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Investigation of Physics Teacher Candidates' Cognitive Structures about "Electric Field": A Free Word Association Test Study

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Abstract

The aim of this study is to investigate the cognitive structures of physics teacher candidates about "electric field". Phenomenographic research method, one of the qualitative research patterns, was used in the study. The data of the study was collected from 91 physics teacher candidates who had taken General Physics II course at Education Faculty of a university in Anatolia. The stimulus word, "electric field" has been presented to teacher candidates through Free Word Association Test (FWAT). The totally 43 responses obtained from FWAT were presented as frequency tables. The responses were divided into 13 categories by the - content analysis. A concept network which reveals cognitive structure of physics teacher candidates about "electric field" was created considering frequencies and categories. According to results of the study, the highest frequency values related with "electric field" which stimulus of physics teacher candidates were power, charge, vector/vectoral quantity, current, magnet, etc. and the categories with the highest frequency of response words were figured out as electrical force, electric charge, magnetic field and magnitude of electric field, etc.

Keywords: electric field, cognitive structures, free word association test, physics teacher candidates

1. Introduction

In the researches on physics education, it is known that the students come to the classroom environment with preliminary knowledge about physics concepts that they have learned with their own experiences before. Many of these concepts and knowledge are far from science and misleading. This negatively affects the learning of the physical phenomena, events and concepts explained to them meaningfully and permanently. In classroom activities where innovative learning methods are not used, students will not be able to have meaningful and lasting learning when they do not perform participatory learning (Bozkurt, 2008). One of the most important conditions for providing meaningful and lasting learning is to have accurate concept knowledge. Students make use of relationships between concepts while explaining a physical phenomenon, event or situation. If any of these concepts are used away from the scientific meaning, misconceptions and misunderstandings will emerge. In physics teaching, more emphasis is placed on numerical applications and mathematical formulas than on conceptual knowledge. However, physics is a broad-spectrum science based on conceptual bases (Bozkurt & Sarikoc, 2008). For this reason, the concept information that should be formed in the students should be given particular importance. Concept knowledge should not be limited to knowing the concept or knowing the name of the concept. Conceptual knowledge also necessitates the ability to make connections and transitions between concepts (Bozkurt & Erdogan, 2014). Conceptual knowledge is expressed as rich information in terms of content and relation. Conceptual knowledge, therefore, includes associations and generalizations between information that an individual has about that concept. When a concept is associated with other concepts related to physics, the concept becomes meaningful and conceptual learning takes place in the mind of the individual.

As the constructivist learning approach is becoming more widespread in learning environments, different techniques, and strategies rather than from traditional measurement-evaluation techniques are used in the measurement-evaluation techniques to reveal the conceptual difference and change. In this sense, researchers have focused on techniques that measure the extent to which learners can relate different kinds of information and concepts, measure how much information they have, and how much they can relate cognitive structures to the real world in their own minds. One of these techniques is the "Free Word Association Test (FWAT)". This test is influential in determining cognitive structure, determining conceptual change and determining conceptual misconceptions (Ay, 2011; Dikmenli, 2010a; Dikmenli,

2010b; Gokbas & Erdogan, 2016; Kurt & Ekici, 2013a; Kurt & Ekici, 2013b; Turan & Erdogan, 2016; Turan & Erdogan, 2017; Erdogan, 2017). By the FWAT, the student is expected to give verbal or written answer to the question what one or more presented words remind, and then the answers given are analyzed. The frequency table of the words that the students have given as response is formed. By relating the emerging concepts to each other, the cognitive structures of the students are revealed (Bahar, Johnston & Sutcliffe, 1999). In this technique, the student is asked to write the concepts that remind stimulant word about any topic given to him within a certain period of time. It is accepted that the sequential answer to stimulus concept given by student from his long-term memory reveals the connection between concepts in cognitive structure and also shows the semantic proximity. According to semantic proximity and semantic distance effect, as two concepts are closer in terms of distance so they have a close relation, and cognitive research will be quick during recall that the answer to both concepts will be faster (Bahar, Johnston & Sutcliffe, 1999; Ozatli, 2006). Although there are many studies about the FWAT (Aydin & Tasar, 2010; Bahar, Johnston & Sutcliffe, 1999; Kostova & Radoynovska, 2008; Kurt & Ekici, 2013a; Eren, 2012 ; Guerrero et al., 2010; Kurt & Ekici, 2013b). There are a few applications in the physics education literature related to the FWAT.

The aim of this study is to reveal the cognitive structures of physics teacher candidates about “electric field” as an important concept of General Physics II course, by using the FWAT.

2. Method

Phenomenological approach as one of the qualitative research methods, was used in the study. The phenomenological approach is used in studies to investigate phenomena that we are aware of but not fully understood. Phenomenographic research may not produce definitive and generalized results in accordance with the nature of qualitative research. However, it can reveal examples, explanations and experiences that will help us to recognize a phenomenon better. In this respect, it can provide important contributions to the literature (Yildirim & Simsek, 2006). In this study, the data of cognitive structures related to the "electric field" stimulus of the physics teacher candidates were analyzed in a detailed way as much as possible.

2.1 Participants

The working group constitutes a total of 91 physics teacher candidates studying at a state university in Anatolia in the 2016-2017 Academic Year. 31 (34%) of the teacher candidates were male and 60 (66%) were female. The average age of the participants was 21,4 years (range 19-23).

2.2 Data Collection

Free Word Association Test (FWAT) was used as data collection tool. The concept of "electric field" has been presented to teacher candidates as a stimulus concept. The concept of "electric field" was written 10 times in a page.

Stimulus Concept: ELECTRIC FIELD
ELECTRIC FIELD:……
ELECTRIC FIELD:……
ELECTRIC FIELD:……
ELECTRIC FIELD:……
ELECTRIC FIELD:……
ELECTRIC FIELD:……
ELECTRIC FIELD:……
ELECTRIC FIELD:……
ELECTRIC FIELD:……
ELECTRIC FIELD:……

The reason why a concept was written one under the other as many as the desired answer was to prevent writing the words that key concept may remind and eliminate the risk of chain reaction. In this regard, it would be avoided to exclude the purpose of the test (Bahar, Johnston & Sutcliffe, 1999; Bahar & Ozatli, 2003). The research conducted using the FWAT was examined and it was decided that the appropriate response time for the stimulus word should be 30 seconds (Bahar, Johnston & Sutcliffe, 1999; Bahar & Ozatli, 2003; Dikmenli, 2010a; Dikmenli, 2010b; Dikmenli, Cardak & Kiray 2011; Eren, 2012; Isikli, Tasdere & Goz 2011; Gokbas & Erdogan, 2016; Kurt & Ekici, 2013a; Kurt & Ekici, 2013b; Simsek, 2013; Timur, 2012; Turan & Erdogan, 2016). After the necessary explanation and examples were given to the teacher candidates for theFWAT, the application was started.

2.3 Data Analysis

The responses to stimulus word given by teacher candidates are investigated using content analysis method to analyze FWAT. In content analysis, similar expressions are brought together and interpreted within the framework of specific concepts and themes (Yildirim and Simsek, 2006). In accordance with the response words given to stimulus word, main categories were created and response words were placed into suitable categories. This process was repeated one week late and some response words were shifted to other categories. After these processes, the categories created for stimulus word and response words in these categories were verified by an expert. Reliability, was calculated using [Consensus/ Consensus + Divergence) X 100] formula (Miles and Huberman, 1994). At the end of this independent verification, interrater reliability was achieved around 90%. It has been seen that a data analysis technique made in this way gives reliable results (Erdogan, 2012). Based on the generated frequency tables, a general conceptual network was drawn out that reveals the cognitive structures of teacher candidates regarding the concept of "electric field" stimulus.

3. Results

In this part, first of all, the responses of physics teacher candidates' to the stimulus concept related with "electric field" in the (FWAT) and the categories obtained from the response words are given. Afterwards, the conceptual network including frequencies and categories is presented.

3.1 Findings Related to the Response Words Given to Stimulus Concept "Electric Field" and Created Categories

In the word association test, 43 different response words were obtained from teacher candidates about the word "electric field" given as a stimulant word. These 43 answer words were categorized in 13 categories. These generated categories are given in Table 1. While these categories are being developed, the physics teaching curriculum in our country has been taken into consideration.

Table 1. The Categories Organized Using the Responses for "electric field" Stimulus Concept

Categories	Frequency (f)	%
1. Electrical Force	90	25
2. Electric Charge	72	20
3. Magnetic Field	51	14,2
4. Magnitude of Electric Field	44	12,2
5. Electric Current	26	7,2
6. Electrical Potential	20	5,6
7. Electric Flux	14	3,9
8. Maxwell's Equations	11	3,1
9. Motion	9	2,5
10. Unit of Electric Field	6	1,7
11. Power-Energy	6	1,7
12. Electromagnetic Wave	6	1,7
13. Electric Potential Energy	5	1,4
TOTAL	360	100,0

As a result of data analysis, the responses given to "electric field" concept by teacher candidates are mostly concentrated under "Electrical Force" (f = 90) category and this category emerged as the most dominant category. When the data in Table 2 is analysed, it is seen that the concept mostly concentrated was "Force/Coulumb Force" (f = 39) concept and this concept is followed by Vector/Vector Quantity, Push-Pull, Force Lines and Direction concepts.

Table 2. Response Words in “Electrical Force” Category

Category	Associations	Frequency (f)	%
1. Electrical Force	Force/Coulumb Force	39	43,3
	Vector/Vector Quantity	23	25,6
	Push-Pull	12	13,3
	Force Lines	8	8,9
	Direction	8	8,9
	Total	90	100,0

When the obtained data were examined, the answers given by the teacher candidates in the second category regarding the concept of "electric field" were collected under the category of "Electric Charge" (f = 72). When Table 3 is analysed, it is seen that Charge Object / Charge (f = 49) concept is the most focused concept in this category, and this concept is respectively followed by Plus and Minus Poles, Dipole / Electric dipole, Charge Density, Point Electric Charge, Unit Charge and Continuous Charge.

Table 3. Response Words in “Electric Charge” Category

Category	Associations	Frequency (f)	%
2. Electric Charge	Charged Object/Charge	49	68,1
	Plus and Minus Poles	9	12,5
	Dipole/Electric dipole	6	8,3
	Charge Density	4	5,6
	Point Electric Charge	2	2,8
	Unit Charge	1	1,4
	Continuous Charge	1	1,4
	Total	72	100

As a result of the data analysis, the third category was "Magnetic Field" (f = 51) category according to the responses given by the teacher candidates regarding the concept of "Electric Field" concept. As can be seen from Table 4, the concept of "Magnet" has become the concept with the greatest frequency of participants focusing on this category. This concept is followed by Magnetic Field, Compass, Right Hand Rule, Electromagnetic Field and N - S poles, respectively.

Table 4. Response Words “Magnetic Field” Category

Category	Associations	Frequency (f)	%
3. Magnetic Field	Magnet	19	37,3
	Magnetic Field	12	23,5
	Compass	11	21,6
	Right Hand Rule	5	9,8
	Electromagnetic Field	2	3,9
	N - S poles	2	3,9
	Total	51	100,0

The fourth category related to the "electric field" stimulus word is "Magnitude of Electric Field" (f = 44). In this category it is seen that teacher candidates responded stimulus concept of “electric field” giving Distance, k constant, Magnitude of Electric Field /Magnitude, $E=k.q/d^2$, $E=F/q$, and Electric field is related to distance words. The response words for “Magnitude of Electric Field” category are given in Table 5.

Table 5. Response Words in “Electric Field Magnitude” Category

Category	Associations	Frequency (f)	%
4. Magnitude of Electric Field	Distance	18	40,9
	k constant	11	25
	Magnitude of Electric Field /Magnitude	8	18,2
	$E=k.q/d^2$, $E=F/q$	5	11,4
	Electric field is related to distance	2	4,5
	Total	44	100,0

As given in Table 1, the fifth category was formed as "Electric Current" (f = 26). The majority of participants have associated the "electric field" stimulus word only with the current word in this category. The response words for "Electric Current" category are given in Table 6.

Table 6. Response Words in “Electric Current” Category

Category	Associations	Frequency (f)	%
5. Electric Current	Current	26	100
	Total	26	100

Participants in the sixth category related the word "electric field" with words related to "Electrical Potential" (f = 20). In this category it is seen that teacher candidates responded stimulus concept of “Electric Field” as Potential, Potential Difference, and Electrical Potential words. The response words for “Electrical Potential” category are given in Table 7.

Table 7. Response Words in “Electrical Potential” Category

Category	Associations	Frequency (f)	%
6.Electrical Potential	Potential	7	35
	Potential Difference	7	35
	Electrical Potential	6	30
	Total	20	100

As seen in Table 1, participants in the seventh category related the stimulus word of "electric field" is "Electric Flux" (f = 14) category. In this category, the most focused response was the word "Electric field lines" (f = 13), followed by the word Flux. The response words for "Electric Flux" category are as in Table 8.

Table 8. Response Words in “Electric Flux” Category

Category	Associations	Frequency (f)	%
7. Electric Flux	Electric field lines	13	92,9
	Flux	1	7,1
	Total	14	100,0

In the eighth category, participants were determined the “Maxwell’s Equations” as stimulus word related with “electric field” (f=11) (Table 1). In this category, teacher candidates have stated that Gauss Law, Faraday Law and Maxwell’s Equations words are stimulus words related with concept of “electric field”. The response words for “Maxwell’s Equations” category are given in Table 9.

Table 9. Response Words in “Maxwell’s Equations” Category

Category	Associations	Frequency (f)	%
8. Maxwell’s Equations	Gauss Law	5	45,5
	Faraday Law	4	36,4
	Maxwell’s Equations	2	18,2
	Total	11	100,0

Participants have associated “Motion” as stimulus word related to the "Electric Field" (f = 9). In this category, it is seen that teacher candidates responded stimulus concept of “Electric Field” as Acceleration and Velocity words. The response words for “Motion” category are given in Table 10.

Table 10. Response Words in “Motion” Category

Category	Associations	Frequency (f)	%
9. Motion	Acceleration	5	55,6
	Velocity	4	44,4
	Total	9	100,0

The tenth category is formed as "Unit of Electric Field" (f = 6). In this category, it is seen that teacher candidates responded stimulus concept of “electric field” as Unit (Newtons per Coulomb), Unit (Volts per meter), and Unit (Newton) words. The response words for “Magnitude of Electric Field” category are given in Table 11.

Table 11. Response Words in “Electric Field Magnitude Unit” Category

Category	Associations	Frequency (f)	%
10. Electric Field Magnitude Unit	Unit (Newtons per Coulomb)	3	50,0
	Unit (Volts per meter)	2	33,3
	Unit (Newton)	1	16,7
	Total	6	100,0

Teacher candidates in the eleventh category, as given in Table 1, associate the "electric field" with stimulus words with concepts related to "Power-Energy" (f = 6). In this category it is seen that teacher candidates responded stimulus concept of “electric field” as Energy and Power words. The response words for “Power-Energy” category are given in Table 12.

Table 12. Response words in “Power-Energy” Category

Category	Associations	Frequency (f)	%
11. Power-Energy	Energy	4	66,7
	Power	2	33,3
	Total	6	100,0

As a result of the analysis done, the twelfth category was formed as "Electromagnetic Wave" (f = 6), as given in Table 1. In this category, it is seen that teacher candidates responded stimulus concept of “electric field” as Electromagnetic Wave and Speed of light words. The response words for “Electromagnetic Wave” category are given in Table 13.

Table 13. Response Words in “Electromagnetic Wave” category

Category	Associations	Frequency (f)	%
12. Electromagnetic Wave	Electromagnetic Wave	3	50,0
	Speed of light	3	50,0
	Total	6	100,0

According to the responses given by the teacher candidates, the thirteenth category was formed as "Electric Potential Energy" (f = 5). In this category it is seen that teacher candidates responded stimulus concept of “electric field” as Potential Energy and Electrical Energy words. The response words for “Electric Potential Energy” category are given in Table 14.

Table 14. Response Words in “Electric Potential Energy” Category

Category	Associations	Frequency (f)	%
13. Electric Potential Energy	Potential Energy	4	80
	Electrical Energy	1	20
	Total	5	100

3.2 The Conceptual Network Related to the Conceptual Structure of Physics Teacher Candidates Concerning "Electric Field"

In Figure 1, the conceptual network related to the conceptual structure of physics teacher candidates concerning "electric field" is given.

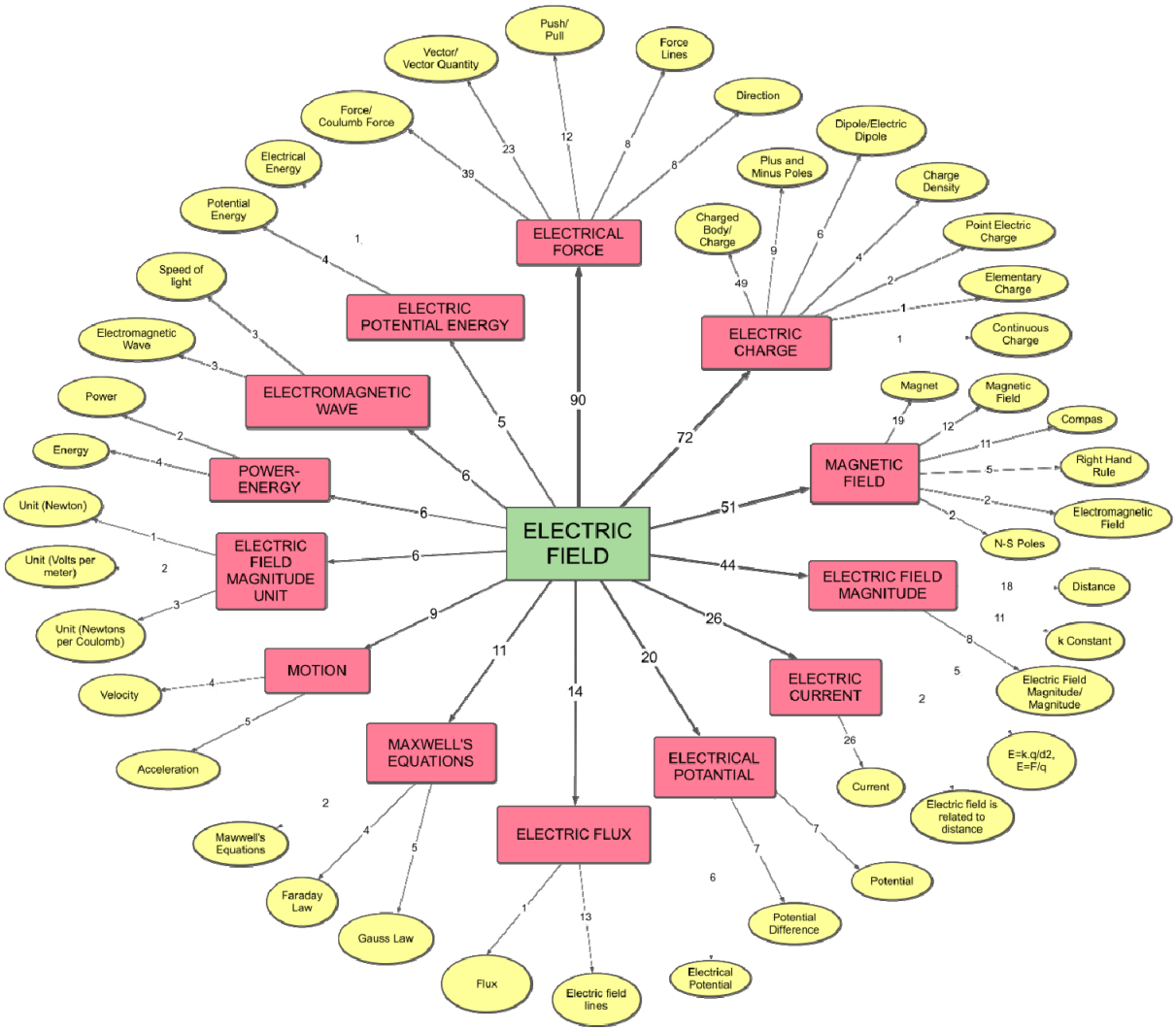

Figure 1. The Conceptual Networks of Physics Teacher Candidates with regard to "electric field".

The conceptual network given in Figure 1, shows that cognitive schema of Physics Teacher Candidates with regard to "electric field" stimulus concept. The stimulus concept presented to the teacher candidates is in the middle of the concept network. In the network of concepts, related words, categories of these words and their frequencies are presented in a two-dimensional diagram. The frequency values of the words and categories associated with the stimulus word are shown on the lines. The concept network is formed clockwise from the words with the most frequency to the ones with the least frequency. Categories are given in the same way on concept network. When the concept network given in Figure 1, is examined, it is seen that the physics teacher candidates often associate the concept of "electric field" stimulus with the concepts of Electrical Force, Electric Charge, Magnetic Field, Magnitude of Electric Field and Electric Current.

4. Discussion and Recommendations

Electricity and magnetism are two main physics topics with relevance to everyday life. In literature, it has been figured out that most of the students do not have clear understanding of the concepts of electricity and magnetism (Bagno & Eylon, 1997; Galili, 1995; Pocovi & Finley, 2002; Pocovi, 2007; Saarelainen, Laaksonen & Hirvonen 2007; Tornkvist, Pettersson & Transtromer 1993; Rainson, Transtromer & Viennot 1994). Misconceptions is one of the main problem

which prevent the clear understanding of many physics subjects. There are many researches figured out the misconceptions in physics (Gurbuz, 2016; Ergin, 2016). For example, Gurbuz (2016) has tried to explore pre-service science teachers' misconceptions on basic astronomy subjects. Ergin (2016) has investigated the effect of group work and traditional method on 9th grade students' misconceptions about Newton Laws.

One of the way to investigate the misconceptions in physics subjects, is using word association tests. The role of word associations in the learning of science has been investigated in many science education studies (Bahar & Ozatli, 2003; Gokbas & Erdogan, 2016; Johnson, 1967; Kurt et al., 2013c; Koseoglu & Bayir, 2011). Word association test is a very effective method in teaching concepts. Because, individuals set up close associations between their previous learning. If the association is set up correctly, meaningful learning can occur. Therefore, in this study the cognitive structures of physics teacher candidates about "electric field" were investigated by using the FWAT.

As a result of the FWAT conducted to examine the cognitive structures of physics teacher candidates about the "electric field" stimulus word a rich data obtained. As a result of the analysis of the data obtained with this test, the response words given to "electric field" stimulus word by the candidates were collected in 13 categories. When these categories were examined, it is seen that some of the words in these categories include "Electric Field" subjects which takes place in curriculum (Electrical Force, Electric Charge, Magnitude of Electric Field , Electrical Potential, Electric Potential Energy) and some of them not include (Magnetic Field, Electric Current, Motion, Power- Energy, Electromagnetic Wave, Electric Flux and Maxwell's Equations).

As a result of the analysis in the research, it was determined that the dominant categories obtained by the FWAT are Electrical Force, Electric Charge and Magnitude of Electric Field. It seems that the response words in these categories are mainly related to the basic electrostatic issues in the school curriculum. Although, the Magnetic Field category is dominant, the response words in this category are included in the basic magnetism topics. When this category and the response words within this category are examined, it is clear that the teacher candidates can not distinguish between the electric field and the magnetic field concepts and therefore they are in a misconception. Guisasola, Almudi, & Zubimendi (2004) have found the similar results in their study. They have figured out that the model of electrical analogy of the students has cause confusion between the electric and the magnetic fields. In addition, the categories of Electric Current, Motion, Power-Energy, and Electromagnetic Wave and the response words in this category are not directly related to the concept of "electric field," and they are indirectly related to the concept of "electric field". It can be seen that distinction can not be made by teacher candidates. Therefore, it can be said that teacher candidates are in misconception about these concepts.

However, in general, it is seen that teacher candidates are not able to relate the topics added to and detailed in curriculum recently. The physics curriculum organized in 2005 based on constructivist philosophy was reorganized in 2017 and new subfields such as electric field sources, behavior of charged particles in the electric field and technological applications topics were added to the field of electrostatic subjects related to the "electric field" concept. The fact that teacher candidates do not address these new concepts, suggests that they have not yet internalized the new curriculum, have not recognized it, and that the expected level of proficiency in this area is not good enough. Thus, in the study about the qualifications of teacher candidates related to technological pedagogical field information, Bozkurt (2014) has stated that the level of physics teacher candidates at field information is inadequate. In addition, the new curriculum includes achievements that need directly or indirectly activities related to the concept of "electric field". Nevertheless, the fact that teacher candidates have not linked the "electric field" stimulus word to these activities suggests that the teacher candidates have not adopted the curriculum based on activity and also observation and experimentation. In his study, Bozkurt (2014) has emphasized that the ability of teacher candidates to perform activities was inadequate.

On the other hand, a remarkable finding of this study is that, when categories and the response words within these categories are examined, important modelings such as "superposition principle", "direction of electric field" which can be in "Electrical Force" category, and "electric field lines" and "the electric field lines for a point charge" which can be in "Electric Charge" category have not been given as response words. Tornkvist, Pettersson & Transtromer (1993) has indicated that difficulties of understanding the hierarchical sequence between the concepts (charge geometry-field line-force vector) are the reason of this result.

As a result of the analysis in the research, it is seen that the physics teacher candidates' conceptual structures of the "electric field" concept are not academically sufficient, also they focus on basic concepts and have conceptual misconceptions while relating to the "electric field" concept. Furio &, Guisasola (1998) have also investigated the difficulties in learning the concept of the electric field. On the other hand, Bilal & Erol (2009) have stated that the university students have some common misconceptions related with concept of electric field too. Therefore, it can be stated that the results of this study related with concept of electric field is agreement with results of the related literature.

In this study, it is seen that teacher candidates do not have as much conceptual ability in the subjects related to the concept of "electric field" in the education stages from high school to the university. The lack of clarity of conceptual knowledge, lack of activities to intensify the concepts, inadequacy of conceptual information, and lack of involvement in daily life events lead students to construct limited structures about the concept of "electric field". Therefore, they do not fully understand the concept of "electric field".

Hiebert and Levefre (1986) pointed out that the most fundamental feature of conceptual information is the richness of content in terms of correctness and relativity. The fact that one has the right information in terms of content requires knowledge of the basic and essential features of a physical concept. However, understanding only conceptual knowledge with these dimensions is insufficient. Because that, in physics a single concept does not make sense on its own. When a concept is associated with other concepts related to physics then the concept gains meaning and conceptual learning takes place in the mind of the individual.

The findings show that the cognitive structures of teacher candidates for "electric field" should be developed more consciously and purposefully. According to the results of this study, the following suggestions can be given:

- The Free Word Association Test (FWAT), which is used more frequently in social fields, is not used sufficiently in the field of physics education with many abstract and concrete concepts. With new studies, FWAT can be used to discover the relationships students have in their minds about physical concepts.
- The FWAT can be used as a measurement tool to understand whether meaningful learning has taken place at the end of physics and science lessons and to determine whether concepts related to it are adequately structured in students' minds.
- Taking into consideration the findings made by the FWAT, the conceptual deficiencies and misconceptions of students may be able to determine. In order to overcome these negativities, textbooks can give more emphasis on the study of texts about conceptual change.

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