme, energy, photosynthesis, respiration, chloroplast, mitochondria, carbohydrate, fat, and protein) were selected based on the studies that were considered to be essential for the subject of the biological energy mechanism. In organizing these concepts and providing the internal validity, 3 experts in the field of science education and 2 lecturers in the field of biology education were consulted, and the data collection tool was given the final form by taking into account the recommendations of the experts. The data collection tool was prepared in such a way that each concept was written on a page, one under the other ten times, and the answer word reminding of the key concept could be written across each concept.

Application Period: Before the application, the students were made practise on the WAT technique using a different word, and it was ensured that they understood the technique. Explanations on the WAT were made to the Pre-service teachers and an average of 30 seconds was given for each concept. This period was determined according to the studies in the literature (Bahar, Johnstone & Hansell, 1999; Bahar & Özatlı, 2003). In the WAT studies, Pre-service teachers were asked to write the words that they thought to be related to each key concept one under the other in the given time. It has also been stated in the studies conducted that the reason for writing the words associated with the key concept one under the other is to prevent the risk of a chained response (Bahar & Özatlı, 2003).

Data Analysis

There are two ways analyzing the responses in the WAT. One way is to measure the number of common words between the responses to the pairs of key word and their rank orders. Another way of looking for relations was offered by Bahar, Johnstone and Hansell (1999). In this study the second approach was adopted. In this procedure, a frequency table was prepared by counting the valid response words for each key word. The response words used in the count were taken to be *valid* by the researchers if they are meaningful and acceptable related to the course. Counting the number of response words to each key word is one way of summarizing the word association data (Shavelson, 1974). It can be assumed that the number of different responses for a word is a significant and direct indication of the individual's understanding of the word, as meaning can be defined as being proportional to the number and complexity of the links the individual can make (Bahar, Johnstone & Hansell, 1999), the meaning of the word is enriched as more connections are formed (Schaefer, 1979). By using the frequencies, a mind map was established. The mind map is very informative about the structure and the complexity of the students' cognitive structure. In the establishment of the mind map, the cut-off point technique developed by Bahar, Johnstone and Hansell (1999) was used. In this technique, the highest frequency in the table was identified and a cut-off point was determined by using an interval. The first cut-off point was shown in Figure 1 where the frequencies 51-42 were taken into consideration. Then the cut-off points were lowered step by step (that is 41-32 and 31-22) and each time the associations between the key words and their response words are drawn. This procedure was concluded when all the key words appeared in the mind map. In this study the cut-off points were lowered one step further (i.e., 21-12) in order to reveal deeper the Pre-service science teachers' conceptual network. It is important to mention that it is not necessary drawing two or more independent mind maps and comparing them in order to find out reliability because the mind map is constructed by using the values in the frequency table and there is not another way of drawing it differently. Only the location of the response words in each cut-off points can be changed, and this does not affect overall quality of the mind map drawn by using exact frequency values.

Results of Research

The total number of different responses to each of the key words is given in Table 1. As can be seen from Table 1, because the WAT was applied after teaching General Biology I-II courses, the total number of different response words to the key words is high. The total number of different response words for the key concept "enyzme" is the highest with "cell" and "energy" being higher than others and for the key concept "photosynthesis" is the lowest. The key concepts "enzyme" and "energy" are not only specific to biology. Pre-service science teachers might be more familiar with these key concepts than with the other as they learn these key concepts and their associate words in other science disciplines such as in chemistry, physics. The total number of different key concepts "chloroplast" and

"photosythesis" are lower than the others, because these key concepts are mentioned mainly in a narrow context in biology. In comparison with other key concepts and their associate words, chloroplast and photosythesis with their associate words can not be emphasized in other information sources such as TV, newspaper etc.

Table 1. The total number of different response words to each key concept in the WAT.

Key concepts	Total number of different response words
Enzyme	201
Cell	175
Energy	172
Mitochondria	166
Fat	166
Protein	142
Respiration	131
Carbohydrate	130
Chloroplast	126
Photosynthesis	114

Cut-off point 51-42

In this research, in which the cognitive structures of Pre-service science teachers in relation to the biological energy mechanism were examined, it was observed that the key concepts of mitochondria, chloroplast, photosynthesis, and respiration appeared by being associated with other concepts at a high frequency at the cut-off point 51-42 (Figure 1).

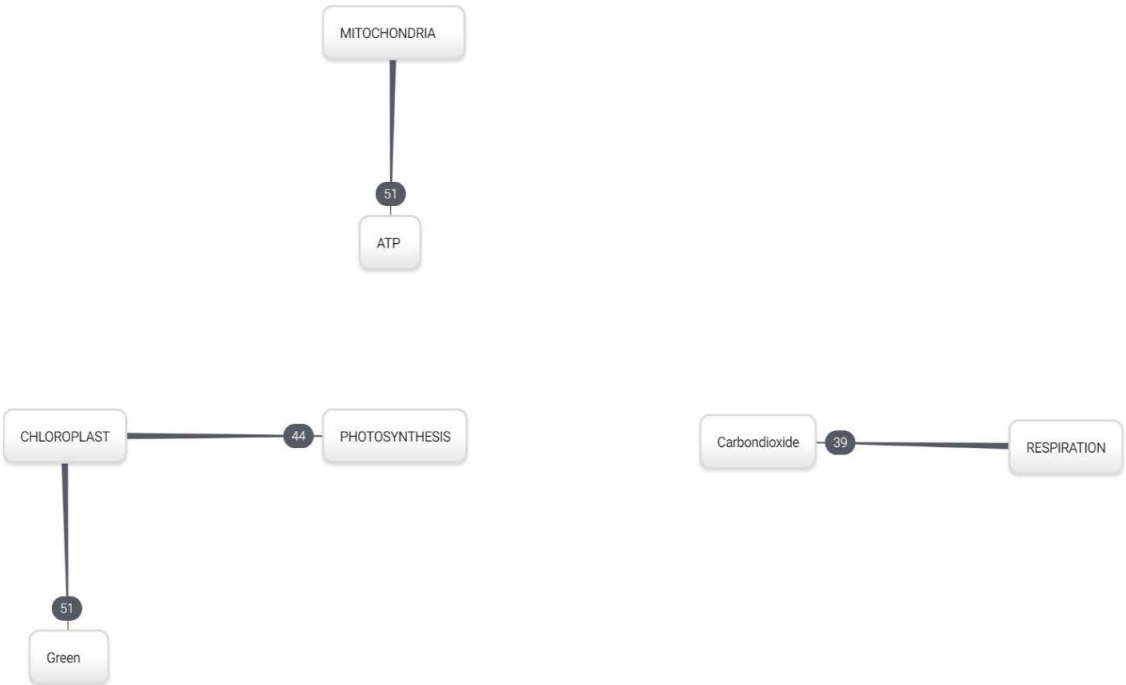

Figure 1: The cognitive structure of pre-service science teachers in relation to the biological energy mechanism according to the cut-off point 51-42.

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

The appearance of the chloroplast key concept as being associated with the word green at a high frequency may be due to the fact that the Pre-service teachers saw this structure under a microscope in laboratory classes, in which microscope applications were performed, and materialized it and thus, it became more permanent in their minds. Furthermore, the fact that the concept of chloro means green in English may have increased the association. It was observed that at the same cut-off point, the key concept of photosynthesis was associated with the chloroplast, the organelle in which this phenomenon occurs, but the key concept of respiration was not associated with the mitochondria, the organelle in which this phenomenon takes place. It was found out that the response word ATP was associated with the mitochondria at a high frequency, but the association of the same word with photosynthesis could not be established at this cut-off point. This is due to the fact that the ATP appears as an end product as a result of a series of reactions occurring in the mitochondria in the mitochondria-ATP association, whereas the ATP is produced as an intermediate product in the photosynthesis process, is reused in the production of nutrients and oxygen, and does not appear as an end product. Furthermore, it is possible that the fact that textbooks mention the mitochondria first from the energy, i.e., ATP, production mechanisms and do not emphasize the ATP produced in photosynthesis in the context of the "energy production", and also that the organic matter and oxygen production brought to the forefront in photosynthesis might have affected this result. However, since it was the first frequency interval, it was observed that three separate and disjointed diagrams appeared as expected for the biological energy mechanism.

Cut-off point 41-32

The key concepts of protein, cell, energy, and carbohydrate are observed to be added to the structure at the cut-off point of 41-32 (Figure 2).

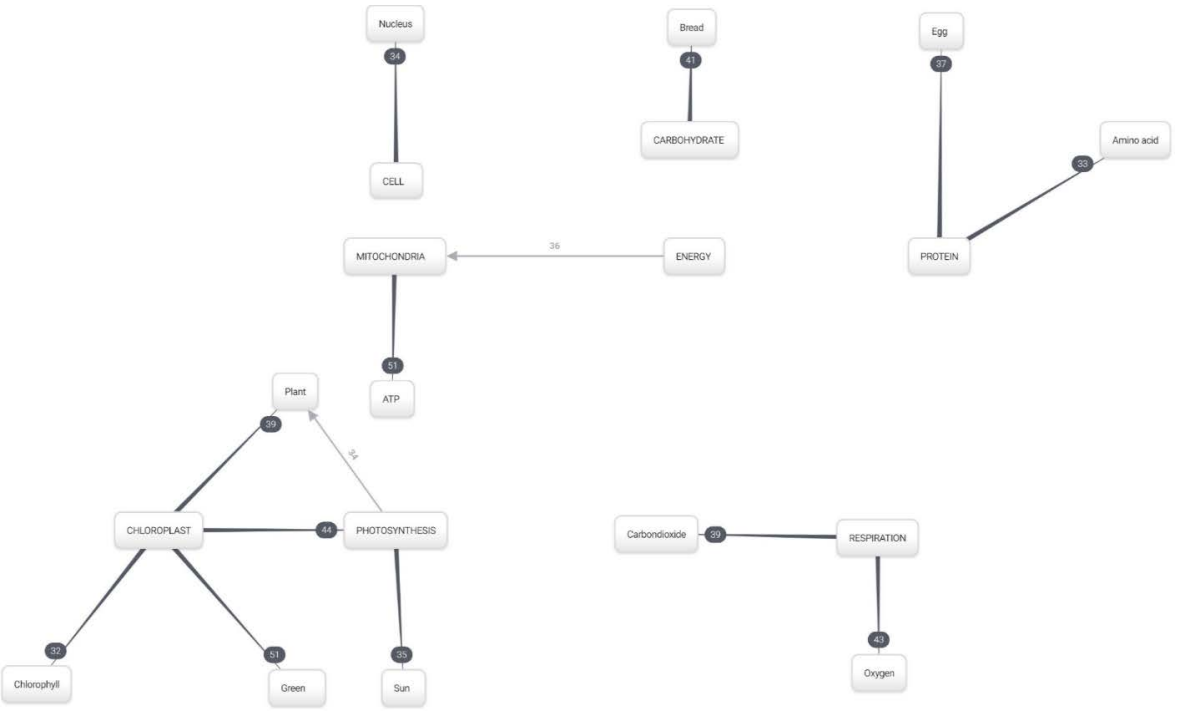

Figure 2: The cognitive structure of pre-service science teachers in relation to the biological energy mechanism according to the cut-off point 41-32.

Since the organelles, in which the biological energy mechanism takes place, are in the cell, it was observed that the key concept "cell" was associated only with the nucleus and appeared disjointedly from other concepts. While the key concept "protein" was expected to be associated with amino acid, its fundamental building block, the association of the egg, among the main protein source nutrients, with protein at a higher frequency and the association of the key concept "carbohydrate" with the word bread suggest that there are also foods affecting the energy mechanisms in the cognitive structures of pre-service teachers. This result also gives the message that in structuring the information network of students, the cognitive structure of them can be shaped by adding not only the concepts they learn in the class but also many concepts from different sources. At this cut-off point, Pre-service science teachers established a trilateral association by adding the word plant as common to the key concepts "chloroplast" and "photosynthesis." The fact that this structure did not include the key concept "respiration" and that this association was not found at other cut-off points may be due to the fact that the pre-service teachers thought that respiration was the process specific only to animals. Moreover, the fact that the word key concept "respiration" was not associated with the words plant, cell, mitochondria, carbohydrate, protein, energy, and ATP in the same cutting interval shows that the phenomenon of respiration is perceived as a system rather than at a cellular dimension. The main source of light required for photosynthesis, the sun, and the word chlorophyll, which is found in the chloroplast and is the main site of photosynthesis, are added to the structure in this interval.

Cut-off point 31-22

At the cut-off point 31-22, the key concepts of enzyme and lipid were also added to the structure, and it was found out that 10 key concepts appeared at this point (Figure 3).

However, it was observed that the key concept "enzyme" was associated only with the substrate disjointedly from the main structure and that the key concept "protein" was not associated with enzyme and was associated with the ribosome, which is the center of the meat, muscle, and protein production. At this cut-off point, the pre-service teachers directly linked the concept of energy with the key words carbohydrate, lipid, and protein that are used as energy sources. The addition of the words chloroplast, green, light, water, ATP, oxygen, and carbon dioxide to the structure at the frequencies close to each other in addition to the words sun and plant that appeared in the previous interval to the key concept "photosynthesis" shows that the key elements required both for the start and the continuation and termination of the phenomenon of photosynthesis take place in their cognitive structure. In addition to these, the emergence of the relationship between the key concept "respiration and only the response words lung and breath in this cutting interval and the inability to establish the association of this concept with the key concepts such as the cell, mitochondria, and enzyme show that the phenomenon of respiration is perceived at the macro level and cannot be reduced to the cellular dimension. It was observed that the concept network formed at the cut-off point 31-22, in which all the key concepts given at the beginning appeared, was quite simple (Figure 3). It was also observed that the links that were supposed to be established were not fully established. The examples are as follows; the inability to associate respiration with other organic substances such as glucose, the inability to perceive the chloroplast as an organelle, while the mitochondria are perceived as an organelle, the inability to establish the protein-enzyme relationship, and the poor association of the cell with other concepts although all phenomena occur within the cell, and the inability to observe the association between the key concepts respiration and photosynthesis.

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

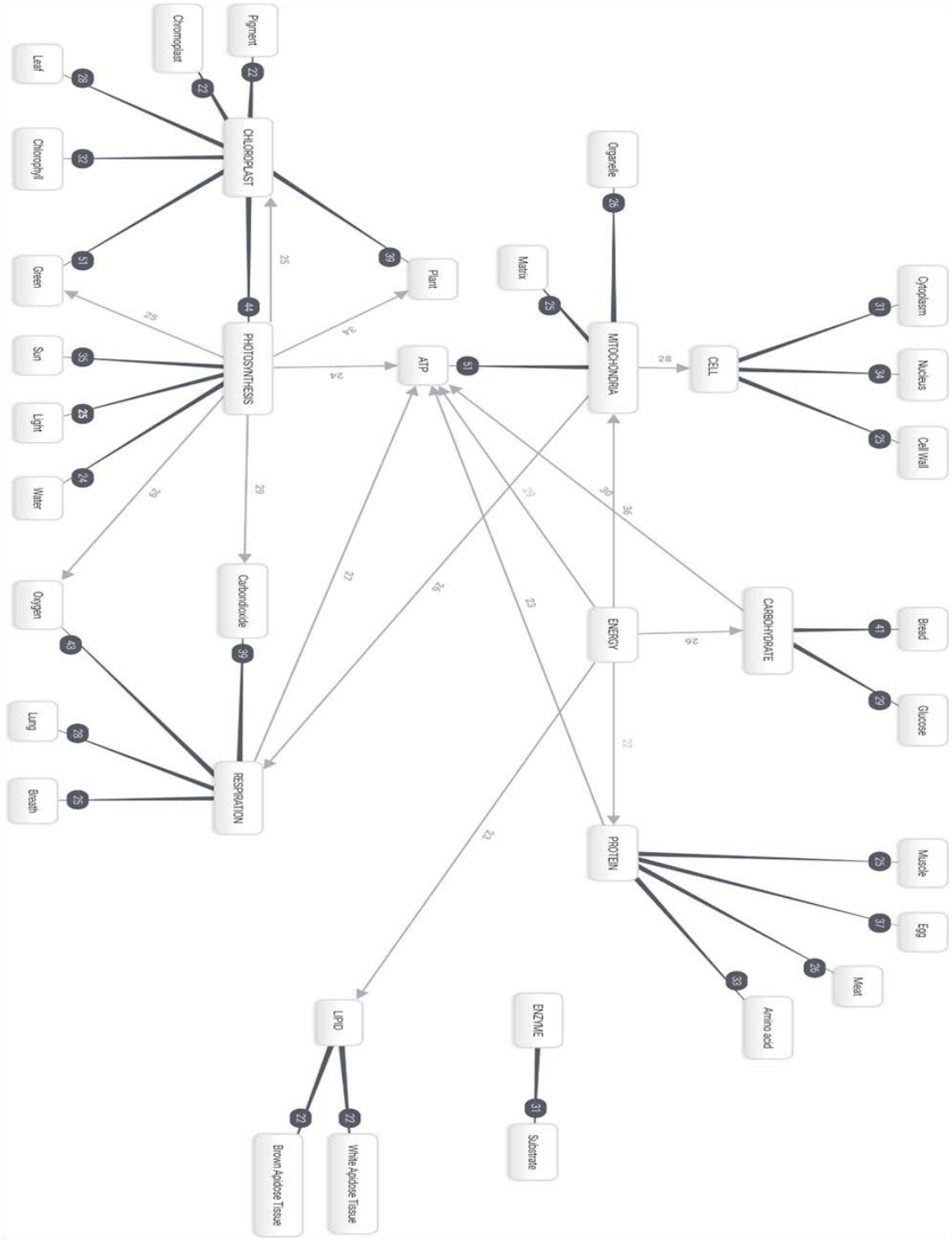

Figure 3: The cognitive structure of pre-service science teachers in relation to the biological energy mechanism according to the cut-off point 31-22.

Cut-off point 21-12

Although all keywords appeared in the previous interval, the cut-off points were once again dragged down to reveal the deeper cognitive network of the Pre-service science teachers. At this cut-off point, which is one more step down, it was observed that the network was much more developed and more complex (Figure 4).

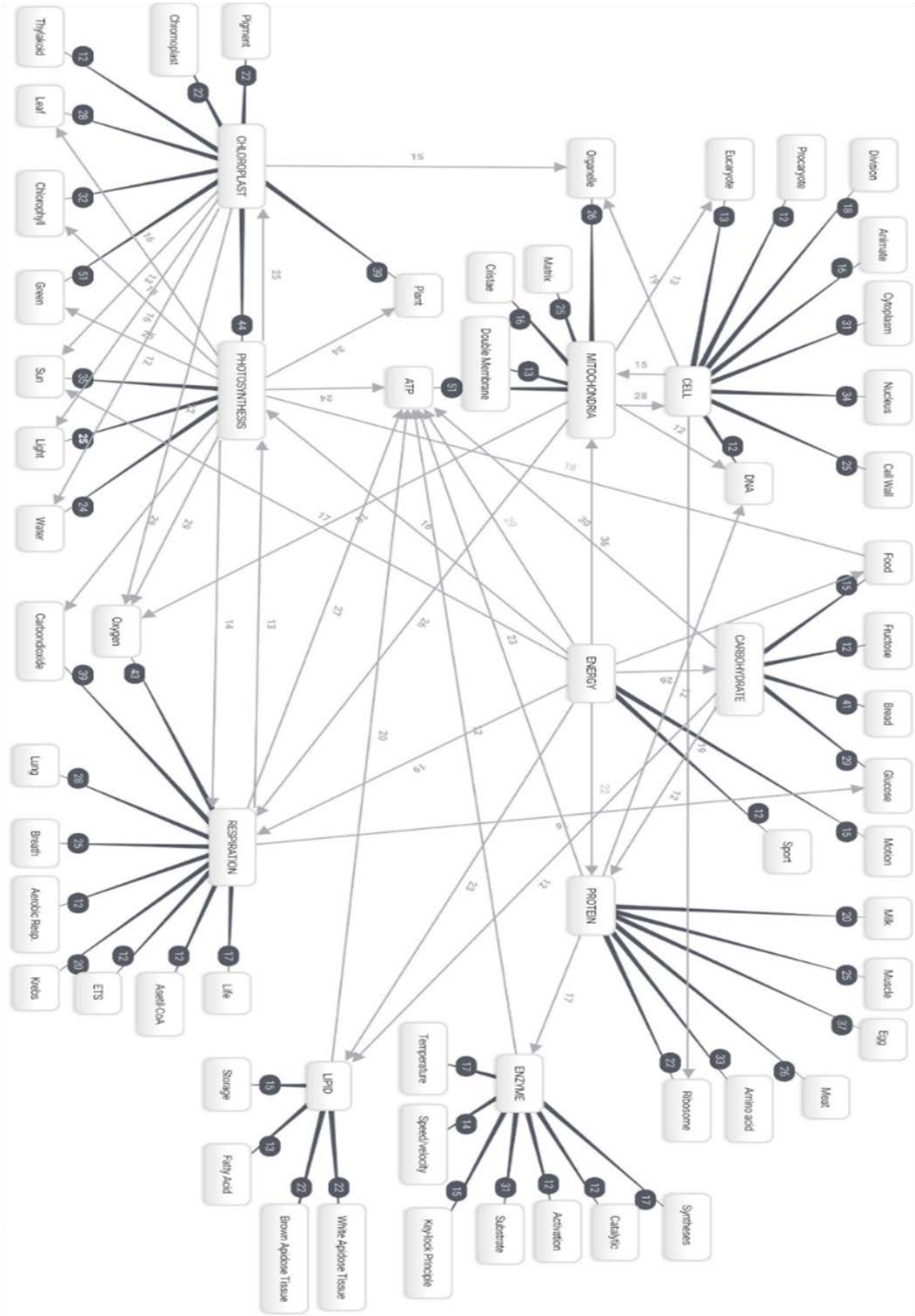

Figure 4: The cognitive structure of pre-service science teachers in relation to the biological energy mechanism according to the cut-off point 21-12.

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

The keyword of enzyme, which appeared disjointedly from the main structure at the previous cut-off point, was observed to be associated with protein and ATP in this interval. It was observed that the Pre-service science teachers drew attention to the variables affecting the enzyme activity in biochemical reactions and the structure of enzymes in the association they made between the keyword of enzyme and the temperature, velocity, catalyst, activation and key-lock words. The association of mitochondria with words related to its structure such as the crista, double membrane, and matrix shows that the areas where respiration occurs were also understood. In the keyword of protein, it was observed that the word milk, together with the words meat and egg appearing in the previous cutting intervals, was added. It can be said that this is caused by considering this food as an energy source. Similarly, it was observed that the components and species of the lipid molecule also appeared in this interval. It was also observed that most of the incompletely established connections observed at the previous cut-off point were also established at this cut-off point.

Discussion

In this research, the cognitive structures of Pre-service science teachers related to the biological energy mechanism were examined by the WAT. In general, it was found out that the Pre-service science teachers based their cognitive perceptions of the biological energy mechanism mostly on scientific concepts that are emphasized in the lessons and are academically acknowledged and included in the concepts used in everyday life at the least. However, the results also showed that the structure of the key concept "enzyme" takes an important place in both respiration and photosynthesis phenomena, which is disjointed from the main template and cannot be associated with other key concepts. The association of the word "enzyme", which is not included in the template in any way until the third cutting interval, was made independently of the energy mechanism, which is the main context, by addressing the operation model (substrate, key-lock principle), the factors affecting its operation (temperature), its definition and properties (catalyst, activation, protein), and its duties (synthesis). Although it was expressed in the study content that the key concept of enzyme needs to be addressed in terms of its role in the energy generation, it is another interesting finding in the enzyme concept that the pre-service teachers made the ATP-enzyme association in the last cutting interval and at a very low frequency and the association of it could not be made with the energy-producing enzyme, the ATP synthase. This can be interpreted as the fact pointed out by Bahar (2002) in his study that "among the subjects in which difficulties are experienced in learning biology, the subject of enzyme is abstract and thus the structural integrity of the biological organization cannot be met" (Lazarowitz & Penso, 1992). In the study conducted by Atav et al. (2004), it was also expressed that students commonly have misconceptions about the enzyme kinetics expressing the enzyme-energy relationship. Although no alternative enzyme-related concept has been proposed in this study, it is debatable to associate it with the energy in a far-end cutting interval from the main network. On the other hand, although enzymes work in an aqueous environment in the cell, the fact that the word water is only included in the photosynthesis-chloroplast-water relationship and cannot be associated with the key concept of enzyme shows that the thoughts of students, as stated in the study conducted by Sinan et al. (2006), that "water is not effective in enzyme activities" may have been thought of by the pre-service teachers in the present study. On the other hand, the association of the concept of enzyme with the word key-lock also appeared in the study conducted by Kurt and Ekici (2013), and they attributed this association to the fact that this model is shown intensively to individuals in the primary, secondary, and high schools and university.

The Pre-service science teachers were found to express the key concept "energy" by materializing the energy obtained or consumed as a result of physical activities such as motion and sports in the cutting interval of 21-12 at a low frequency. This finding supports the findings of the study conducted by Trumper (1997) with 189 biology teachers. Similarly, the fact that the pre-service teachers associated the energy obtained from foods with carbohydrate, protein, and fat molecules can be considered as an effort to materialize the energy conversion. This tendency of the Pre-service teachers is similar to the tendencies of Pre-service teachers in the studies of Trumper, (1998); Trumper, Raviolo & Shnerch, (2000). As Kaper and Goethart (2002) pointed out in their study, the individuals' definition of the concept of energy primarily as an observable phenomenon was encountered in the energy-respiration association obtained in this study, which brings to mind the principle of learning from the known to the unknown. In the study of Kurt (2013) in which the cognitive structures of the concept of energy were examined, it was found out that Pre-service teachers addressed the biological energy mechanisms at most and they associated this energy with the energy obtained from the foods, respiration, and photosynthesis. However, it was observed that especially the concepts of photosynthesis and respiration were intensively included in the studies on the concept of energy, which

is the subject of research in the discipline of biology (Al-Khawaldeh & Al-Olaimat, 2010; Bacanak et al., 2004; Brown & Schwartz, 2009; Çakıroğlu & Boone, 2002; Cepni et al., 2006; Ekici et al., 2007; Griffard & Wandersee, 2001; Günes et al., 2011; Keles & Kefeli, 2010; Kose, Coştu & Keser, 2003; Lin & Hu, 2003; Tekkaya & Balcı, 2003; Wang, 2004; Yenilmez & Tekkaya, 2006). In these studies, it is observed that the biological energy mechanism has been similarly established in the minds of Pre-service teachers primarily through photosynthesis and respiration.

In this study, it is observed that the motion-energy-sports connection, which emerged in the last cutting interval at a low frequency, was established by making the association with the physics discipline. On the other hand, as a result of the analysis of the data obtained with 10 open-ended questions about the definition of energy, energy conversion, and interdisciplinary transfer of knowledge in the study conducted by Güneş and Taştan-Akdağ (2016) with 40 science high school students, it was indicated that the majority of the students could only associate the energy with the physics lesson, and had difficulty in associating it with the chemistry and biology lessons. While the energy-sun association drew attention in the studies conducted by Bahar and Özatlı (2003) with high school students, the energy-sun association was observed to appear later than the photosynthesis-sun association, and in the last cutting interval in this study. According to Bahar and Özatlı, the energy-sun association is an example of the meaningful learning that the individual brings from the elementary school. As a result of the study of Bahar and Özatlı, while it was observed the students who had gone through a certain education process could not establish the energy-ATP association again, the establishment of this association by Pre-service teachers at the end of the undergraduate education can be a demonstration of the fact that learning in the scientific sense is realized after a certain period.

Another notable point from the first cutting interval is that the Pre-service science teachers associated the ATP molecule only with the mitochondria and could not establish the chloroplast-ATP association and that the ATP-photosynthesis association appeared in the third cutting interval. It can be said that there is mentally incomplete structuring at this point in pre-service teachers. In their studies, Bajd, Praprotnik, and Matyášek (2010) concluded that Czech pre-service teachers have more opinions on the respiration-energy association than Slovenian pre-service teachers. A similar situation emerged in this study, and it was observed that the pre-service teachers expressed the respiration-ATP-energy association more than the photosynthesis-ATP-energy association. Furthermore, in the study conducted with 152 Pre-service teachers, Çokadar (2012) found that the concepts of photosynthesis and respiration were related to the concept of energy, similarly to the findings of this study.

Similarly to the study conducted by Köse (2008), in this study, it was also observed that the Pre-service teachers associated photosynthesis only with the leaves among the parts of the plant. This association is incomplete, and the information that photosynthesis can occur in the metamorphosed roots and trunks of some plants and that in addition to this, the photosynthesis phenomenon can occur in blue-green algae and some protozoa such as certain bacteria and some single cell eukaryotes such as euglena has not settled in the cognitive structures of Pre-service teachers. Moreover, the association of the phenomena of photosynthesis and respiration commonly with only the words of carbon dioxide and oxygen and the inability to establish the association of respiration with the plant support other studies, in which the misconception that "the phenomena of photosynthesis and respiration do not occur at the same time and respiration is not obligatory in plants" is detected (Bajd, Praprotnik & Matyášek, 2010; Köse, 2008; Sanders, 1993; Syandova, 2014; Wodajo, 2012). Furthermore, the fact that pre-service teachers associated the respiration phenomenon with words such as lungs and breath shows, that this association was perceived at the macro level and could not be reduced to the cellular dimension. This is mainly due to a language problem because the concept of respiration in the daily language is associated with breathing and lungs. In fact, giving the concept of respiration to students and expecting answers related to the cellular respiration emerge as a problem.

Conclusions

It has been shown with this research that Pre-service science teachers are able to establish the necessary connections directly or through response words related to a significant part of the key concepts of the biological energy mechanism. However, it has been determined that the key concept of "cell", and especially "enzyme", is not perceived as a part of this reticular structure but is structured as an islet. It is an important deficiency that enzymes, which are active not only in the phenomena of photosynthesis and respiration but also in and outside the cell in almost every phenomenon, are associated only with the concept of "substrate", disjointedly from all concepts. In order to eliminate this deficiency, it is necessary to make the concept of "cell", which is the building block of the living things, and the concept of "enzyme", which plays an important role in this structure, the focal point of the subject during the education to be provided in relation to biology both at the secondary and high school and university level, and to explain

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

them by making associations with other concepts frequently. Furthermore, before the start of the educational activity, WAT can be applied to students to determine the cognitive structures of students in relation to the subject and in accordance with the obtained results, the course process can be improved with the teaching methods that can make the subject more concrete in order to eliminate the incorrect associations detected in students. In addition, students may also be encouraged to compare their own responses with those of other students to show them that there is more than one way of seeing things. With this, they can recognize that learning is individual and involves individual construction of meaning. Finally, teachers are able to construct a model mind map from the responses to the WAT in any topic and can let them see this mind map as a permanent reminder to them of the links they saw. This approach might encourage them to look for new links in new topics (Bahar et all., 1999).

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Received: *December 06, 2017* Accepted: *May 18, 2018*

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