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Investigating the High School Students' Cognitive Structures about the Light Concept through Word Association Test

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Abstract

Cognitive structure is a structure exhibiting the mutual associations of concepts recorded in the long-term memory. Students set up cognitive bridges between their previous knowledge and new knowledge during the creation of the cognitive structure. Learning a concept does not mean learning what a concept is called or learning only its definition, but it also means being able to set up the associations between the concept and the whole. This study determines high school students' cognitive structures about the concept of light by using a two-stage word association test. Content analysis was used in analysing the data collected. Content analysis is a very effective method yielding accurate results in reaching the concepts, correlations and logical patterns which can describe the data. The data obtained were analysed by using the technique of semantic relations in order to be able to set up logical ties between the number of words and words. 136 high school students (88 female and 48 male) were included in the research. The words having semantic proximity were divided into five categories by analysing the data through word association test. Consequently, the most used categories were as in the following, respectively: Structure of Light (223), Propagation of Light (143) and Properties of Light (142). The findings obtained in this study indicate that high school teachers and university instructors should take special care with some points in the teaching of subjects related with light. Besides, the formation of scientific knowledge about the concepts in individuals' minds will also encourage the emergence of complex organised knowledge about the phenomena.

Keywords: cognitive structure, high school students, light, word association test

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Lise Öğrencilerinin Işık ile ilgili Bilişsel Yapılarının Kelime İlişkilendirme Testi ile Araştırılması

Öz

Bilişsel yapı, uzun süreli belleğe kayıt edilen kavramların birbirleriyle olan ilişkilerini ortaya koyan bir yapıdır. Bilişsel yapının oluşturulması sırasında öğrenci eski bilgileri ile yeni bilgileri arasında bilişsel köprüler kurar. Bir kavramı öğrenmek o kavramın adını ya da sadece tanımını öğrenmek anlamına gelmez, aksine bu kavram ile bütün arasındaki ilişkileri de kurabilmek demektir. Bu çalışmada iki aşamadan oluşan kelime ilişkilendirme testi kullanılarak lise öğrencilerinin ışık ile ilgili bilişsel yapıları tespit edilmiştir. Araştırmaya kaynak oluşturacak verilerin çözümlenmesinde içerik analizi kullanılmıştır. Verileri açıklayabilecek kavramlara, ilişkilere ve bunlara bağlı olarak mantıklı örüntülere ulaşmak için içerik analizi oldukça etkili ve doğru sonuçlar veren bir yöntemdir. Çalışma sonunda elde edilen veriler, kelime sayısı ve kelimeler arasında mantıklı bağlantılar kurulabilmesi amacıyla anlamsal ilişki tekniği kullanılarak incelenmiştir. Çalışmaya lisede öğrenim gören 136 (88 kadın, 48 erkek) öğrenci katılmıştır. Kelime ilişkilendirme testi kullanılarak elde edilen verilerin analizi ile anlamsal yakınlığı bulunan kelimeler beş kategori altında toplanmıştır. Çalışmada sık kullanılan kategoriler sırasıyla Işığın Yapısı (223), Işığın Yayılması (143) ve Işığın Özellikleri (142) olmuştur. Bu çalışma ile elde edilen bulgular, lisede öğretmenlik yapanlar veya üniversitedeki öğretim üyelerinin ışık ile ilgili konuların öğretiminde bazı noktalara özellikle dikkat etmeleri gerektiğini göstermektedir. Ayrıca bireylerin zihinlerinde kavramlarla ilgili bilimsel bilgilerin oluşması, onların olgular hakkında karmaşık organize bilgilerin ortaya çıkmasını teşvik edecektir.

Anahtar Sözcükler: bilişsel yapı, lise öğrencileri, ışık, kelime ilşkilendirme testi

Introduction

Physics is a branch of science trying to describe all the structures from macro scale to micro scale and studying the incidents we encounter in daily life and the laws between sub-atom particles. It employs a series of theories and laws to describe the existing situations in relation to those structures. Knowledge about these theories and laws used is presented to students by using rich learning environments to facilitate their acquisition. When seen from learners' perspective, it is certain that the situation is not so clear and understandable because students see physics as a boring and difficult course containing formulas needing memorisation (Temiz, 2001). Physics lessons contain several abstract concepts as well as concrete concepts according to the specific nature of each subject. Those abstract concepts in particular cause students to form many incorrect/incomplete concepts and they stand as a problem in front of both students and teachers (Yağbasan & Gülçiçek, 2003). Therefore, students have difficulty in forming the cognitive structure about the concepts learnt in lessons, and thus they have learning difficulties. Those learning difficulties cause students to have different alternative conceptions about physics concepts and to have misconceptions about some of the concepts.

Cognitive structure is a structure exhibiting the mutual associations of concepts recorded in the long-term memory. Students set up cognitive bridges between their previous knowledge and new knowledge during the generation of the cognitive structure (Gilbert & Watts, 1983). Learning a concept does not only mean learning what a concept is called or learning its definition, but it also means being able to set up the associations between the concept and the whole. In other words, when the newly learnt knowledge can be associated with the previous knowledge available, cognitive structure about the concept in question is formed (Skemp, 1971). In this context, if the newly learnt concepts and the concepts available are associated in students' cognitive structure and scientific ties are set up between them; meaningful learning will occur (Ausubel, 1968).

Modifications were made in recent years in the curricula of physical sciences, and context-based learning which was based on constructivist learning was considered essential. Thus, it has become important that students configure knowledge in their mind, interpret it and set up ties with daily life (Güneş & Gözüm, 2013). Regulations made to constructivist approach-based curricula also made modifications to the conception of measurement and evaluation necessary (Taşdere, Özsevgeç & Türkmen 2014). Thus, alternative measurement tools in addition to traditional measurement tools were used in the curriculum of physical sciences course (MEB, 2013). One of those measurement tools is word association test. Word association test, suggested first by Galton (1880), was developed by Carl Gustav Jung so as to investigate conceptual systems and it has been used for a long time (Kostova & Radoynovska, 2008). The majority of teachers liken students' mind to a clean blackboard and they want to organise it as they wish (Yağbasan & Gülçiçek, 2003). However, students have a considerable amount of prior knowledge. This prior knowledge is the greatest factor influential in their meaningful learning (Ausubel, 1968). For this reason, it is important to determine prior knowledge students have and the associations between concepts shaped by this knowledge (Hewson & Hewson, 1981). In this context, revealing students' cognitive structure will be the determiner of techniques and methods teachers use in teaching a lesson. Today, learning is regarded as a conceptual rather than a procedural process. In addition to that, knowledge students obtain in their daily life and through experiences are inaccurate or incomplete. Students' misunderstanding in relation to their previous learning is likely to have negative impacts on new knowledge. Therefore, complete learning in scientific sense cannot occur without eliminating students' misunderstanding (Çepni, Ayaş, Johnson & Turgut,

1997). A way to understand this is to uncover students' cognitive structures. A way to achieve this is to analyse the ties between concepts formed in students' minds through key words (Gilbert, Boulter & Rutherford, 1998a; 1998b).

The concept of light is a concept about which students of every level from primary school to university have incomplete knowledge and misconceptions (Bendall, Goldberg & Galili, 1993; Cansüngü, 2000; Cansüngü & Bal, 2002; Yeşilyurt, Bayraktar, Kan & Orak, 2005; Şahin, İpek & Ayas, 2008; Kara, Avcı & Çekbaş, 2008). Hubber (2006) researched primary school students' mental models about the nature of light. Accordingly, the researcher obtained findings on how students described the behaviours of light displayed in nature in wave-particle duality models, on the origins of their mental models, on the levels of the models, and on whether or not any changes occurred in the models as a result of education they had received. Another study investigated 99 pre-service science teachers' levels of knowledge about the concept of light (Kara et al., 2008). In consequence, the study found that the majority of the pre-service teachers had misconceptions. In their study performed with first year university students Blizak, Chafiqi and Kendil (2009) found that those students had learning difficulties about the concept of light.

Several techniques and methods such as word association tests, concept maps, structured grids, analogy, and prediction-observation were used in revealing students' cognitive structures. Word association test (WAT) is one of the oldest methods and it has the widest range of use (Kostova & Radoynovska, 2008). This technique, which was used in many studies (Deese, 1962,1965; Johnson, 1964; 1965; 1967; 1969; 1970; Kiss, 1969; Rothkopf & Thurner, 1970; Shavelson, 1973, 1974; Geeslin and Shavelson, 1975; Preece, 1976, 1978; Johnstone & Moynihan, 1985; Carrie, 1984; Cachapuz & Maskill, 1987; Bahar, Johnstone & Sutcliffe, 1999; Cardellini & Bahar, 2000; Bahar & Özatlı, 2003, Nakiboğlu, 2008; Ercan, Taşdere & Ercan, 2010) is also used in this study. Thus, this study aims to analyse high school students' cognitive structures about the concept of light by using WAT. In this context, the high school students' conceptual framework about the concept of light was examined by using word association test and the following research questions were intended to be answered:

- How is the cognitive structure of high school students related to the concept of light?
- How do the high school students configure the concept of light in their mind and which words evoke the concept of light to them?

Method

This study employs phenomenology, one of the methods of qualitative research. Phenomenology is very influential in studies investigating the phenomena of which we are aware but which we cannot fully comprehend. Research using this method may not present certain and generalizable results compatible with the nature of qualitative research but it can present examples and descriptions to help us recognise and understand a phenomenon better (Yıldırım & Şimşek, 2008). In this context, this study determines high school students' cognitive structures by putting the data collected through word association test to content analysis.

Participants

The participants in the research were the 11th and 12th graders attending an Anatolian high school in Balıkesir. All of the participants learnt subjects including basic knowledge

about light successfully. Word association test prepared was administered to 136 students (88 of whom were girls and 48 of whom were boys). The students participating in the research on the basis of volunteering were in 15-17 age range.

Data Collection Tool

This study uses a two-part word association test as the tool of data collection. Part one of the test included the key concept. First, students were asked to write down what the key concept evoked. In part two, they were asked to write a sentence about the key concept. The students were allowed 40 seconds to write the words evoked in their mind and 20 seconds to write the sentence about the key concept. The concept which is the subject matter of research is written several times one under another in word association tests. The reason for this is to minimise the likelihood of chain answers. Even though writing the key concept only once seems to be easier in application, students can move away from the key concept with each word they write in relation to the key concept (Bahar & Özatlı, 2003). The students were asked to write a sentence about the key concept in 20 seconds. The reason for this is that the words related with the key concept remain at the level of remembering unless there are semantic ties with the key concept (Kurt, 2013). In this case, the words written will not form a meaningful whole with the key concept. At this point, students' sentences about the key concept will come into play. Analysing students' sentences about the key concept will suggest a clearer result about students' cognitive structures because the sentences will be more complex than only one word.

Data Analysis

Content analysis was used in the analysis of the research data. Content analysis is a very effective method in reaching the concepts, correlations and resultant logical patterns and it yields accurate results (Patton, 2002; Yıldırım & Şimsek, 2008). The data obtained were analysed by using the technique of semantic relations in order to be able to set up logical ties between the number of words and words (Atasoy, 2004). The words written by students in relation to the key concepts were brought together according to semantic proximity and thus categories were distinguished. In addition to that, the words which were considered to be unrelated, which were not relevant to the main concept and which were repeated two times or below two times were excluded from the analysis.

Findings

The data collected with word association test were put to analysis and the words having semantic proximity were divided into five categories. Table 1 shows the words and the categories to which the words belong. According to the results of WAT, 681 words in total were obtained, and the first category distinguished after data analysis was labelled as "Structure of Light". This is also the category with the highest frequency in this study (f=223). In this category, the students concentrated on the words alpha rays, wave, wavelength, linear, photon, frequency, velocity, speed of light, colour, spectrum, intensity and particle. The second category distinguished was the category of "sources of Light" (f=95).

Table 1. *The categories and the words in high school students' minds related to the concept of light*

Categories	Concepts Frequencies in the Categories	Total Frequencies
Structure of Light	Alpha rays (7), Wave (23), Wavelength (22), Linear (9), Photon (24), Frequency (13), Velocity (18), Light speed (23), Color (35), Spectrum (24), Intensity (11), Particle (14)	223
Sources of Light	Sun (40), Lamp (41), Candle (6), Lightning (3), Star (5)	95
Propagation of Light	Angle (3), Moon (4), Bright (38), Mirror (14), White light (12), Space (5), Einstein (6), Rainbow (8), Shadow (9), Light flux (3), Beam (6), Darkness (9), Quantum (5), Brightness (8), Prism (13)	143
Properties of Light	Double slit experiment (8), Energy (15), Photoelectric effect (4), Candela (8), Refraction (29), Diffraction (13), Lens (10), Optic (27), Rutherford (4), Scattering (3), Blackbody (4), Absorption (4), Reflection (13)	142
Interaction of Light	Resistance (3), Electric (7), Photo (3), Photolysis (5), Photosynthesis (33), Phototroph (4), Eye (6), Eye glasses (3), Temperature (6), Chloroplast (5), Chlorophyll (3)	78
Total	**56 words**	**681 words**

The words in this category were sun, lamb, candle, lightning and star. The third category was the category of "Propagation of Light" (f=143). This category included the words angle, moon, bright, mirror, white light, space, Einstein, rainbow, shadow, light flux, beam, darkness, quantum, brightness and prism. The fourth category was labelled as "Properties of Light" (f=142). The words in this category were double slit experiment, energy, photoelectric effect, candela, refraction, lens, optic, Rutherford, scattering, black body, absorption and reflection. The fifth category, the one with the lowest frequency, was the category of "Interaction of Light" (f=78). The words in this category according to students' answers were resistance, electric, photo, Photolysis, photosynthesis, prototroph, eye, eye glasses, temperature, chloroplast and chlorophyll.

The sentences students had written about the concept of light were also analysed, and the ones related with the themes distinguished are shown as in the following. On examining the distribution of frequencies according to the words written by students, it was found that the most dominant category was "Structure of Light" whereas the category containing the biggest number of sentences was "Interaction of Light". This was because of the fact that the category of "ınteraction of Light" was also closely related with the concept of light in other courses (such as biology and chemistry). Some of the sentences about each category are cited below. Accordingly, the sentences about the category of "Structure of Light" were as in the following:

St 31: *Light is the ray coming from the Sun. It carries energy. It has the properties of both waves and particles.*

St 50, 55, 56, 61: *Light is an electromagnetic wave.*

Sample sentences written by students in the category of "Sources of Light" were as in the following:

St42, 44: *The sun is a source of light.*

Two sample sentences in the category of "Propagation of Light" were as in the following:

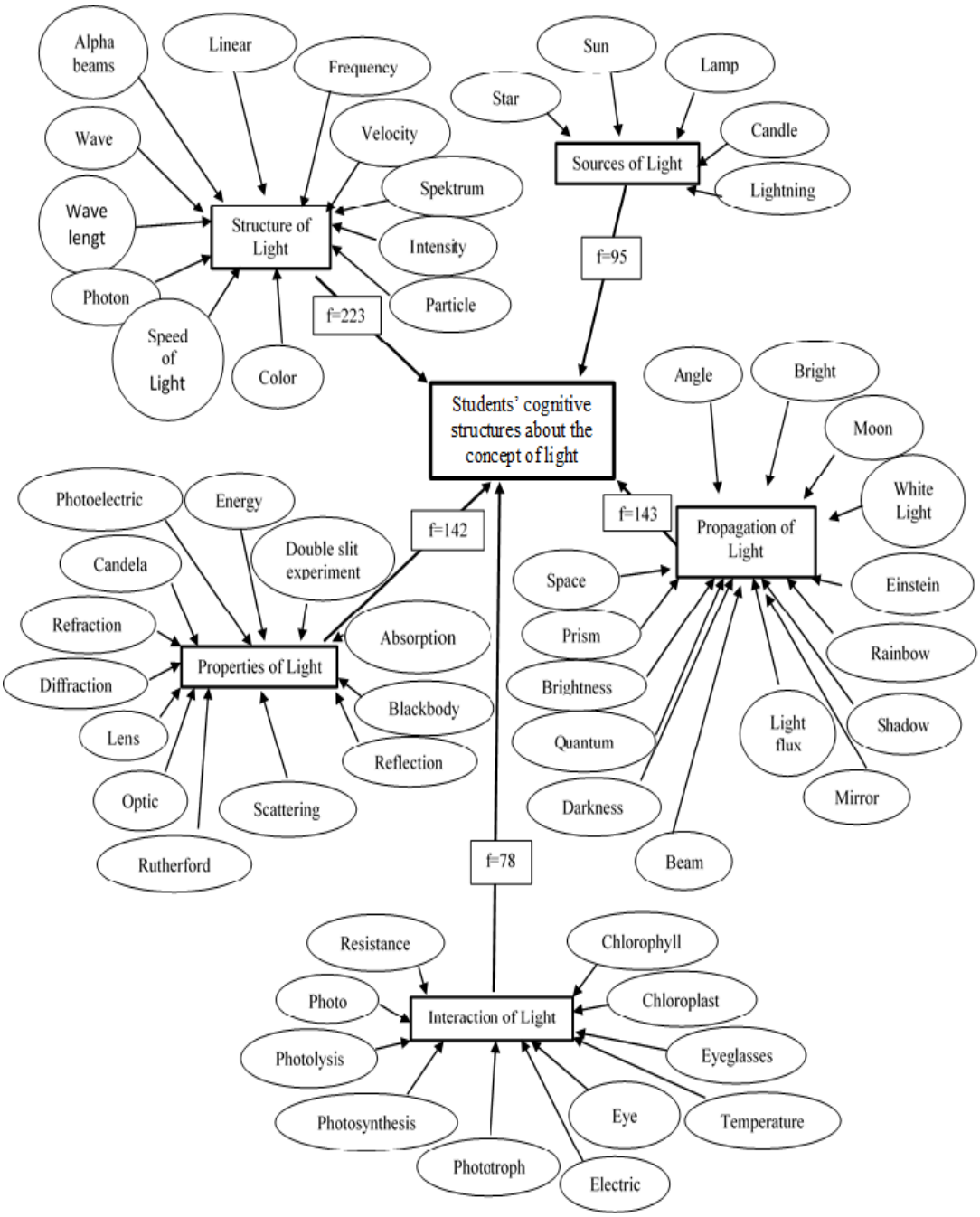
St 14: *Light propagates in space.*

St 26, 37, 69, 118: *Light moves in linear direction.*

Sample sentences in the category of "Properties of Light" were as in the following:

St 52: *It has the property of refraction and reflection.*
St 35, 79, 104, 133: *Light is energy.*
St 8, 22: *The unit of light is candela.*

Figure 1. *The model of high school students' cognitive structure of light concept*



And finally, the sentences in the category of "Interaction of Light" were as in the following:

St 17, 21, 28, 43, 54, 128, 129: *Light makes it possible for use to see (in darkness).*
St 97, 105, 110, 121, 135: *Light is necessary in photosynthesis.*
St 98: *Light is necessary in photosynthesis in reactions which are dependent on light.*

Apart from the above mentioned findings, it was also found that some high school students had incomplete or alternative concepts about light. The students' statements cited below are some of the examples for this.

St 11: *Light is the luminousness protecting us from darkness.*
St 10: *The moon and the sun illuminate our world.*

Although "the moon" in the final sentence was reported as a source of light, it is indeed not a source of light. In another sentence, as in the following, an incorrect relationship was established between light and wave length.

St 101: *Light intensity is inversely proportional to wavelength.*

A network of concepts having themes and words clustering around the themes was created so that the research findings could demonstrate students' cognitive structures more clearly. An examination of Figure 1 indicates that high school students' cognitive structures about the concept of light are basically connected with the five categories.

Conclusion and Discussion

This study analysed high school students' cognitive structure through word association test. The students wrote both words and sentences about the concept of light. At the end of the study, 5 categories were distinguished in relation to the key concept "Light". The categories contained 57 concepts. On examining the frequency distributions of the categories, it was found that the theme of "Structure of Light" had the highest frequency. The five concepts repeated most frequently in this category were wave (23), wave length (22), photon (24), light velocity (23), colour (35) and spectrum (24). The property these words had in common was that they were all directly related with the concept of light; because these concepts appeared very often in classes and in other published and visual materials about physics that students used. In other words, they are the indispensable key concepts in describing the concept of light, and thus they are often used in explaining the concept. The most frequently used concepts in the category of "Sources of light" were "the sun" (40) and "lamp" (41) respectively. However, this was the category with the lowest frequency. This indicated that even though students had fundamental knowledge about the sources of light, they could not diversify the sources. The category having the lowest frequency was the category of "Interaction of Light". The category included concepts in the field of biology such as Photolysis", "Photosynthesis", "phototroph", "Chloroplast" and "Chlorophyll. Thus, the words students reported in relation to "Interaction of Light" were related with biology course rather than physics. The reason for this could be the effects of practice activities in biology course. That is to say, the fact that the words included in this category are also used in other disciplines caused this. The words written by students were mostly at the stages of knowledge and comprehension. In the light of these results, it may be said that students do not have in-depth knowledge about the concept- that is to say; they do not have meaningful learning in this respect. Examining the results, it could be stated that word association test was effective in revealing students' cognitive structures (Bahar, Johnstone & Sutcliffe, 1999; Bahar & Kılınç, 2001; Bahar & Özatlı, 2003; Aydemir, 2014). Associations that this concept, which we frequently encounter in daily life, causes in students are large. In other words, students tried to describe this concept with many words (see Table 1). The fact that the concept of light triggers differing words in students also explains the fact that they have different mental models about this concept. Studies on light in the literature

also confirm this result (Hubber, 2006; Özcan, 2015; Şengören, 2010). The emergence of such mental models in students' mind could be attributed to the fact that they try to explain the incidents they encounter in daily life in relation to light in a wrong and unscientific approach. All of the approaches students adopt cannot of course be said to be wrong or incomplete. It was found in research that the mental models of students having a scientific approach were scientific models (Hubber, 2006; Özcan, 2015; Şengören, 2010). In order for connections made about this concept to be scientific and correct, it would be useful if teachers gave more real life examples in their lessons.

The findings obtained in this study showed that students used scientific and unscientific knowledge fragments together in explaining the concept of light. That is to say, students made explanations by setting up connections between these two types of knowledge fragments and they gave incorrect examples for the concept. Thus, the inappropriate use of unscientific knowledge structure about light resulted in unscientific explanations and examples. Therefore, the cognitive structures and word choice of students using correct and scientific words in their explanations about this concept differed considerably from those who used unscientific words.

Implications for Teaching

The findings of study indicated that high school teachers and university instructors should take special care with some points in the teaching of subjects related with light. Students should be exposed to content about light or about subjects containing the concept of light in classes to facilitate learning scientific knowledge; or different contexts should be designed in relation to light. Advance organisers such as concept maps or conceptual frameworks should be used in preparing such content. In this way, whether or not the connections students set up between concepts can also be found. Besides, such content would also encourage students to set up relevant connections with the concept. Determining students' prior knowledge is very important at this point. Their prior knowledge should be determined before starting a lesson by using concept maps or word association tests. This will ensure that students construct connections between concepts in a coherent way and thus will help them to organise the knowledge in their mind. The formation of scientific knowledge about concepts in individuals' minds will incite the emergence of complex organised knowledge about phenomena.

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