INVESTIGATING 12TH GRADE STUDENTS' COGNITIVE STRUCTURES ABOUT THE ATOM CONCEPT USING DIFFERENT ASSESSMENT TOOLS

12. SINIF ÖĞRENCİLERİNİN ATOM KAVRAMI İLE İLGİLİ BİLİŞSEL YAPILARININ FARKLI ÖLÇME ARAÇLARI KULLANILARAK ARAŞTIRILMASI

Serkan EKİNCİ

A Thesis Submitted to the Graduate School of Educational Sciences of

Hacettepe University

in Partial Fulfillment of the Requirements for the Degree of

Master of Science

in

Secondary Science and Mathematics Education, Physics Education

2015

To the Directorate of Graduate School of Educational Sciences,

The work titled "Investigating 12th Grade Students' Cognitive Structures About the Atom Concept Using Different Assessment Tools" by Serkan EKİNCİ has been approved as **a thesis for the degree of Master of Science in Secondary Science and Mathematics Education Department, Division of Physics Education** by the Examining Committee Members.

Head	Prof. Dr. Musa SARI,	....
Member *(Supervisor)*	Prof. Dr. Ahmet İlhan ŞEN,	....
Member	Assoc. Prof. Dr. Erdat ÇATALOĞLU,	....
Member	Assoc. Prof. Dr. Deniz GÜRÇAY,	....
Member	Assoc. Prof. Dr. Ömer Faruk ÖZDEMİR,	....

Approval of the Thesis

This thesis, in accordance with rules and regulations governing Graduate Schools of Hacettepe University, has been approved by the above examining committee members on … / … / …., and it has been approved by the Administrative Board of Graduate School of Educational Sciences of Hacettepe University on … / … / …

Prof. Dr. Berrin AKMAN
Director of Graduate School of Educational Sciences

INVESTIGATING 12TH GRADE STUDENTS' COGNITIVE STRUCTURES ABOUT THE ATOM CONCEPT USING DIFFERENT ASSESSMENT TOOLS

Serkan EKİNCİ

ABSTRACT

The main purpose of this study was to investigate 12th grade students' cognitive structures about the atom concept with the help of concept mapping, semi structured interview, and drawing tools. 299 students from five schools in Ankara (four schools were state high schools, one was a private high school) were involved in this study in the fall and spring semesters of 2013-2014 academic year. The students had drawn concept maps. In addition, 37 students, randomly selected among 299 students, have involved in semi structured interviews and drew an image of an atom on a piece of paper.

In the analysis of concept maps, 37 students' propositions related to four fundamental concepts in quantum physics; atom, electron, light, and photon were analyzed. The interview data and students' drawings of an atom were analyzed based on the categories developed with respect to the atomic models. In addition, the results derived from the analysis of semi structured interview data and students' drawings were compared.

The results obtained from the analysis of all three assessment tools revealed that most students conceived the atom's structure in terms of classical and/or semi classical atomic models. In particular, the results indicated that the Bohr model had a strong influence on students' cognitive structures. In addition to this, the results of the semi structured interview data revealed that some students had knowledge about the quantum model of the atom. However, a significant number of these students drew classical and/or semi classical models. For that reason, it is suggested that multiple assessment tools should be used to have more definite information about students' cognitive structures related to the structure of the atom.

Keywords: Atom, Cognitive Structure, High School Physics Curricula, High School Chemistry Curricula, Concept Mapping, Drawing, Semi Structured Interview

Supervisor: Prof. Dr. Ahmet İlhan ŞEN, Hacettepe University, Department of Secondary Science and Mathematics Education, Division of Physics Education

12. SINIF ÖĞRENCİLERİNİN ATOM KAVRAMI İLE İLGİLİ BİLİŞSEL YAPILARININ FARKLI ÖLÇME ARAÇLARI KULLANILARAK ARAŞTIRILMASI

Serkan EKİNCİ

ÖZ

Bu çalışmanın temel amacı, 12. sınıf lise öğrencilerinin atom kavramı hakkındaki bilişsel yapılarını kavram haritalama, yarı yapılandırılmış görüşme ve çizim yöntemleri yardımıyla araştırmaktır. Çalışmaya, 2013-2014 eğitim öğretim yılı güz ve bahar döneminde Ankara ilindeki 4 devlet lisesi ve 1 vakıf lisesinde okuyan toplam 299 öğrenci katılmış ve bu öğrenciler atom kavramıyla ilgili kavram haritası oluşturmuşlardır. Ayrıca, kavram haritası çizen 299 öğrenci arasından rastgele seçilen 37 öğrenci ile yarı yapılandırılmış görüşmeler yapılmış ve görüşmelerin bitiminde öğrencilerden atomun yapısını çizmeleri istenmiştir.

Kavram haritalarının analizinde kuantum fiziğinin önemli kavramlarından olan atom, elektron, ışık ve foton ile ilgili 37 öğrencinin oluşturduğu önermeler incelenmiştir. Yarı yapılandırılmış görüşmelerden elde edilen veriler ile öğrencilerin atomun yapısına yönelik çizimleri atom modelleri ile ilgili geliştirilen kategoriler yardımıyla incelenmiştir. Ayrıca, görüşme verileri ile çizimlerin analizinden elde edilen sonuçlar birbiriyle karşılaştırılmıştır.

Her üç yöntemden elde edilen analiz sonuçları, öğrencilerin önemli bir bölümünün atomun yapısını klasik ve/veya yarı klasik modellere ait özellikler çerçevesinde ele aldıklarını göstermiştir. Atom modellerinden özellikle Bohr atom modelinin birçok öğrencinin bilişsel yapısına güçlü bir etkisinin olduğu tespit edilmiştir. Bununla birlikte, yarı yapılandırılmış görüşmelerde kuantum modeline ilişkin bilgilere sahip olduğu tespit edilen öğrencilerin önemli bir bölümünün atomun yapısını klasik ve/veya yarı klasik modeller çerçevesinde çizdikleri tespit edilmiştir. Bu nedenle, öğrencilerin atom yapısına ilişkin bilişsel yapıları hakkında daha kapsamlı bilgiye sahip olmak için farklı ölçme araçlarının bir arada kullanılması önerilmektedir.

Anahtar Sözcükler: Atom, bilişsel yapı, lise fizik öğretim programı, lise kimya öğretim programı, çizim, kavram haritalama, yarı yapılandırılmış görüşme

Danışman: Prof. Dr. Ahmet İlhan ŞEN, Hacettepe Üniversitesi, Ortaöğretim Fen ve Matematik Alanlar Eğitimi Bölümü, Fizik Eğitimi Bilim Dalı

ETHICS

As prepared in accordance with the thesis spelling rules of Graduate School of Educational Sciences of Hacettepe University, in this thesis study,

I declare that

- all information and documents have been obtained in accordance with academic rules,
- all audio-visual and written information and results have been presented in accordance with scientific ethical conduct,
- in case of using other works, I have fully cited all related works in accordance with scientific norms,
- I have fully referenced all cited works,
- I did not do any distortion in the data set,
- I did not present any part of this thesis as any other thesis at this or any other university.

Signature
Serkan EKİNCİ

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my supervisor, Prof. Dr. Ahmet İlhan ŞEN. I could not complete this study without his encouragement, patience, and guidance. It is very difficult to express in words how his invaluable criticisms helped my academic career.

I also would like to thank all students that participated in this study.

Special acknowledgement is expressed to The Scientific and Technological Research Council of Turkey (TÜBİTAK) for providing me partial financial support throughout my master education.

I am also thankful to my parents, Emine and Mehmet EKİNCİ, and my sister, Esra GÖNÜLLÜ, for their endless love and support throughout my life.

Lastly, I would like to express my deepest gratitude to my wife, Günnur EKİNCİ, for her love, encouragement, and moral support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CSCM: Classical and/or Semi Classical Model

HM: Hybrid Model

QM: Quantum Model

O: Other

R: Researcher

1. INTRODUCTION

At the very beginning of his influential book, David Ausubel (1968) stated: "If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly" (p. vi). In accordance with this crucial statement, by proposing meaningful learning theory, Ausubel implied that the meaningful learning can be accomplished when the new knowledge is related with the existing knowledge in an individual's cognitive structure. From this point of view, it can be stated that the prior knowledge has a key role on individual's new learning.

In addition, cognitive structure is described as the knowledge involving "facts, concepts, propositions, theories, and raw perceptual data that the learner has available to him at any point in time" (Ausubel & Robinson, 1969, p. 51). From the perspective of meaningful learning theory, it can be inferred that the knowledge in an individual's cognitive structure has a significant influence on his/her learning a concept meaningfully. The following excerpt indicates the role of that knowledge on meaningful learning explicitly:

> *If cognitive structure is clear, stable, and suitably organized, accurate and unambiguous meanings emerge and tend to retain their dissociability strength or availability. If, on the other hand, cognitive structure is unstable, ambiguous, disorganized, or chaotically organized, it tends to inhibit meaningful learning and retention (Ausubel, 1968, p. 128).*

Emphasizing the conditions for meaningful learning, Ausubel also led us to investigate what has been present in students' cognitive structures. For instance, students may have scientifically accurate and concrete pre knowledge on which the new learning related to that concept can be constructed easily. Conversely, if they have inaccurate knowledge or misconceptions about a given concept, then meaningful learning may not occur. Specifically, in his study, Taber (2001a) clarified that the latter takes place when there is a connection between students' "alternative frameworks" and the new knowledge. As a result, it can be stated that such alternative frameworks or learning difficulties will prevent meaningful learning, and students will still hold them in their cognitive structures. For that reason, it can be argued that a detailed investigation of such 'obstacles' to meaningful learning is the first step to help students comprehend the scientific knowledge. In this respect, researchers have developed and used several assessment tools such as interviews, multiple choice tests, two or three tier diagnostic tools, concept maps etc. Among these, concept mapping has been one of the salient techniques used in science education research. Novak (2010) simply defined concept map as “a knowledge representation tool” (p. 4). Generally, there are several concepts in a concept map and students link them to form propositions. Each proposition indicates how students make sense a pair of concepts in their cognitive structures.

Concept maps are mainly used as an instructional and assessment tool in the literature (Markow & Lonning, 1998; Özgün-Koca & Şen, 2006; Pankratius, 1990). Considering these, they have been widely used in science education research. For example, researchers used concept maps in different chemistry subjects such as convection and heat (Jones, Carter, & Rua, 2000), composition of matter (Pozo, 2001), concepts of solution (Uzuntiryaki & Geban, 2005) and thermodynamics (Francisco, Nakhleh, Nurrenbern, & Miller, 2002). In physics education, there are also studies related to electricity and magnetism (Anderson, Lucas, & Ginns, 2000), impulse-momentum (İngeç, 2009), concepts such as atom, electron, and photon (Sen, 2002), basic ideas in quantum mechanics (Rebello & Zollman, 1999) and atomic physics (Zele, Lenaerts, & Wieme, 2004). Nevertheless, Sen (2002) implied that further concept mapping research should be conducted in quantum physics education.

Furthermore, it is evident that incorporating more than one data collection tool in a research provides much more complete information about students’ cognitive structures. This is also known as methodological triangulation of data in which researchers use multiple assessment tools to collect data from the subjects of the study. For this strategy, Patton (2002) pointed that “studies that use only one method are more vulnerable to errors linked to that particular method (e.g., loaded interview questions, biased or untrue responses) than studies that use multiple methods” (p. 248). In accordance with this statement, three instruments were incorporated in this study. The first instrument was concept mapping, which has been used in few studies in quantum physics education. The second instrument was the semi structured interviews that researchers have frequently used in qualitative studies. The third was the drawing tool. All instruments were used to examine cognitive structures of grade 12 students related to the atom concept.

For many centuries, the atom has been one of the most important concepts in science. This concept was firstly emerged in BC 400, when Greek philosopher, Democritus used it to label the indivisible and the smallest part of matter. The origin of the term comes from the Greek word, *atomos*, which means ‘uncuttable’. About two thousands year later, in 1808, John Dalton proposed a theory related to atom. The formation of his theory was based on scientific methods; however, he was not able to propose a new idea about the atom’s structure; thus, his atomic model resembles the Democritus’ model. For that reason, until J. J. Thomson’s discovery of electrons in 1897, it had been believed that the atom was indivisible. However, in 1897, Thomson made a significant contribution to our understanding related to the atomic structure. When conducting an experiment with cathode rays, he discovered that the atom consists of smaller particles. By this discovery, a new atomic model was emerged. In this model, negative charges, namely electrons, are embedded in a sphere of positive charges. This model is also known as ‘the plum pudding model’. After this discovery, scientists’ ideas about the structure of atom changed drastically; they began to question the possibility of the existence of other particles like electrons in the atom.

In 1911, E. Rutherford and his colleagues conducted gold-foil experiment in order to verify Thomson’s model. The results of that experiment yielded another remarkable discovery: a positively charged structure at the center of the atom! Then, this structure was called as nucleus. As a result, Thomson’s model was replaced with a new atomic model which is likened to the Solar system. According to this model, the nucleus is depicted as the Sun which is located at the center, and electrons are like planets moving around the Sun. However, it was observed that the line spectra of the hydrogen atom could not be explained by that model. To find solutions associated with this model, N. Bohr proposed several important ideas:

> *1. An electron in an atom moves in a circular orbit about the nucleus under the influence of the Coulomb attraction between the electron and the nucleus…*
>
> *2.…it is only possible for an electron to move in an orbit for which its orbital angular momentum L is an integral multiple of ℏ, Planck’s constant divided by 2π.*

3. … an electron moving in such an allowed orbit does not radiate electromagnetic energy (Eisberg & Resnick, 1974, p. 109).

Of the items above, the second idea is crucial because Bohr used the quantization idea that was proposed by M. Planck in 1900. As a result, Bohr not only made a significant contribution to research in atomic physics, but he also solved the problems of the Rutherford's model. However, studies following the Bohr's theory revealed that it had also some deficiencies. For example, in 1924, L. de Broglie focused on the Bohr model to find out a rationale behind the energy quantization in the hydrogen atom. He focused on the wave-particle duality of light and proposed that particles could also have wave behavior. In addition, to describe this behavior, the term, 'matter wave' was used. Experimental proofs for de Broglie's theory were also provided by C. Davisson and L. Germer, and also by G. P. Thomson in 1927. In his well-known textbook, Beiser (2003) made an ingenious comment about Thomsons: "J. J. Thomson, G. P.'s father, had earlier won a Nobel Prize for verifying the particle nature of the electron: the wave – particle duality seems to have been the family business" (p. 104).

Although de Broglie explained the quantization of energy in the hydrogen atom with the help of the wave-particle duality of light, his explanation brought a new problem. The problem was related with the position of an electron in an atom because it also behaves as waves! In 1927, W. Heisenberg studied on this problem, and proposed the 'uncertainty principle'. According to this principle, we are not able to know simultaneously both the position and momentum of a particle (e.g. electron). To make this statement explicit, Fishbane, Gasiorowicz, and Thornton (2005) provided a simple application for an electron in the atom:

The mass of an electron is about 10^{-30} kg, and its speed in an atom is in the range of 10^{6} m/s. The momentum of an electron in an atom is then about 10^{-24} kg•m/s. The diameter of an atom is on the order of 10^{-10} m. If we try to pin down the location of an atomic electron to within 10 percent of the atom's size ($\Delta x \cong 10^{-11}$ m), then the momentum becomes uncertain to about 10^{-23} kg•m/s, 10 times the value of the electron's momentum in its classical atomic orbit. The momentum becomes so uncertain that we are not even sure that the electron will stay within the atom! (p. 1123).

The simple calculation above clearly shows that Bohr's model is not correct: an electron does not move in well-defined orbits in the atom. As being compatible with the uncertainty principle, in 1926, E. Schrödinger developed a wave equation by which an electron's position in an atom is expressed in terms of probabilities. A mathematical term, orbital, was also proposed in order for defining the probable positions of electrons. As a result, these successive attempts to discover the atom's structure eventually ended with the modern theory of the atom, and today, it is still accepted as the most scientific theory that explains that structure correctly.

The brief information above clearly presents how ideas related to the atomic structure changed gradually in time. In science education, generally, all historical ideas are taught students. However, for two decades, there has been a continuous debate on how the 'modern' structure of the atom should be introduced. The debate is generally rooted in whether the classical ideas/models of the atom should be used in teaching. While some researchers believe that they assist students to comprehend the structure of the modern atom, others criticize their uses in education for several reasons. For instance, in their study, Fischler and Lichtfeldt (1992) claimed that using mechanical models of the atom inhibits students' understanding of quantum physics. To prevent this, they made the following suggestions:

> *(a) Reference to classical physics should be avoided.*
>
> *(b) The teaching unit should begin with electrons (not with photons when introducing the photoelectric effect).*
>
> *(c) The statistical interpretation of observed phenomena should be used and dualistic descriptions should be avoided.*
>
> *(d) The uncertainty relation of Heisenberg should be introduced at an early stage (formulated for ensembles of quantum objects).*
>
> *(e) In the treatment of the hydrogen atom, the model of Bohr should be avoided (Fischler & Lichtfeldt, 1992, pp. 183-184).*

In addition, Ekinci and Şen (2014) conducted a document analysis of elementary science & technology, high school chemistry and physics textbooks published by Turkish Ministry of Education. They found that the Bohr model was excessively used in the textbooks. They contended that students could apt to imagine the atomic structure in terms of the Bohr model.

On the other hand, in their studies with the university students in US, Mckagan, Perkins and Wieman (2008) asked a question about the structure of the hydrogen atom in a final examination of a modern physics course. They analyzed students' responses in terms of three distinct models: "Bohr", "de Broglie", and "Schrödinger". While the Bohr model was taught them during the course, they revealed that the percentages of students who used the Schrödinger model were greater than those using the Bohr model. Mckagan et al. (2008) argued that students would be able to assimilate the ideas of the Schrödinger model provided that the Bohr model was compared and contrasted with the Schrödinger model.

The atom concept is used to explain many related concepts such as compounds, molecules, radioactivity, and sub-atomic particles etc. in high school chemistry and physics curricula in Turkey. Considering this strong relationship, it is argued that learning the atom concept meaningfully might affect students' understanding of the related concepts positively. For that reason, as being a 'first step', it is aimed to investigate grade 12 students' cognitive structures about the atom concept in the present study.

1.1. Purpose of the Study

The main purpose of this study is to investigate 12th grade high school students' cognitive structures about the atom concept using three assessment tools. The tools are concept mapping, semi structured interview, and drawing. Students' responses to semi structured interview questions and their drawings are also compared.

1.2. Research Questions

The following research questions are investigated in this study:

1. Considering grade 12 students' responses to the semi structured interview questions, how do they conceive the atom's structure?
2. Considering grade 12 students' drawings of an atom, how do they conceive the atom's structure?
3. Does the comparison between grade 12 students' interview responses and their drawings reveal any similarities or differences? If so, what are these?
4. Considering grade 12 students' concept maps,

   4.1. Which concepts do students link to the 'atom' concept?

   4.2. Which concepts do students link to the 'electron' concept?

   4.3. Which concepts do students link to the 'light' concept?

   4.4. Which concepts do students link to the 'photon' concept?

1.3. Definition of Important Terms

Concept is described as “a perceived regularity or pattern in events or objects, or records of events or objects, designated by a label” (Novak, 2010, p. 25).

Concept Map is described as “a schematic device for representing a set of concept meanings embedded in a framework of propositions” (Novak & Gowin, 1984, p. 15).

Drawing, in this study, refers to an instrument in which students draw an image of an atom.

Proposition, is defined as “two or more concepts semantically “linked” to illustrate a specific regularity…” (Novak, Gowin, & Johansen, 1983, p. 626).

1.4. Significance of the Study

The national elementary and high school science curricula in Turkey include specific learning outcomes that students are expected to attain at the end of each course. In addition, the spiral approach was implemented in science curricula between the years 2005 and 2013. This approach brought some restrictions when introducing new concepts, as a result, students have dealt with them in several times. For example, the participants involved in this study have studied the concept of atom through their elementary and high school years. For example, students were first introduced the atom concept in grade 6 science & technology course. Then, in grade 7, they studied the atomic structure (from Democritus’ ideas to the modern atomic theory). In high school, they thoroughly dealt with that concept in grade 10 chemistry course. Following this, they also studied it in the modern physics unit of grade 11 physics course. By doing so, it was intended to help students integrate new knowledge into their existing knowledge which they have constructed in preceding years. Thus, it can be concluded that students’ cognitive structures about the atom concept may have changed when the new knowledge was introduced them.

In educational studies, researchers have generally focused on one course (i.e. chemistry of physics) to formulate research questions, design their study, and obtain data. However, students may have studied the same concept or content in different courses as well. For that reason, researchers’ analyses and interpretations are restricted to the extent of one course only; then, some other valuable data are lost. This gap in the literature allowed me to follow an interdisciplinary approach when designing this study. As explained later in detail, both high school chemistry and physics curricula in terms of the atom concept were reviewed in this study.

When educational studies related to the subjects in quantum physics are analyzed, it is observed that researchers have not sufficiently paid attention to the use of multiple instruments when assessing students' conceptions. Generally, data were collected with one instrument merely. However, methodological data triangulation is a valuable strategy since different aspects of students' cognitive structures can be investigated with each instrument. In this study, data were collected by using three different instruments: concept mapping, semi structured interviews, and drawing. In addition, drawing tool was implemented separately from the semi structured interviews in the present study. In other words, students did not draw the structure of the atom during the interviews. As a result, the results obtained from these tools are compared with each other.

It is also believed that this study will have important implications for curriculum developers and science teachers. For instance, the results of this study will help curriculum developers review the related curricula. Moreover, the results may help teachers re-consider the important terms, concepts, or subjects related to the atom concept when developing their students' understanding during instruction.

These significances are also discussed at the last section of the literature review chapter.

2. REVIEW OF LITERATURE

In the macroscopic world, individuals have generally a direct interaction with the phenomena and they have first-hand experiences about them. Hence, they develop intuitive ideas or beliefs such that they are “based on their everyday experience” (Vosniadou & Brewer, 1992, p. 536). However, Vosniadou and Brewer expressed that these ideas are accepted to be different from the scientific knowledge. Similarly, Eryılmaz (1996) listed several sources of difficulties students have in the field of physics such as “mathematical skills required”, “degree of logical precision in problem solving,” and “sophistication in the types of reasoning required” (p.1). He also stated that intuitive beliefs are also one of the sources of difficulties. For instance, mechanics is a branch of physics and deals mostly with the phenomena in the macroscopic world. In numerous educational studies dealing with concepts in this field, it was implied that students who had intuitive beliefs or ideas were not able to understand the related fundamental principles, theories or laws (Halloun & Hestenes, 1985a; Halloun & Hestenes, 1985b; Hestenes, Wells, & Swackhamer, 1992).

Unlike classical physics, quantum physics focuses on the microscopic phenomena which students cannot make sense by their everyday experience. As a result, they do not develop intuitive beliefs related to these phenomena. However, there are several resources such as textbooks, media and teachers from which students gather information. While they may help students’ understanding of a phenomenon, it is also evident from the literature that they may also cause many misconceptions (Garnett & Treagust, 1992; Justi & Gilbert, 2000; Sanger & Greenbowe, 1999).

For instance, Justi and Gilbert (2000) examined twelve textbooks used in Brazil and UK in terms of the atomic models. For instance, they found that one of the textbooks embedded the idea of the proton in the Thomson model of the atom. They also revealed that one textbook used the s, p, d and f orbitals with the Bohr model. For that reason, they concluded that these would result in hybrid models and prevent students to understand the historical models of the atom.

In addition, Garnett and Treagust (1992) put an emphasis on teachers’ roles on students’ misconceptions about the electrochemistry. In their study, they conducted semi structured interviews with 32 high school students to investigate their conceptions about the electrochemical and electrolytic cells concepts. The analysis of students' interviews indicated that students had several misconceptions about these concepts. They argued that students' misconceptions may have been derived from the teaching process. For that reason, they suggested diagnostic tests to assess students' prior knowledge and appropriate teaching approaches to prevent such misconceptions.

The results of these studies clearly indicate that students may also gather information about a phenomenon from such resources without regarding whether they are accurate. In particular, they may become primary resources for the phenomena that take place in the microscopic world, like the ones in quantum physics world. Thus, the resources may shape students' cognitive structures. From this point of view, in this study, it was aimed to probe how they have shaped students' cognitive structures about the concept of atom.

Up to this time, many researchers have dealt with students' understandings related to classical and modern ideas of the atom. In the following sections, I will discuss many of them. In the first section, I will discuss the results of studies having used the concept mapping tool. Then, I will present the results of studies in which students' drawings of an atom were discussed. After that, I will mention the results of studies which did not involve either concept mapping or drawing tool. At the end of the chapter, I will give a summary of the results of these studies.

2.1. Results of Concept Mapping Studies in Quantum Physics Education

This section involves a discussion of the results of studies in quantum physics education in which concept mapping was mainly used as a data collection tool. Generally, the review of literature revealed that there were five studies using concept maps. A review of them is given below.

Rebello and Zollman (1999) conducted a study with 17 prospective science and mathematics teachers at Kansas State University in US. The researchers aimed to introduce several quantum mechanics topics by using hands-on activities and computer visualization materials. Rebello and Zollman stated that worksheets, examinations, interviews and concept maps were used to draw conclusion about their understanding related to the topics in focus. Particularly, students were divided into two groups to construct a concept map about the topics covered in the course. While students in second group were given 50 concepts, students in the first group constructed their maps with the concepts they generated. They found that there were 12 clusters in each of which the concepts that belonged to the same instructional unit like “Solids & Light” or “The Waves of Matter” were connected with each other. It was noted that the clusters were more intense in the second group’s concept maps. Although the researchers did not explain why this was the case, in my opinion, providing concepts to the students might be the probable reason since they may have found easy to group the concepts in terms of the instructional units. Rebello and Zollman also stated that students’ concept maps did not include some expected links between several concepts.

Sen (2002) conducted a research using concept mapping tool with 88 university students in Turkey. There were three groups that comprised the sample; sophomores, juniors, and seniors. Three concepts; atom, electron, and photon were given them to construct a hierarchical concept map. He analyzed students’ concept maps both quantitatively and qualitatively. The analysis revealed that the seniors used more concepts in their maps than sophomores. In addition, Sen analyzed the first links to these three concepts. Although he did not explicitly state how they were related with the atom, he indicated that almost half of the students in all three groups (50 % for sophomores, 44 % for juniors, and 40 % for seniors) connected electron, proton and neutron to the atom. Furthermore, the analysis of the first links to the electron revealed that approximately the same number of students in three groups used the “circular orbit” concept. In contrast to the results about the atom concept, Sen explained the relationship between these concepts and stated that students believed that electrons are moving around the atom in circular orbits. In this respect, he concluded that they perceived the electron as a classical object. It was also indicated that cognitive structures of the students in different grades were similar with respect to the concepts of atom and electron.

While Sen (2002) focused more on students’ understanding about the quantum physics concepts, Zele, Lenaerts and Wieme (2004) mainly focused on the use of concept maps as a research tool; yet, they designed their research using the atom concept. In the study, a methodological study was held for the analysis of concept maps with 2nd year university engineering students. They criticized several existing concept mapping analysis techniques and stated that a) scoring was based on counting the number of concepts and propositions, b) they ignored students' mistakes and misconceptions, and c) the use of a criterion map that caused loss of data. Thus, they proposed a new qualitative method for analyzing concept maps. In the study, there were 170 students who were studying an introductory quantum physics course. In the data collection procedure, the researchers first introduced the concept mapping to the students and gave a list of concepts related to the atom concept like electron, electron cloud, elliptical trajectory, energy level etc. Students completed their maps in three weeks. Then, they were interviewed about the propositions in their maps. They revealed that most students wrote propositions like "An atom has a nucleus", "Electron clouds are made of electrons", "An electron moves in/is located in an orbital", and "An electron is located on a circular orbit" (p.1059). Since the study mainly dealt with the method for analyzing concept maps; thus, the physics knowledge of students about the atom concept was not discussed in detail. Nevertheless, they concluded that concept mapping could be used effectively to examine students' knowledge structures.

Ke, Monk, and Duschl (2005) conducted a cross-sectional study with Taiwanese students to investigate whether they could have an understanding about the differences between classical and quantum concepts. Students from undergraduate to Ph.D. levels were involved in the study. The researchers used a three-item questionnaire related to atomic structure. They analyzed 140 students' responses and grouped them into three different stages of historical development of quantum theories. Then, 28 students were selected from the entire sample and interviews were conducted with them. In the interviews, the researchers aimed to further investigate the students' responses for the questionnaire items. Furthermore, they also conducted a "card sort task" in the interview settings. In the task, they formed two groups and each group consisted of 10 classical and quantum concepts in total for each question in the questionnaire. For instance, while the "electron" concept took place in all three classical groups, the "probability" and "uncertainty principle" concepts were commonly involved in all quantum groups. The students linked the concepts and explained the links. Using students' links and their explanations, the researchers constructed concept maps to analyze their understanding about the concepts. Here, as this section's main focus is about concept maps, I would like to discuss the results of concept mapping analysis. To analyze the concept maps, Ke et al. (2005) developed three codes and labeled the links like “within a classical model”, “not within any model”, or “within the quantum model” (p.1582). They discussed three students’ maps. Each student was representative for different stages that were discussed earlier in the study. They found that students’ propositions in the concept maps were compatible with their responses for the questions in the questionnaire and subsequent interviews. For example, an undergraduate student who used classical ideas for explaining the atomic structure in the interviews was not able to use the quantum concepts in the card sort task. Instead, he/she relied more on constructing propositions between classical concepts. It was implied that concept maps, without regarding how they were formed, could provide important cues for students’ understanding and they could support the data collected by different instruments. In addition, the coding scheme used in that study for the analysis of concept maps seems to be useful because the propositions can be analyzed in terms of the atomic models.

For several decades, concept maps have been accepted as useful learning and teaching tools in education, and in this respect, researchers have been deeply concerned with developing methods for analyzing concept maps. As a result, many analysis methods have been suggested. Generally, these methods can be classified as qualitative and quantitative. In their study with 10 pre service chemistry teachers, Nakiboğlu and Ertem (2010) took the atom as a central concept and provided them 12 concepts like nucleus, proton, neutron, element, orbit etc. They analyzed students’ maps in terms of three concept mapping analysis techniques and revealed that qualitative analysis of concept maps yielded the lowest scores. Their main focus was not to discuss students’ knowledge about the atom concept; however, they drew important conclusions about the analysis of concept maps by comparing qualitative and quantitative techniques.

2.2. Results of Studies Investigating Students’ Drawings of an Atom

It is evident from the literature that several studies investigating students’ conceptions about the atomic structure integrated drawing as a data collection tool into their research designs (Adbo & Taber, 2009; Cokelez, 2012; Griffiths & Preston, 1992; Harrison & Treagust, 1996; McKagan, Perkins, & Wieman, 2008;

Müller & Wiesner, 2002; Park & Light, 2009; Tsaparlis & Papaphotis, 2009). In addition, some researchers also embedded this tool in interview settings or open - ended questions and probed students' conceptions and misconceptions. Below, I will discuss both researchers' inferences from students' drawings and other results related to the atom concept.

To begin with, in a study with 18 upper secondary science students in Sweden, Adbo and Taber (2009) conducted a three-step semi structured interviews to investigate their mental models related to concepts of states of matter, phase transitions. They asked students to draw the structure of the atom in the first step of the interviews. The analysis of students' drawings and interview transcripts revealed that they had several conceptions about the atom's structure. For instance, all students believed most of the volume of the atom was comprised by the nucleus. In addition, fifteen students stated that the nucleus of the atom was stationary, and Adbo and Taber contented that textbooks as well as teachers were the underlying causes for these conceptions. Although students' drawings were not a three dimensional image of an atom, they stated that students used their hands to make a sphere and described a three dimensional structure of the atom. Therefore, they concluded that students knew this structure.

Müller and Wiesner (2002) developed a course that was based on the fundamental ideas of quantum mechanics and conducted a research with 60 students in Gymnasium schools in Germany. Implementing a questionnaire and interviews, they assessed whether the course was effective regarding the students' understanding. In the questionnaire, they also asked them to draw an atom. However, it is worth noting that they led students to explain "whether there are features that cannot be drawn." (p. 206). They analyzed students' responses for three Likert-type items in the questionnaire and their drawings as well. It was found that the experimental group favored more quantum mechanics ideas against the ideas of classical mechanics than the control group. When their drawings were analyzed and grouped, 61% of students in the experimental group drew a cloud model. On the other hand, while 29% of students in the control group drew that model, 32% of them drew the Bohr model.

In another study, Cokelez (2012) studied with 126 elementary school students and investigated their ideas related to the atomic structure. Grade 6 and grade 7 students were involved in the study. In the data collection procedure, students were given three open-ended questions. In the first question, they were asked to draw what they saw when they looked at the atom under a powerful microscope. Students' responses were categorized and it was found that students mainly drew classical models of the atoms such as "solar system model" or "composition atom model". On the other hand, Cokelez stated that 4 7th grade students drew the electron cloud model despite that they did not take an instruction about this model. Then, he concluded "students did not always prefer simple, concrete models but instead tended to select complex, abstract models." (p. 683). However, this was a weak claim since he did not further probe in detail what students actually meant by their drawings. Furthermore, as noted, these students did not even learn that model; for that reason, it may be concluded that the students actually may not have preferred this model.

In their study, Tsaparlis and Papaphotis (2009) developed a questionnaire and conducted interviews with Greek university students studying Chemistry, Biotechnology, and Material Science in 2001. In the questionnaire, there were 14 questions that focused on several aspects of quantum ideas. In one of the questions, the researchers also asked students to draw the hydrogen atom. They analyzed students' drawings and emphasized that students tended to draw the Bohr model because they had already been familiar with and they did not show the motion of electron in their drawings. Tsaparlis and Papaphotis (2009) discussed this as follows:

> *Most students accepted that a picture of an electron cloud is just a collection of dots representing probable positions of the electron at various instants in time, but could not accept that such a picture is representative of what we would see if we could see inside the hydrogen atom. So the students, being unable to illustrate motion in a static drawing, ended back with at a planetary model (pp. 905- 906).*

The above statement implies the discrepancy between students' explanations and their drawings. Moreover, they found that students relied more on "concrete or simple abstract models". In accordance with this, they had hybrid models of the atom. It was also found that they did not comprehend the Heisenberg principle and the orbital concept. Then, they concluded that the old quantum theory students had learned before affected their conceptions.

Up to this time, a general list of misconceptions students held about the atom was provided by Griffiths and Preston (1992). They conducted semi structured interviews with 30 students in grade 12 and asked thirteen questions in terms of structure, size, weight, and animism of the atoms. It was detected students had several misconceptions. Table 2.1 represents them below.

Table 2.1: A List of Misconceptions about Atoms

Investigated Terms	*Misconceptions*
Structure / Shape	An atom resembles a sphere with components inside.
	An atom resembles a solid sphere.
	An atom looks like several dots/circles.
	Electrons move in orbits.
	Atoms are flat.
	Matter exists between atoms.
Size	Atoms are large enough to be seen under a microscope.
	Atoms are larger than molecules.
	All atoms are the same size.
	The size of an atom is determined primarily by the number of protons.
	Heat may results in a change of atomic size.
	Collisions may result in a change of atomic size.
Weight	All atoms have the same weight.
Animism	All atoms are alive.
	Only some atoms are alive.
	Atoms are alive because they move.

Source: Griffiths, A., K. & Preston, K., R. (1992). Grade-12 Students' Misconceptions Relating to Fundamental Characteristics of Atoms and Molecules. *Journal of Research in Science Teaching*, *29(*6), 611-628

They noted that the first three misconceptions in Table 2.1 were detected from students' drawings. They also identified some students who believed that atoms were alive. However, they did not discuss the underlying reason(s) for these misconceptions. On the other hand, Garnett, Garnett, and Hackling (1995) thought that such misconceptions were stemmed from several reasons. For instance, they argued that students confused the atom and "biological cell" because these concepts were concurrently introduced to the students. Similar findings were also detected in another study (Harrison & Treagust, 1996) in which the atom was depicted as a cell by one fifth of students. They also revealed that the nucleus of the atom was described as the "control center."

Other findings were also obtained in the study of Harrison and Treagust (1996). They examined 48 high school students' mental models about the atom in

Australia. Students were incorporated in the study from three different grades. They were asked to describe the atom on their mind and draw the model of the atom in the interviews. Then, six diagrams depicting the atomic structure were given them to select which represented their models best. Moreover, they asked the students to show their second and third preferences for the atomic structure. They found that the orbits model was selected by most students (n=22) as the best representation. When the second and third preferences for this model were considered, this number increased to 34. In addition, solar system model was found to be acceptable by 21 students. On the other hand, it was indicated that the number of students who preferred or did not prefer the electron cloud model was 16 and 8, respectively. Considering these findings, Harrison and Treagust claimed that students "favor distinct, concrete models because such models resemble their everyday world objects" (p. 519).

When students' drawings were analyzed, Harrison and Treagust discovered that they generally drew a ball model. However, they observed that more than half of these students tended to prefer three dimensional diagrams. For that reason, they concluded that students did not have a deep understanding related to the atomic structure.

Park and Light (2009) studied three university students' mental models about the atomic structure in US. Two interviews were held with the students both before and after an introductory chemistry course. During both interviews, they drew the structure of the atom. Their responses were analyzed according to four models of the atom: particle model, nuclear model, Bohr's model, and quantum model. The analysis revealed that two students had an understanding of the basic ideas of the quantum model after the course, and their drawings were generally compatible with the responses they gave during the interviews. Other student drew the Bohr model and his mental model was labeled as the Bohr model. Despite this, the researchers noted that while this student explained the Heisenberg uncertainty principle and remembered that it proved Bohr model had weaknesses, he did not use it when drawing the atom's structure. In addition, they emphasized that the Bohr model had a strong effect on students' mental models.

2.3. Results of Other Studies Related to the Atom Concept

While several studies attempting to investigate students' conceptions, models or misconceptions about the atom with the help of their drawings, there are also other studies which did not use it. At this section, I will discuss the results of studies in which researchers did not use concept mapping or drawing. Furthermore, I will discuss several studies dealing with some key terms and concepts that are relevant to the atomic structure.

Petri and Niedderer (1998) focused on a secondary school student's learning process in a quantum atomic physics course in Germany. Several tools were used to gather data from the student such as observation, questionnaire, semi structured interviews, and examinations. The student, Carl, developed several conceptions throughout the course such as "planetary model", "the probability orbit model", the "state - electron model" and "the electron cloud model". It was reported that although there was an improvement in Carl's learning, he held three of these conceptions in his "final cognitive system" with different "strengths" and "status". By referring the strength, Petri and Niedderer meant the tendency of using a conception in different contexts, and by referring the status they meant "the scientific value students attach to them" (p. 1084). It was concluded that Carl accepted the electron cloud model as more scientific than others; that is, it had a higher status. However, he held the planetary model more strongly; in other words, he tended to use it in different contexts.

In many studies, the planetary model or the Bohr model of the atom was strongly accepted by students in almost all grades. For instance, in the study of Şen (2002), 45.6% of all prospective physics teachers (n = 188) stated that they would use the Bohr/Sommerfeld model of the atom to teach the structure of the atom. On the other hand, 35% of them stated they would use the electron cloud model for that purpose.

In addition, Şen (2002) provided other findings which are worth discussing. When students were asked whether electron had a position in an atom, Şen found almost 66% of them implied that electron had a definite position. 5.3% of them used the Heisenberg uncertainty principle and stated electron did not have a position. He then noted that electron was believed to be a classical particle. In another question, Şen asked what they inferred from the Heisenberg principle equation. More than half of students' responses were found to be acceptable. Although he did not discuss the findings of these two questions together, it is clear that students having the knowledge of Heisenberg uncertainty principle were not able to recall it when explaining the behavior of an electron in the atom, unfortunately. As a result, it was inevitable for them to believe that electron is a classical particle. Park and Light (2009) also drew attention to this principle and argued that "probability for finding electrons based on Heisenberg's uncertainty principle" (p. 251) is a prerequisite for learning the quantum model of the atom.

Similar to the study of Şen (2002), Nakiboğlu (2003) also studied prospective chemistry teachers' misconceptions about atomic orbitals and hybridization concepts in Turkey. The study consisted of 2^{nd}, 3^{rd}, and 4^{th} year university students studying chemistry. A diagnostic test including open - ended questions and multiple choice questions was implemented to the students. It was revealed that one fifth of students used the solar system model when they were asked to explain the atomic orbital.

While students easily accept the ideas of classical models of the atom, it is shown that some undesired consequences in their later learning (i.e. about the modern theory of the atom) may occur. In his paper, Taber (2001b), taking this fact into account, yet favored the use of solar system model as an analogy for the classical model of the atom. He argued that the Solar system model and the atom have common similarities which are worth emphasizing when the concept of atom is first introduced to the students. He also pointed that teachers should ensure students' familiarity with the solar system before using the analogy. In contrast, Fischler (1999) noted that "problems of elementarization (that is, of reducing more difficult concepts into simpler terms) become central to didactic reflection in quantum physics more than in any other topic" (p. 33).

In their study, Steinberg, Wittmann, Bao, and Redish (1999) drew attention to the importance of students' understanding the classical concepts when they learn quantum mechanics concepts. To show this, they dealt with two classical concepts, physical optics and conductivity. For example, they revealed that students had some difficulties even about the basic electrical concepts such as voltage and current. They concluded such difficulties had negative effects on students' learning quantum mechanics. These results indicated that a solid prerequisite knowledge help students' subsequent learning in the future. Although the results of the study do not seem to be related with the atom concept, I believe that some critical things can be underlined for this current study. Turkish students should learn the modern theory of the atom based on their prior knowledge about the concepts of light and photons. The high school chemistry and physics curricula were designed in this perspective. Hence, a critical analysis of both students' interview responses and propositions they wrote in their concept maps related these concepts might provide us important information about the roots of learning difficulties and misconceptions they probably hold about the modern structure of the atom.

Ireson (2000) examined 342 pre-university students' understanding about the quantum phenomena with the help of a 40 item Likert type questionnaire. Students' responses were analyzed by cluster analysis. The analysis yielded four clusters for the pre study group while it yielded three clusters for the post study group. The clusters for the post study group were observed to be "quantum thinking", "conflicting quantum thinking", and "conflicting mechanistic thinking". For instance, the latter included statements such as "electrons are waves" and "the electron is always a particle" (p. 19). Ireson concluded that students had a lack of understanding about the quantum phenomena. Considering the scope of his study, he referred the ideas of Fischler and Lichtfeldt (1992), and made several suggestions. For example, he proposed "quantum object" term for electrons to prevent students to perceive them as either "waves" or "particles". Similarly, he also suggested this term for light and photons when introducing students the photoelectric effect. By doing so, he believed that students would not conceive photons as "classical particles".

Mashhadi and Woolnough (1999) conducted a study to investigate how students visualized electrons and photons. 83 secondary school students were involved in the study. The researchers asked them how they imagined the electrons. Below, there is a list of answers given by at least 10 % of students who stated that they had an image of electrons:

1. *An electron is a very small spherical object moving very fast.*
2. *An electron orbits the nucleus at high speed, rather like a planet orbiting the sun.*

3. *An electron is a small ball of negative charge (Mashhadi & Woolnough, 1999, p. 514).*

They also found that only 2 % of the students believed that electrons were waves. Furthermore, they asked the same question for photons and found that students generally imagined a photon as a “bright (small) spherical ball” (p. 515). According to these results, Mashhadi and Woolnough concluded that a “particle - like” image was dominant for both electrons and photons.

Considering wave - particle duality, Olsen (2002) focused on students’ understanding about light and electrons. He conducted a study with 236 upper secondary school students from 20 schools in Norway and asked two multiple choice questions related to wave - particle duality of light and electrons, and also asked an open - ended question to further investigate their reasoning when they gave answers to the multiple choice questions. He found that 59% of students thought that electron is a particle. On the other hand, 77% of them were found to think that light has a dual characteristic. Olsen pointed that students did not think that light and electrons shared a similar characteristic in terms of the wave - particle duality. Furthermore, he analyzed students’ explanations in the open - ended question and revealed that some students believed that light and electrons are “undulatory particles”. He stated that concepts such as momentum, mass, and charge were generally attributed to the electrons by students who thought that electron is a particle. It was suggested that the wave - particle duality should not be taught students when they were studying quantum physics.

In her another study with 40 elementary mathematics education students studying at a state university in Turkey, Nakiboğlu (2008) investigated the possible changes in students’ knowledge structures about the atomic structure after they took a general chemistry course. For this purpose, she developed a words association test (WAT). There were 10 “stimulus words” such as electron, proton, orbit, and orbital. During the implementation, these were given students and asked them to write “response words” which are relevant to each stimulus concept in 30 seconds. The test was implemented before and after the course. She firstly used two analysis techniques for WAT and discussed the results derived from the analyses; however, she was not satisfied with them and highlighted their own strengths and limitations. For that reason, she developed another analysis technique by considering the strengths of each existing technique. The new technique indicates both the direction and the strength of the relationship between two concepts/words. It was found that a strong relation existed between orbit and the electron in students' knowledge structures before the course. After students took the course, the results indicated that two separate "islands" (i.e. groups of concepts) formed. In the first island, orbit and orbital concepts were strongly related to the electron. In the second island, the proton was strongly related to both nucleus and a response word, positive charge. When the weak relationships of students' knowledge structures considered before the course, there were two groups of words/concepts and they were not connected each other. On the other hand, the analysis of students' responses after the course revealed that there was only one island which was in fact formed by two separate islands connected with just one link. Nakiboğlu concluded that students' knowledge structures were influenced due to the general chemistry course. However, there are also some important points to be discussed in detail for that conclusion. For example, Nakiboğlu (2008) stated:

> *It is important to note that there was no association between the concepts orbital and orbit after instruction. This can indicate that students did not form a hybrid model of Bohr atomic theory and quantum mechanical model of the atom during learning (p. 320).*

She drew such a conclusion probably by considering the common confusion some students have when they are assimilating orbital concept into their cognitive structures where the orbit concept also exists. On the other hand, they were connected to the electron but we did not actually know 'how' they were related to the electron. For example, while completing WAT, a student may have intended to say 'An electron is moving in the orbits', besides that he/she may also have thought 'An electron is found in orbitals.' This example might indicate that the student holds a hybrid model and it therefore contradicts with her assertion. In this respect, one might conclude that WAT is unable to provide a deep understanding about the relationship between two concepts; even the arrows show the direction of the relationship. Furthermore, WAT yielded superficial results to evaluate the effectiveness of the course in terms of the stimulus words.

2.4. Summary of Review of Literature

The following things can be drawn from the above studies:

- The atom is an abstract concept and students have learning difficulties and misconceptions. The origins of these are generally attributed to the previously taught classical or semi classical models of the atom.
- Classical or semi classical atomic models have some negative effects on students' subsequent learning related to modern structure of the atom.
- Independent of their academic levels, many students have similar learning difficulties and misconceptions.
- The main assessment tools used in these studies are interviews, questionnaires and open - ended questions.
- Drawing has also been used in studies seeking students' conceptions about the atomic structure. Furthermore, it is evident that the students still draw classical models of the atom in these studies even after studying the modern theory of the atom.
- The results of these studies dealing with students' conceptions about the atom concept are generally discussed within the framework of only one course (i.e. either chemistry or physics); however, students might have studied that concept in other courses.
- Studies related to the atom concept generally failed to incorporate more than one assessment tool; in addition to this, researchers failed to compare and discuss the results obtained from each tool; simply, the studies lacked of methodological data triangulation.

From this point, in the present study, three instruments; concept maps, semi structured interviews, and drawing were used and the results were compared and discussed in detail. In addition, I conducted an analysis of high school chemistry and physics curricula to determine (1) the extent of knowledge students had to learn in these courses, (2) the key concepts which commonly take place, (3) semi structured interview questions.

3. METHODOLOGY

This study was conducted in the fall and spring semesters of 2013 - 2014 academic year with 12th grade students from five schools in Ankara. In this chapter, a general description related to the subjects of the study, instruments, data collection procedure, analysis of data, trustworthiness of the study, and assumptions is given.

3.1. Subjects of the Study

Patton (2002) proposes several purposeful sampling strategies for qualitative research. In this study, criterion sampling strategy was used to select the schools and students. In the first stage of the data collection procedure, 299 students were selected from four state high schools (School A, School B, School C, and School D) and a private school (School E). All students were asked to draw a concept map. Table 3.1 shows the distribution of the students with respect to five schools.

Table 3.1: Students Having Constructed Concept Maps

Schools	***Number of Students***
School A	74
School B	27
School C	74
School D	74
School E	50
Total	299

As discussed in section 3.2.1, there are two groups (Group 1 and Group 2) that two different concept lists were given. While the students studying at schools A, B, C, and D were given 16 concepts, the students studying at school E had a list of 23 concepts when drawing a concept map.

In the second stage of the data collection procedure, 37 students were selected randomly among 299 students. All 37 students participated in semi structured interviews and drew an image of an atom as well. The total number of female students (n=18) was almost equal to the number of male students (n=19). As seen in Table 3.2, almost one third of the sample was derived from School A. On the other hand, School B had the least contribution to the sample; there were only four students.

Table 3.2: Students Having Participated in Semi Structured Interviews and Having Drawn an Image of an Atom

Schools	*Female*	*Male*	*Total*
School A	6	6	12
School B	2	2	4
School C	5	1	6
School D	3	3	6
School E	2	7	9
Total	18	19	37

3.2. Instruments

There were three instruments used in the study, these are concept mapping, semi structured interviews and drawing. In the next three sections, brief descriptions for each instrument are given.

3.2.1. Concept Mapping

It can be seen from the literature that there are various concept mapping techniques that researchers and teachers have used for several decades. In their study, Ruiz-Primo and Shavelson (1996) presented a very concise summary of mapping techniques. They focused on three components of concept maps; “task”, “response”, and “scoring system”, and they provided several variations for each component (p. 586). Considering these variations, in this study, students were given a list of concepts related to atom, and simply, they were asked to draw a concept map.

In high school chemistry and physics courses, the number of learning objectives changes with respect to course hours. From grades 9 to 11, Table 3.3 illustrates the weekly course hours of high school chemistry and physics courses.

Table 3.3: The Weekly Hours of High School Chemistry and Physics Courses

	9th Grade	*10th Grade*	*11th Grade*
Chemistry	2	2 or 3	2 or 4
Physics	2	2 or 3	2 or 4

Table 3.3 implies that there are many possibilities students may have taken both chemistry and physics courses. Considering this, 37 students were divided into two groups. The students of the first four schools (i.e. School A, B, C, and D) comprised the first group (Group 1) and the students of School E comprised the

second group (Group 2). There are 9 students in Group 2. The students have taken 3 hours of chemistry and physics courses in 10th grade. Moreover, they have taken 4 hours of chemistry and physics courses in 11th grade. The hours of the courses that Group 2 students have taken is given in Table 3.4 below.

Table 3.4: The Weekly Hours of High School Chemistry and Physics Courses Group 2 Students Having Taken

	9th Grade	*10th Grade*	*11th Grade*
Chemistry	2	3	4
Physics	2	3	4

In contrast to Group 2 students, Group 1 students did not take maximum number of hours of chemistry and physics courses in grades 10 and 11. For instance, they may have taken 2 hours of chemistry course and 3 hours of physics course in 10th grade, and they may have taken 2 hours of chemistry and physics courses in 11th grade.

Such variations in the course hours led me to conduct a content analysis of grades 9, 10, and 11 chemistry and physics curricula to determine which concepts commonly take place. The analysis revealed that there are many concepts commonly found in the curricula. To check the content validity, I asked several high school chemistry and physics teachers and researchers in science education and to conduct the same analysis. Their analyses results and feedbacks led me construct two concept lists in terms of the course hours. While the first concept list includes 16 concepts that were given Group 1students, the second concept list consists of 23 concepts that were given Group 2 students. The first concept list is shown in Table 3.5 below.

Table 3.5: The Concept List Consisting of 16 Concepts

Atom	Light	Orbit	Position
Atomic Model	Mass	Particle	Proton
Charge	Neutron	Photon	Wave
Electron	Nucleus	Planck's Constant	Wavelength

On the other hand, Group 2 students had 7 extra concepts in addition to the concepts given in Table 3.5. As seen in Table 3.6, the extra concepts are 'de Broglie's wavelength', 'photoelectric effect', 'interference', 'black body radiation', 'diffraction', 'momentum', and 'orbital'.

Table 3.6: The Concept List Consisting of 23 Concepts

Atom	Electron	Nucleus	Planck’s Constant
Atomic Model	Interference	Orbit	Position
Blackbody Radiation	Light	Orbital	Proton
Charge	Mass	Particle	Wave
De Broglie Wavelength	Momentum	Photoelectric Effect	Wavelength
Diffraction	Neutron	Photon	

3.2.2. Semi Structured Interviews

The interview schedule consisted of 4 open-ended questions to investigate how students conceived the atom’s structure. In fact, there were two groups of questions. The first group questions directly aimed to probe students’ cognitive structures about the atomic structure: a) ‘How do you conceive the atom and its structure?’ b) ‘What can you talk about the electron’s behavior in an atom?’ During the interviews, several probing questions were also asked to investigate their cognitive structures in detail: For instance, questions like ‘Is there anything inside the atom?’ or ‘How can you describe an electron’s motion in an atom?’ were asked to the interviewees.

Furthermore, the second group involves two questions related to light and photon concepts. Students were asked to respond to these questions: a) ‘What is light?’ and b) ‘What is photon?’ Besides these, I asked some probing questions like ‘What characteristics of light do you remember?’ or ‘Do you remember any experiment related to the characteristics of light/photon?’

Here, I would like to talk more about the interview questions. Firstly, it should be pointed that the chronological order of the discoveries related to atomic structure has been followed in high school chemistry and physics curricula. For instance, de Broglie’s postulate that particles (e.g. electrons) have also wave characteristics as light has a crucial role in the development of quantum theory of the atom. In chemistry and physics courses, students learn the wave - particle duality of light before studying the wave characteristics of electrons. Most probably, it is expected that students should construct their knowledge about wave nature of electrons by using the information provided them about light and photons. Thus, it clearly explains the reason why students’ existing knowledge about these concepts was investigated in the interviews. For that reason, I asked the second group questions in the interviews.

Furthermore, Tables 3.5 and 3.6 represent that there are several concepts related to the light such as photon, diffraction, wave, interference etc. In this respect, concept mapping was another tool to assess students' knowledge about these concepts. Therefore, the analyses of students' concept maps may also provide important clues about how they conceived these concepts. Therefore, both semi structured interview and concept mapping give us more information about students' cognitive structures related to concepts of light and photons.

It should also be noted that the formation of interview questions was based on the concepts given in Table 3.6. In other words, all interview questions probed students' understanding related to all 23 concepts. Here, it may be criticized that the same questions were also asked students having taken 16 concepts. However, the extra concepts were not introduced them in the interviews. As a result, the same questions were asked both groups.

3.2.3. Drawing

This instrument was used to elicit how students visualized the atom's structure in their cognitive structures. After having answered the interview questions, students were asked to draw an image of an atom on a piece of paper. They were also asked to explain their drawing.

3.3. Data Collection Procedure

In this study, data were obtained from the students approximately in four weeks. Before implementing the concept mapping tool, I conducted a pilot study with 30 12^{th} grade high school students who satisfied the aforementioned criteria for having taken 16 concepts. To accomplish this, firstly, I discussed the definitions of several terms such as concept, link, cross-link and concept map with students. Then, a short concept mapping activity was conducted to inform students how to construct a concept map. In the activity, the concept, 'New Year', was given students as a key concept. Then, I asked them to suggest many concepts related to New Year. In general, they suggested concepts like lottery, gift, turkey, family, holiday etc. I have drawn an illustrative concept map on the board to show how concepts were linked to each other. Then, I gave the concept list. During the implementation, they were allowed to add many concepts besides the ones in the list. After collecting students' maps, an analysis was conducted to detect if there were any ambiguities related to the formation of the maps. The analysis indicated that there were not any serious problems.

After the pilot study, data were collected in four steps. Firstly, following the same procedure, 299 students constructed their maps. The students generally completed the task in 30 - 40 minutes. After implementing this tool, I analyzed their maps and eliminated some of them because some students constructed their maps inaccurately. At the second step, I randomly selected at least five students from each section. I asked them whether they would voluntarily participate in the interviews. Then, I conducted interviews with the students at laboratories or in empty classrooms. At the end of the interviews, I also asked them to draw an atom's structure. Finally, in another session, the same students were asked to talk about the propositions in their concept maps to assure what they actually meant. Then, as explained below, all data were analyzed.

3.4. Analysis of Data

In the next three sections, I will explain how students' concept maps, their interview responses and drawings were analyzed.

3.4.1. Analysis of Concept Maps

Students' concept maps were analyzed in terms of four key concepts: atom, electron, light, and photon. Firstly, first linkages for each key concept were determined, and then the related propositions were written. If two key concepts were linked to each other (i.e. atom - electron or light - photon), the proposition was written for the first concept. A sample analysis of student 21's concept map (Figure 3.1) is given below.

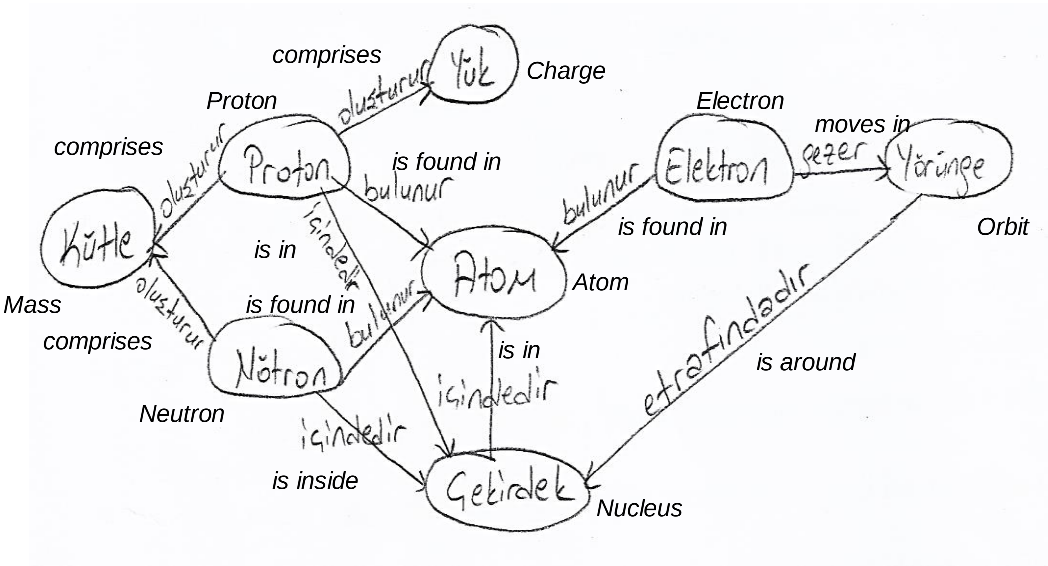

Figure 3.1. Student 21's Concept Map

As seen in the figure, Student 21 used 8 concepts and wrote 11 propositions in her concept map. For example, there are 4 concepts linked to the atom. Then, we can write the propositions constructed for the atom:

- Proton is found in the atom.
- Neutron is found in the atom.
- Nucleus is in the atom.

However, the proposition between electron and atom is not written the above list because the first concept is the electron, which is also a key concept. Hence, this proposition is written for the electron. Besides this, there is one more concept, orbit, linked to the electron. Then, the propositions for the electron are:

- Electron is found in the atom.
- Electron moves in orbits.

On the other hand, the student did not use the concepts of light and photon in her map. Therefore, only the propositions listed above were taken in the analysis. When the same analysis procedure was applied for the remaining students' concept maps, it was observed that some students wrote same/similar propositions. Then, frequencies were determined by counting such propositions. As a result, a general picture was drawn for all students.

3.4.2. Analysis of Semi Structured Interviews

As mentioned previously, four questions were asked students in the interviews. In the analysis, firstly, all interviews were recorded and transcribed verbatim. Several codes were developed when analyzing the interview transcripts. Then, the codes were used and students' interview transcripts were categorized in terms of four distinct atomic models. These are Classical and/or Semi-Classical Model (CSCM), Hybrid Model (HM), Quantum Model (QM), and Other (O). Some key features of the models are described below.

1. Classical and/or Semi-Classical Model (CSCM): Students having this model, mainly use the ideas and features of classical and/or semi classical models of the atom. In addition, they attribute classical and/or semi classical properties to the electron in the atom. For example, they state that there are orbits around the nucleus and electrons move in these orbits.
2. Hybrid Model (HM): Students who have this model use conflicting ideas of classical/semi classical models and quantum model together to explain the atom's structure. For instance, students explain that electrons are found in orbitals and move in orbits around the nucleus.
3. Quantum Model (QM): Students having this model are able to comprehend the key ideas of modern theory of the atom (i.e. Heisenberg uncertainty principle, probability, and orbital etc.) and explain them accurately.
4. Other (O): Students' responses are coded as Other (O) when they are not categorized as CSCM, QM, or HM.

3.4.3. Analysis of Drawings

Similarly, students' drawings of an atom were analyzed in terms of the four models given in the previous section. Some key aspects of these models are given below:

1. Classical and/or Semi-Classical Model (CSCM): Students draw classical or semi-classical atomic models such as Thomson model or Bohr model. For example, they depict electrons like point particles and/or draw orbits to show the positions where electrons are found.

2. Hybrid Model (HM): Students draw hybrid or mixed models of an atom. For instance, they draw an electron cloud on which electrons are represented as point particles.
3. Quantum Model (QM): Students draw electron clouds and they reflect a quantum description of atomic structure; thus, their drawings are coded as QM.
4. Other (O): Drawings that cannot be categorized as CSCM, QM, or HM, are coded as other (O).

In order to ensure whether the students’ interview responses and drawings were categorized consistently, two methods were employed. First, I categorized all transcripts of students’ interviews and their drawings of an atom in two different occasions. It was found the agreement between two analyses results was 100% for both students’ interview responses and their drawings. Second, the inter-rater reliability method was employed. Since analyzing all students’ interviews and their drawings required a large amount of time, I randomly selected ten students (27% of all students) and sent their interview transcripts and drawings to a researcher who had taken his Ph.D. in physics education. I informed him about the coding procedure. After he completed the analysis, we compared our analyses results and found that the agreement for the interviews was 90%, and the agreement for students’ drawings was 100%.

3.5. Concerns for the Trustworthiness of the Study

Considering the trustworthiness of the analysis results of a qualitative study, Lincoln and Guba (1985) proposed several strategies such as prolonged engagement, triangulation, negative case analysis, and thick description. In the present study, methodological data triangulation, member check, and thick description were used.

3.5.1. Data Triangulation

Methodological data triangulation was used for two purposes in this study: (1) to establish the trustworthiness of the study, (2) to fill the gap in the literature as mentioned in Section 1.4. The research design involved three instruments (concept mapping, semi structured interviews and drawing) in order to obtain a rich variety of data from the students. Furthermore, students' semi structured interview responses were compared with their drawings of an atom.

3.5.2. Member Check

The application of this strategy was mainly held during the data collection process. Firstly, I conducted short interviews with 37 students after they had completed their concept maps. In particular, I asked them to state all propositions in their own words to ensure that my inferences about the propositions would be accurate.

In semi-structured interviews, I have paraphrased the responses students gave for the questions and asked them to verify whether my inferences were compatible with what they intended to mean.

For the drawing tool, I asked students to provide a detailed explanation about their drawings to avoid any possible ambiguities or misunderstandings that could affect their analyses negatively.

3.5.3. Thick Description

For thick description, Erlandson, Harris, Skipper and Allen (1993) stated "Effective thick description brings the reader vicariously into the context being described" (p. 33). From this point of view, it was aimed to provide an exhaustive description of the data obtained with the instruments. To accomplish this, I describe four exemplars explicitly: one CSCM, two HM, and one QM. The descriptions include students' own expressions for the interview questions, their concept maps, and drawings of an atom. I also give several exemplary concept maps of students when presenting the results of concept mapping data analysis.

3.6. Assumptions

In this study, I implemented the concept mapping in 14 out of 16 sections. However, for remaining two sections, I informed physics teachers how to administer the concept maps. In this respect, it was assumed that all students constructed their maps under the same conditions. It was also assumed that they had reflected their knowledge about the atom concept in their maps.

In addition, to avoid any interruption during the interviews, I interviewed with students at different places such as empty classes, laboratories etc. Even I used different places when interviewing with students studying at the same school. In this respect, it was assumed that the location did not have negative effects on students when responding to the interview questions. It was also assumed that students answered the interview questions sincerely.

4. RESULTS

As stated in the first chapter, this study aimed to investigate 12th grade high school students' cognitive structures about the atom. For that purpose, four research questions were formulated. In this chapter, there are four sections in which the analyses results of the data are discussed by considering the research questions. In the first section, analysis results of 37 students' interview responses and their drawings are presented. In the second section, the interview responses, drawings, and concept maps of four exemplary students are given. In the third section, analyses results of Group 1 students' concept maps are presented in terms of four key concepts: atom, electron, light, and photon. Similarly, analyses results of Group 2 students' concept maps are presented in the last section.

4.1. Analysis Results of Students' Interview Responses and Drawings

Figure 4.1 shows the analysis results of students' interviews and their drawings of an atom. According to the coding scheme, it was found that 60.7% of the students' interview responses were coded as CSCM. Moreover, there are 8 students whose responses were coded as HM. The analysis also revealed that two students reflected a quantum understanding; therefore, their responses were coded as QM.

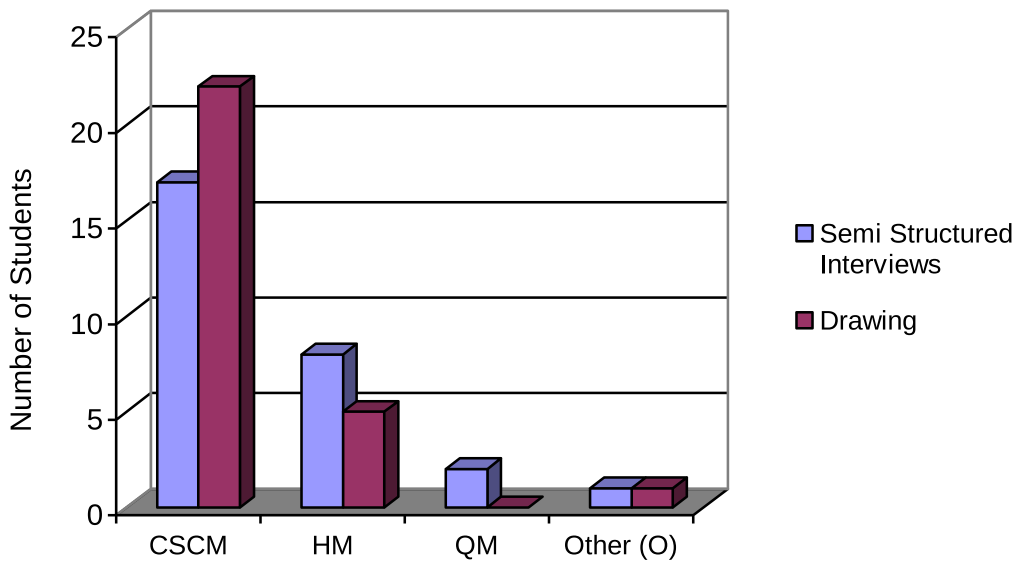

Figure 4.1. Group 1 Students' Interview Responses and Drawings of an Atom

When students' drawings were coded, similar findings were obtained. As seen in Figure 4.1, most of the students (78.6%) attributed the features of classical or semi-classical models of the atom to their drawings. As a result, their drawings were coded as CSCM. It was also found that 17.8% of the students' drawings were coded as HM. There is another student whose drawing was coded as Other (O). However, none of the students' drawings of the atom were coded as QM.

The coding scheme also revealed that 57.1% of the students were coded as CSCM in both semi structured interviews and drawing. Moreover, among eight students having hybrid model in the interviews, six of them drew classical or semi classical models. It is evident from the Figure 4.1 that the classical and/or semi-classical models of the atom have a dominant influence on 12th grade high school students' cognitive structures.

The same procedure was followed for students in Group 2. As seen in Figure 4.2, two third of the students' responses to the interview questions were coded as hybrid model (HM). According to the coding scheme, each of the remaining three students was coded as CSCM, HM, and O (Other), respectively.

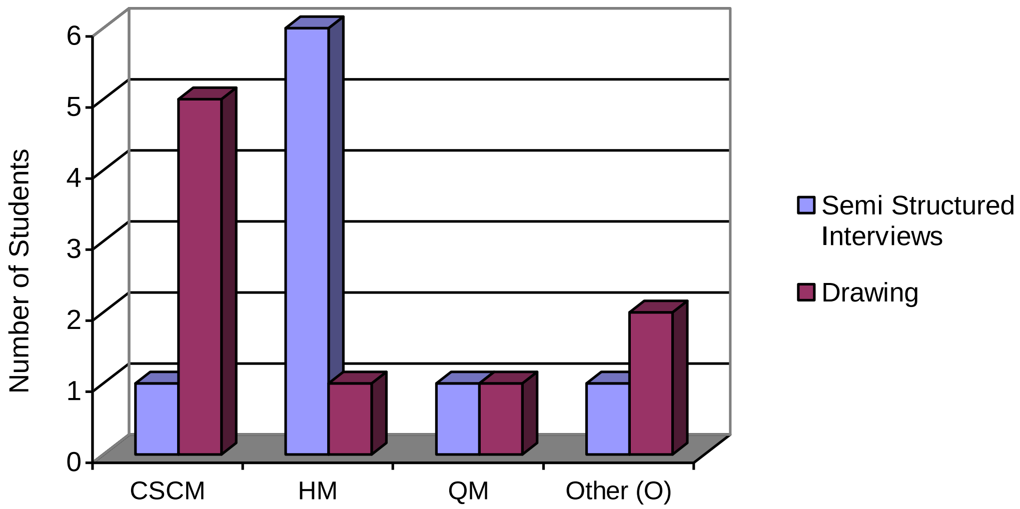

Figure 4.2. Group 2 Students' Interview Responses and Drawings of an Atom

When their drawings were analyzed, it was found that there were five students that having drawn a classical and/or semi-classical model. Furthermore, there are two students whose drawings were coded as O (Other). There was only one student whose drawing was coded as hybrid model (HM). Moreover, one student's drawing was coded as QM.

It can be observed from the figure that there is a sharp contrast between the analyses results of students' interview responses and drawings. While most students reflected hybrid thinking in the interviews, they tended to draw classical and/or semi-classical models.

4.2. Exemplary Cases for Atomic Models

Based on the decisions about their responses to the interview questions, four students' interview responses, drawings, and concept maps are described in this section. The first student's interview data exemplify the classical and/or semi-classical model (CSCM), and the next two students' interview data exemplify the hybrid model (HM). I give two examples for HM because most of the Group 2 students' interview responses were coded as HM (See Figure 4.2). Therefore, one student is representative for Group 1 and another student is representative for Group 2. Lastly, the fourth student's interview data and drawing exemplify the quantum model (QM).

4.2.1. An Exemplary Case for Classical and/or Semi Classical Model

A 17 year-old student from School D is a typical example for Classical and/or Semi-Classical Model (CSCM). In the interview, when I asked how he conceived an atom, he first described it as an "indivisible unit of structure" of matter consisting of protons, neutrons, and electrons. Then, he told that there are electrons moving in the shells around the atom. He also continued to describe atom's structure. His description is given below:

> **Student 26:** …as far as I know, protons have positive charges, and I know that they are in the nucleus. For neutrons, they are neutral… the positive and negative charges are equivalent to each other… they [neutrons] are in the nucleus as well. Electron is a negatively charged particle moving around the atom in orbits.

Considering the above statements, he used shell and orbit concepts interchangeably when talking about electrons. To gain insight about how he conceived electrons in an atom, in the second question, I asked him to talk about electrons. Especially, his responses for this question implied that he held semi-classical ideas about the structure of the atom. As the quotations represent below, again, he tended to use orbit and shell concepts interchangeably but he also tried to make a distinction between them.

R: How can you describe an electron's motion in an atom?

Student 26: I know that an electron can be added to the atom or be removed from the atom with the help of a force. It moves around the orbit [i.e. nucleus]… the number of electrons found in each shell is not arbitrary. For the first shell, [there are] two electrons, for the second shell, [there are] 8 electrons…

R: What is shell?

Student 26: Shell… the orbit that electrons move around the atom.

R: Do you mean that shell is synonymous with the orbit?

Student 26: I use them synonymously… maybe…orbit is the road that electrons move, and shell is that space.

R: What do you mean by that space?

Student 26: Now… Well, I actually explain it by drawing… when I draw protons, neutrons, orbit… this is the first shell, that space [distance between the first orbit and the outer surface of the nucleus]…, the second orbit, but that is the second shell.

R: You said that the second shell is the distance between the nucleus and the second orbit?

Student 26: Yes.

Student 26 probably heard the term shell in chemistry and/or physics courses and tried to integrate it into his explanations for the motions of electrons in the atom. However, he still used the orbit concept at the rest of the interview.

R: How can you explain its' motion in these orbits or shells?

Student 26: I know that it is moving because of an attraction force.

R: What attracts it?

Student 26: Presumably, there is a force that leads it to move in the orbits, there should be a force…

These statements show that his thinking was restricted within the semi-classical model of the atom. Furthermore, he did not reflect any quantum understanding or provide any explanations related to quantum model. Thus, he had a very limited knowledge about the modern structure of an atom.

Similarly, while answering the last two questions, he was not able to reflect an adequate understanding about light. This lack of understanding can be represented as follows:

> **R:** What is light?
>
> **Student 26:** We know that light moves along lines… nothing comes to my mind…
>
> **R:** You said that light moves along lines, what do you mean?
>
> **Student 26:** Maybe, light also possesses electrons. I can't know...

Unfortunately, his explanations were not clear for light concept. Therefore, his responses were categorized as CSCM.

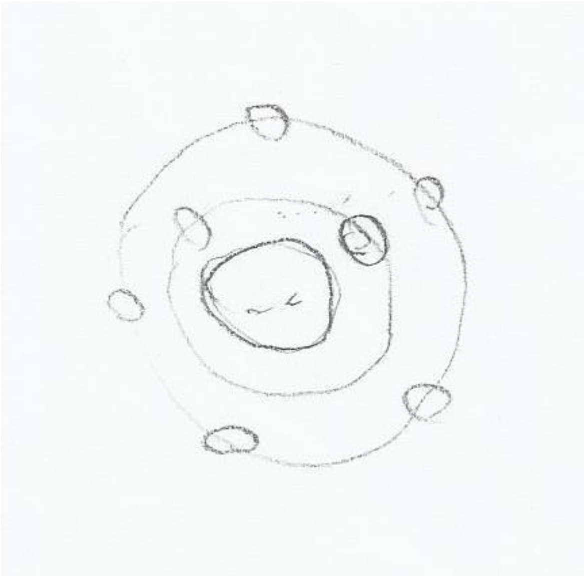

Figure 4.3. Student 26's Drawing of an Atom

As seen in Figure 4.3, his drawing of an atom resembles a semi-classical model. He drew a 'large' nucleus at the center, and located electrons as point particles in orbits around the nucleus. Therefore, it was coded as CSCM.

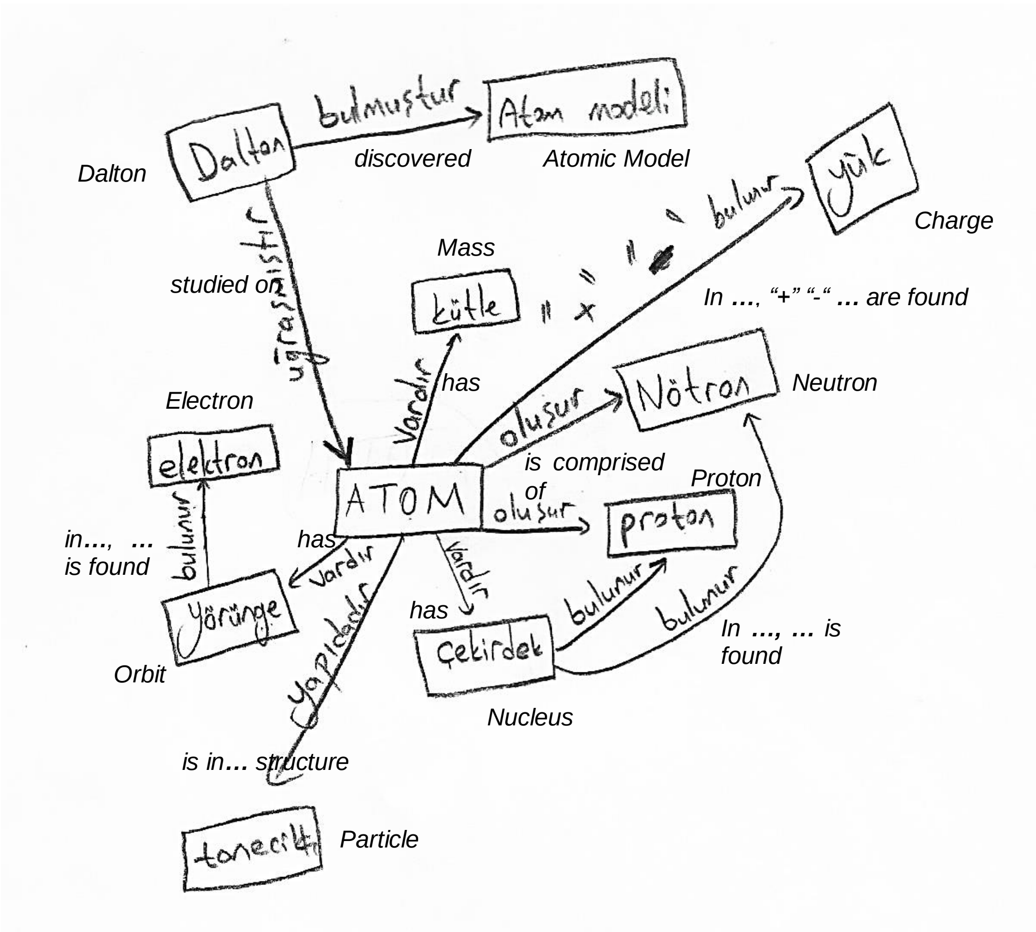

Figure 4.4. Student 26's Concept Map

In Figure 4.4, the concept map of Student 26 is given. He used 10 out of 16 concepts while drawing his map. For example, he did not use light, photon, or wave concepts. He drew most of the links to the atom concept. For instance, he wrote "Atom has mass", "Atom is comprised of neutron/proton", and "Atom has orbit." In addition, the proposition, "Electron is found in the orbits", was also stated in the interview.

4.2.2. First Exemplary Case for Hybrid Model

Student 5 from School A held a hybrid model (HM). At the very beginning of the interview, she stated that there were not orbits in which electrons move in the atom. However, her later explanations and examples were based on classical ideas of the atom.

R: How do you conceive an atom in your mind?

Student 5: It is a structure that consists of very small and invisible particles.

R: Can you tell me what these particles are?

Student 5: As we know… these are electron, proton, and neutron, and probably, their sub particles, but I don't know…

R: Suppose that you are able to see the atom and its particles, how can you describe its' structure?

Student 5: …a complex structure… we learned that many electrons move in various shells… we learned that orbitals are very complex… it is a complex structure.

R: What is orbital?

Student 5: Electrons… it is not a… not an orbit but places that electrons are mostly found or I know that [the orbitals] the most probable places that electrons can be found…

R: You think that it is different from the orbit. Now, suppose that you look at the atom, how do electrons move?

Student 5: Let me imagine… it rotates on its axis… maybe like a Solar system.

R: How does it like?

Student 5: Electron's mass is negligible but there is a gravitational force. The same thing in the Solar system…

R: You mentioned that the atom has a very complex structure. Considering this, what can you say?

Student 5: It is a little more complex than the Solar system.

R: What about orbitals?

Student 5: It cannot be explained by considering my statements. I don't know, in this respect, it [atom] does not resemble [the Solar system].

R: Tell me more about the electron's motion.

Student 5: I know that there are not orbits in the atom…it just resembles the Solar system, but it is different from the Solar system in terms of the orbital [concept].

The quotations above show that the Solar system analogy had a strong influence on her cognitive structure. Furthermore, it seems that the analogy prevented her to assimilate the orbital concept. Thus, she experienced difficulties when trying to explain the atomic structure by using the orbital concept.

During the interview, when I asked her to explain what light is, she immediately answered that light has both particle and wave characteristics. She expressed them as follows:

> **Student 5:** …particle characteristics… as if light does not have either wave characteristics or particle characteristics… because when it shows wave characteristics, particle characteristics are not observed… I don't know, light may be a different thing.

To determine whether she had a concrete understanding about the dual nature of light, I asked her if she gave any related examples or experiments. She referred Young double slit experiment to explain the wave nature of light, but her explanations were not sufficient. For the particle nature of light, she gave irrelevant responses. However, when she was asked what photons were, she said that photon is probably a term related to particle property of light.

At the end of the interview, I intended to determine whether she could make a relation between light and sub-atomic particles in terms of this duality. She used the following statements when answering this question:

> **Student 5:** Well, I haven't thought this before… I think, it is not observed in sub-atomic particles… You mean electrons, protons?
>
> **R:** Yes.
>
> **Student 5:** I don't think…because, when we say light, we refer particle and wave, how a particle represents particle and wave characteristics together? …I can't make any comment about it because I haven't thought it before.

The statements above indicate that she could not attribute wave characteristics to sub-atomic particles. She conceived them as particles only.

After the interview, I asked her to draw an image of an atom (Figure 4.5). She first drew a nucleus and made several small balls to represent protons and neutrons inside the nucleus. She also drew several circles around the nucleus. While drawing these, she stated that she was trying to make a three dimensional drawing. In addition, when I asked her what the ‘circles’ were she confused and referred the orbital concept. This dialogue is presented below:

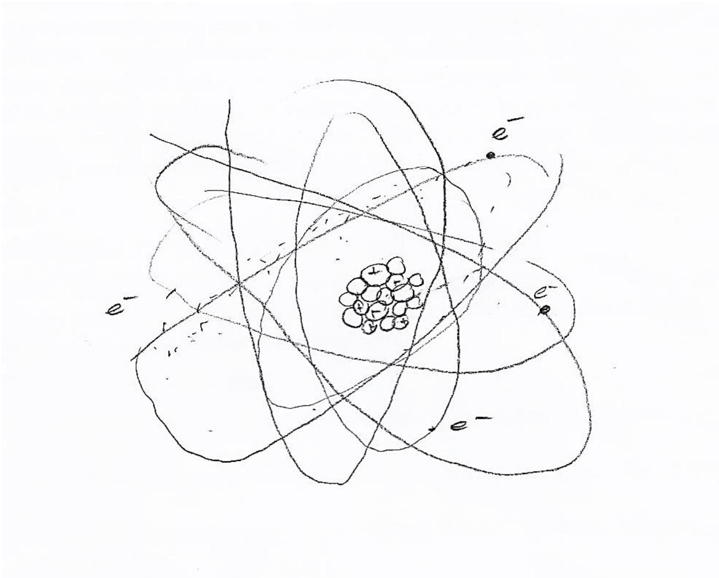

Figure 4.5. Student 5’s Drawing of an Atom

> **Student 5:** This does not seem to be a three dimensional structure but I intended to draw it as having a three dimensional structure… these [circles] do not intersect with each other.
>
> **R:** What are they?
>
> **Student 5:** Well… again… they are orbitals… let me call them as the route that electrons follow.

When I asked her to re-explain each part of the drawing, she again confused when explaining the ‘circles’.

> **Student 5:** …they are orbitals but they are not well defined lines… well, they are like [making several dots around one of the circles] clouds… here, I drew circles but it would be more logical if I drew dots here [again, she was making some dots]…
>
> **R:** Do you think that this is the image of an atom on your mind?
>
> **Student 5:** this [image] is what I have learned until now…

When she was asked to describe her drawing, she realized that the “well-defined” circles conflicted with her orbital image. Then, she felt a need to illustrate orbitals;

thus, she made several dots around the orbits. Considering the additional drawings, her drawing was coded as HM rather than CSCM.

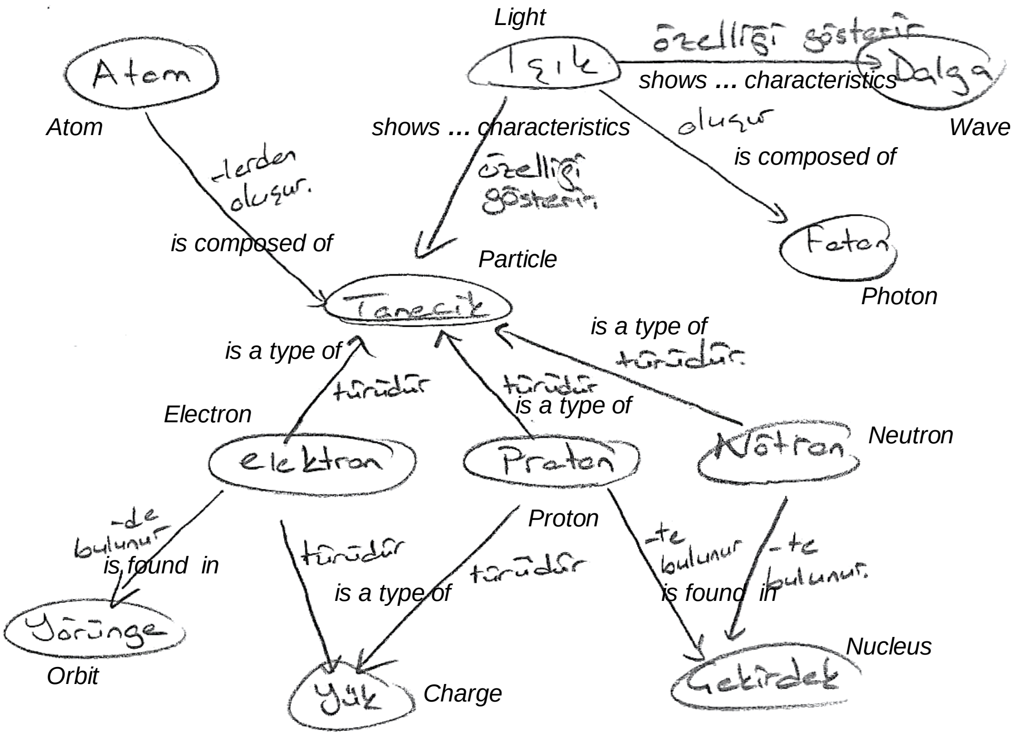

Figure 4.6. Student 5's Concept Map

Figure 4.6 represents the concept map of student 5. She used 11 concepts from the list but did not add any extra concepts to the map. It seems that the particle is a central concept for which she wrote five propositions. These propositions provide us important things about student's cognitive structure. For instance, she drew a link between electron and particle, and stated that "Electron is a type of particle." On the other hand, she connected light to particle, and wrote "Light shows particle characteristics." These links together tell how she conceived particle concept in terms of electron, and light. Similarly, the wave concept provides another significant finding. It was pointed that light has also a wave nature, however, she even did not connect wave to the electron. Considering wave and particle concepts, it can be stated that her interview responses and concept map revealed similar findings.

Moreover, the concept map shows that there are two clusters of concepts. To illustrate, the first cluster is formed with three concepts which are light, wave, and photon; the second cluster is formed with particle, electron, proton, neutron, and so on. The lack of connection between these clusters supported the data obtained in the interview where she did not relate the characteristics of light to electrons.

4.2.3. Second Exemplary Case for Hybrid Model

In the second group, most of the students' interview responses were coded as hybrid model (HM). Student 31 was selected as a representative student, and his interview responses, drawing and concept map are described below.

Student 31 is a 17 year-old male student studying at School E. In 10th grade, he took three hours of chemistry and physics courses; in 11th grade, he took four hours of chemistry and physics courses, respectively. For that reason, he was given 23 concepts in the concept mapping implementation.

At the beginning of the interview, firstly, he said that there are three fundamental particles in the atom, and he called them protons, neutrons, and electrons. Then, he immediately told the basic features of the particles; "protons are positively charged", "neutrons are neutral", "protons and neutrons together construct the nucleus", and "electrons are negatively charged particles that move in orbits around the atom."

At this point, I asked him to explain an electron's behavior in an atom. He provided a very detailed answer. As presented in the quotations below, he mentioned several concepts like energy level, orbital, and shell, and used them interchangeably.

> **Student 31:** There are energy levels around the nucleus. There are also orbitals like s, p, d, f in which they [energy levels] are located. There is only s [orbital] in the first energy level, there are s, and p in the second level, and in the third, there are s, p, and d…when the energy shells are very close to each other, the order [of orbitals] changes… I remember that 4s comes before 3d.
>
> **R:** You mentioned energy levels and orbitals, can you explain them more?
>
> **Student 31:** Orbitals are probable regions that electrons are found. We can't observe them [electrons] without disturbing and we can't get

information about their positions and velocities simultaneously. We just make predictions about electrons… the regions are orbitals.

R: At the beginning, you stated that electrons move in orbits, and you also said that orbitals are the probable places where electrons take place. What can you tell about electron's motion in an atom?

Student 31: … the motion of an electron is a motion in orbits around the nucleus of the atom, and in this motion, there are probable regions that electrons take place…I can say that they are orbitals…

While he was talking about electrons in the atom, he referred to atomic models as well. Firstly, he tried to explain Thomson's model by describing the electrons' positions in an atom, then he said that Bohr model corrected Thomson's model. After that, I asked him if he remembered other atomic models. The rest of the dialogue is given below:

Student 31: There are also models of Dalton and Rutherford. I'm not sure, but by gold-foil experiment, Rutherford discovered that atom has a nucleus… Dalton proposed the first model of the atom. He explained that atom is indivisible like a bowling ball…

R: Except these models, do you remember any models?

Student 31: I don't remember now.

R: When you consider the atomic models, which model do you think best describes the structure of the atom?

Student 31: Among these four models, I think, Bohr model is the best

R: Can you explain this model?

Student 31: There are positive charges at the center and negative charges are around the nucleus. Moreover, Bohr model accepted Rutherford's statements. He [Rutherford] stated that most of the volume of an atom is empty and nucleus is in a small region… but different from Rutherford, Bohr stated that electrons do not move randomly around the nucleus, instead they have motions in orbits…

For the questions related to light and photon concepts, firstly, he said that light is comprised of photons. Then, he stated that light has a dual nature. For this nature, he said that it behaves as particles and as waves in some situations. At this point, I asked him to clarify these "situations." For the wave nature of light, he said that there were interference experiments like "single slit interference", and "two slit interference". In addition, he stated that those experiments show the wave behavior of light. For particle nature of light, he first stated that the structure of photons resemble more to the particles. He then referred photoelectric effect and mentioned de Broglie hypothesis. Below, his statements are given.

> **Student 31:** …based upon this experiment [photoelectric effect], de Broglie, I'm not sure, [he] proposed that there is a wavelength associated to particles…
>
> **R:** What de Broglie stated? Can you explain it more?
>
> **Student 31:** …all moving particles have wave characteristics and there is a wavelength due to wave characteristics… but this characteristic may be dominant or not…it is based on other features…
>
> **R:** When you consider this, do you think that sub atomic particles have wave characteristics?
>
> **Student 31:** Electron is fast and light, in this respect, it resembles to photons… I think, the associated wavelength of an electron can be calculated…
>
> **R:** Considering this, can we say that electrons show wave characteristics?
>
> **Student 31:** …I don't know, but they resemble to photons, but I don't know whether they show wave characteristics.

Although student 31 had the knowledge of wave-particle duality of light, and de Broglie hypothesis, it seems that he did not conceive electrons behaving as waves.

In figure 4.7, student 31's drawing of an atom is given. He represented a nucleus at the center by drawing 2 neutrons and 2 protons. He also wrote the first capitals of the particles. He drew two electrons on a dashed line which he called as "an energy level." This simple drawing was coded as CSCM.

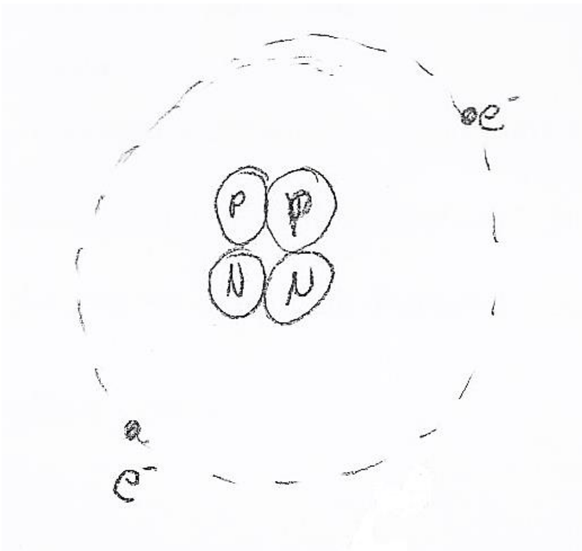

Figure 4.7. Student 31's Drawing of an Atom

Figure 4.8 represents the concept map of student 31. He used all 23 concepts in the map. However, he did not write anything on the links between several concept pairs such as 'position - orbit", 'wave - de Broglie wavelength', and 'particle - de Broglie wavelength.' As observed in the interview, he reflected a similar understanding about light by stating "Light represents characteristics of wave", and "Light represents characteristics of particle." In addition, he drew links to the light concept by using photoelectric effect, blackbody radiation, interference, and diffraction. Besides these, two pairs of concepts, wave - interference, and wave - diffraction, together indicate that he had knowledge about the wave nature of light. On the other hand, when the particle concept is considered, he did not draw such links to photoelectric effect or blackbody radiation.

Student 31 linked five concepts to electron. However, he did not write anything on the link between momentum and electron. When other concepts are considered, for instance, he wrote "Electron is found in orbital", and "Electron's position is not determined" in his map. He also drew a link between orbit and orbital, and wrote "Orbit consists of orbital." He also used all these statements in a similar way during the interview. Therefore, it can be concluded that student 31 reflected a similar understanding in both concept mapping and semi-structured interview.

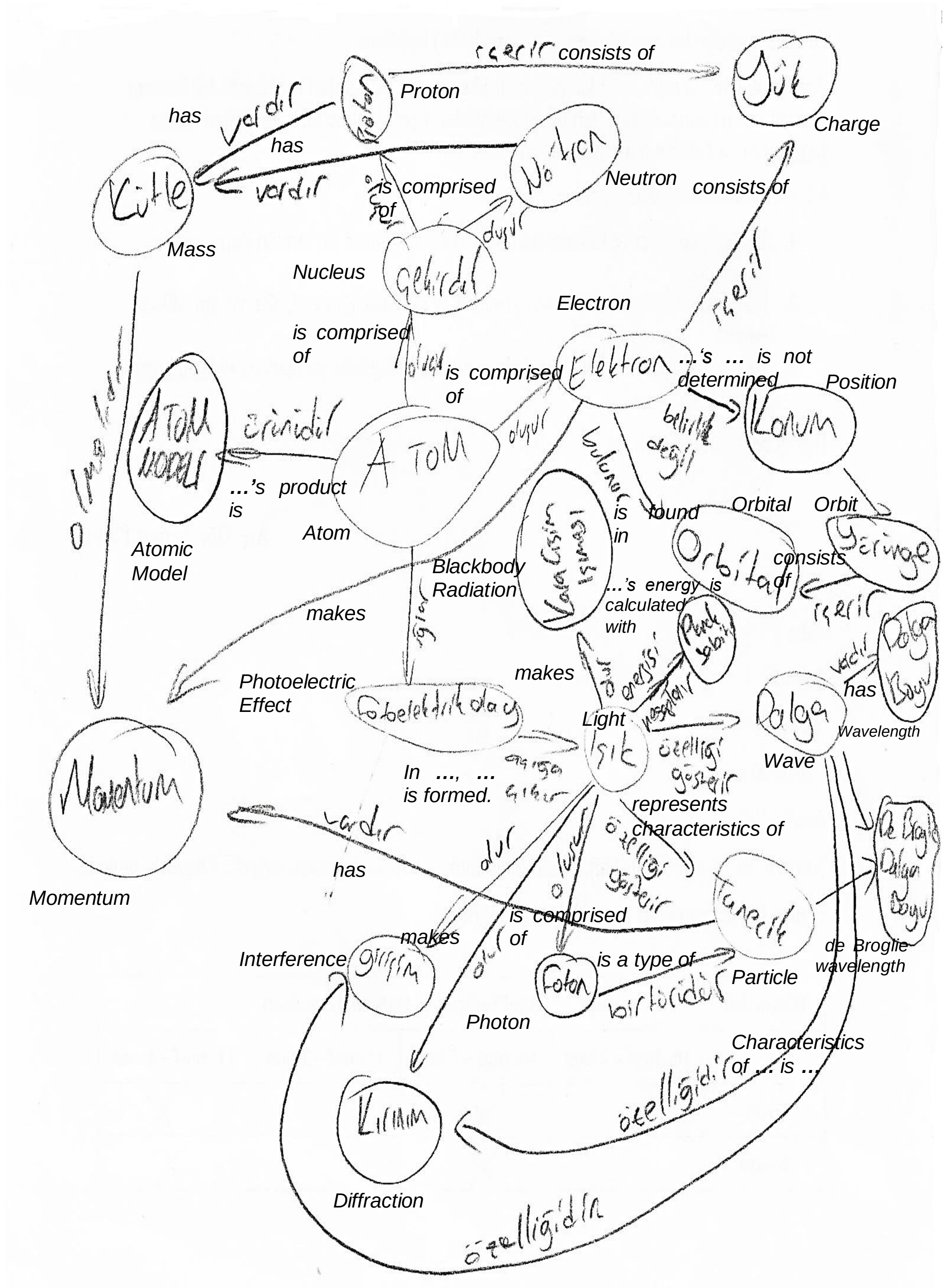

Figure 4.8. Student 31's Concept Map

4.2.4. An Exemplary Case for Quantum Model

According to the coding scheme, among 37 students, there are only three students whose responses to the interview questions were coded as QM. On the other hand, there is only one drawing coded as QM. In this part, a representative student for quantum model is described.

Student 29 is a 17 year-old female student studying at School E. Firstly, when she was asked to describe the atom she mentioned the sub-atomic particles like electron, proton, and neutrons and gave explanations related to the features of these particles.

> **R:** How do you conceive the atom?
>
> **Student 29:** a smallest structure… inside it, neutrons and protons are at the center, most of the mass is concentrated here [at the center] … there is a large distance between electrons and the center, … according to the probability of moving in orbits, electron moves [around the center] and its position and speed are not measured simultaneously…

Then, she continued to explain these particles.

> **Student 29:** While the atom is the smallest structure that constitutes the substance, there are also smaller things than atom… Generally, we know these as electron, proton, and neutron. Proton and neutron determine the mass number, proton determines the atomic number, while electron has negative charge, proton is positive, and neutron is categorized as neutral.

After that, she clearly explained the studies of several scientists chronologically.

> **Student 29:** … the indivisible particle, probably it [indivisible particle] was originated from Democritus, he said “atomos”. After many years later, Dalton said that all atoms comprising the matter were same and they were indivisible… Then, contrary to the idea of indivisible particle, Thomson said that positive and negative charges were homogeneously distributed in the atom, and he likened the atom to plum pudding… Contrary to this homogeneity, there was a gold foil experiment of Rutherford. He sent rays to the gold foil and he found that few rays were scattered. Based on this, he said that a very small volume of the atom was dense and the remaining volume was empty. In contrast with the Thomson’s plum pudding model, he also stated that positive charges were inside the nucleus and negative charges were arranged around it [nucleus]. Then, Bohr…hydrogen and helium atoms are probably compatible with his calculations… after Bohr,

> modern atomic theory… According to modern atomic theory, ok, the electrons are around the nucleus, but we don't know where they are because when we send rays with high energies, then the positions we see are their [electrons] old positions, I mean, we can't calculate their positions… and we stated [in lectures] that we draw an image of clouds based on the most probable places in orbitals…

After that, I asked her to talk about electrons' motions more, but she almost gave similar responses:

> **Student 29:** … we know that it is negatively charged, and compared to proton, it has a small mass. We also know that its position and speed can't be calculated at the same time, and therefore we talk about probabilities… there are also smaller particles than electron, quarks… they exist but I only know their names.

Up to this point, it can be stated that student 29 often referred the Heisenberg uncertainty principle and the concept of probability when explaining the behavior of electrons in the atom. The quotations above also indicate that she clearly discriminated each atomic model from the previous models.

Then, I also asked questions related to light and photons. She stated that light has two characteristics. She mentioned the photoelectric experiment when explaining the particle characteristics of light, however, she did not use the 'particle' term, instead she stated that "light travels linearly". For wave characteristics of light, although she mentioned the concepts of diffraction and interference, however, she did not explain them in detail.

At the end of the interview, I asked her whether she conceived that sub-atomic particles have also dual nature as light, she again mentioned the photoelectric effect.

> **R:** Do you think that the dual nature of light can also be observed in sub-atomic particles?
>
> **Student 29:** … light moves in energy packages… and if we project it on a matter, then it removes electrons from that matter… and kinetic energy is transmitted to the electron… Considering this, I can draw a relation between light and electron.

After the interview, she drew an image of an atom. As seen in Figure 4.9, she made two drawings. While the image at the top represents the outside view of an atom, the image at the bottom represents atom's internal structure. The quotations below indicate how she explained these drawings.

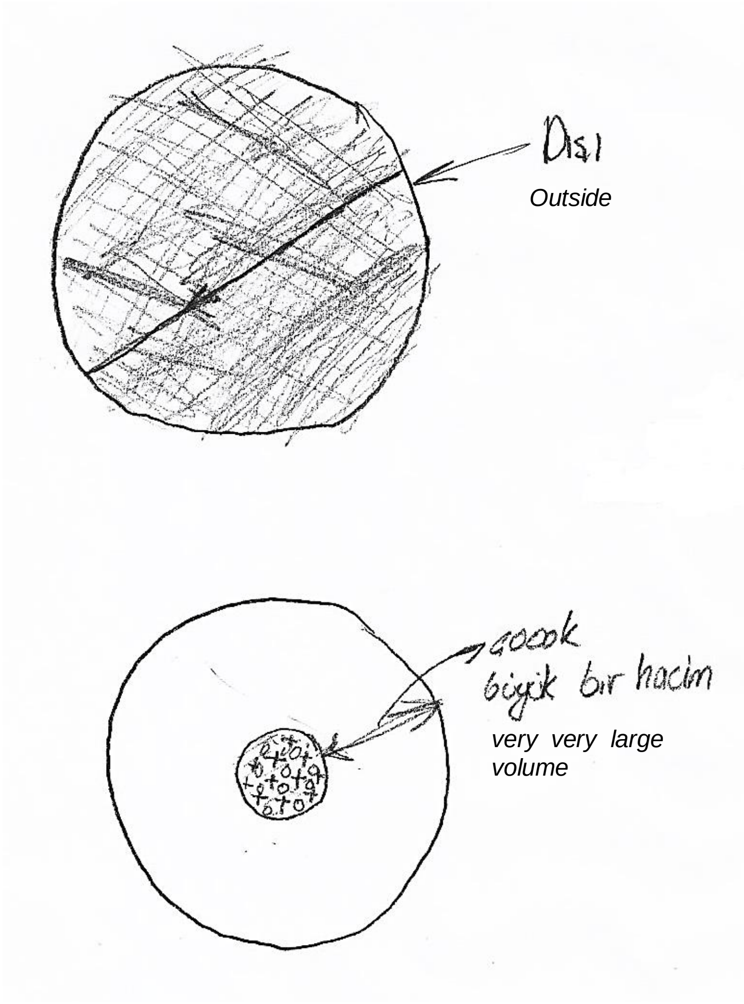

Figure 4.9. Student 29's Drawing of an Atom

Student 29: … Certainly, there is a sphere… Can I draw the outside [view of the atom]?

R: Yes, of course.

Student 29: …I think, the outside is like… like yarn… it has a cloudy structure… as if we look at the Earth from the outer space but there are some regions that are denser [i.e. she means darker places in her drawing]… I also draw the internal structure of the atom… there are also regions that are less dense, and we can't say something certainly.

R: Can you explain this spherical thing [first drawing]?

Student 29: … in fact, these shadows are moving electrons, they move very fast and they become denser in a region, they become less dense in other region, and I can't draw it like a particle or bead… but only motion… as if I look at the Earth from the outer space… it could be like this…

Then, she drew the internal structure of the atom and explained as follows:

Student 29: Now, I draw the internal structure… I draw a circle to show the region… we passed through the clouds and now we are looking at its internal structure… There is a dense structure here [she was drawing the nucleus]…I don't know whether there are anything here [the distance between nucleus and the circle] but I know there is an empty space here… if we liken the atom as a stadium, the nucleus can be likened to a pea, and the volume [of atom] is like this… there are positive charges and neutrons… this volume is very large…

Taking her above explanations into account, her drawing of an atom was coded as QM.

In Figure 4.10, student 29's concept map is given. She did not show the concepts in circles. Although she added extra concepts (e.g. energy and matter) to the map, she did not use several concepts in the list like atomic model, mass, and photoelectric effect. She used several concepts (e.g. particle and position) twice in the map. When the propositions for the atom concept were analyzed, it could be stated that she described the atom's structure. As she mentioned in the interview, she drew links to light by using concepts of diffraction and interference. In the map, she also implied that these two concepts are related with the wave nature of light by drawing links to the concept of wave. For the electron concept, she wrote "Electron moves in orbit". In addition, she wrote "Orbital comprises orbit." However, she did not draw such a relation between orbit and orbital in the interview.

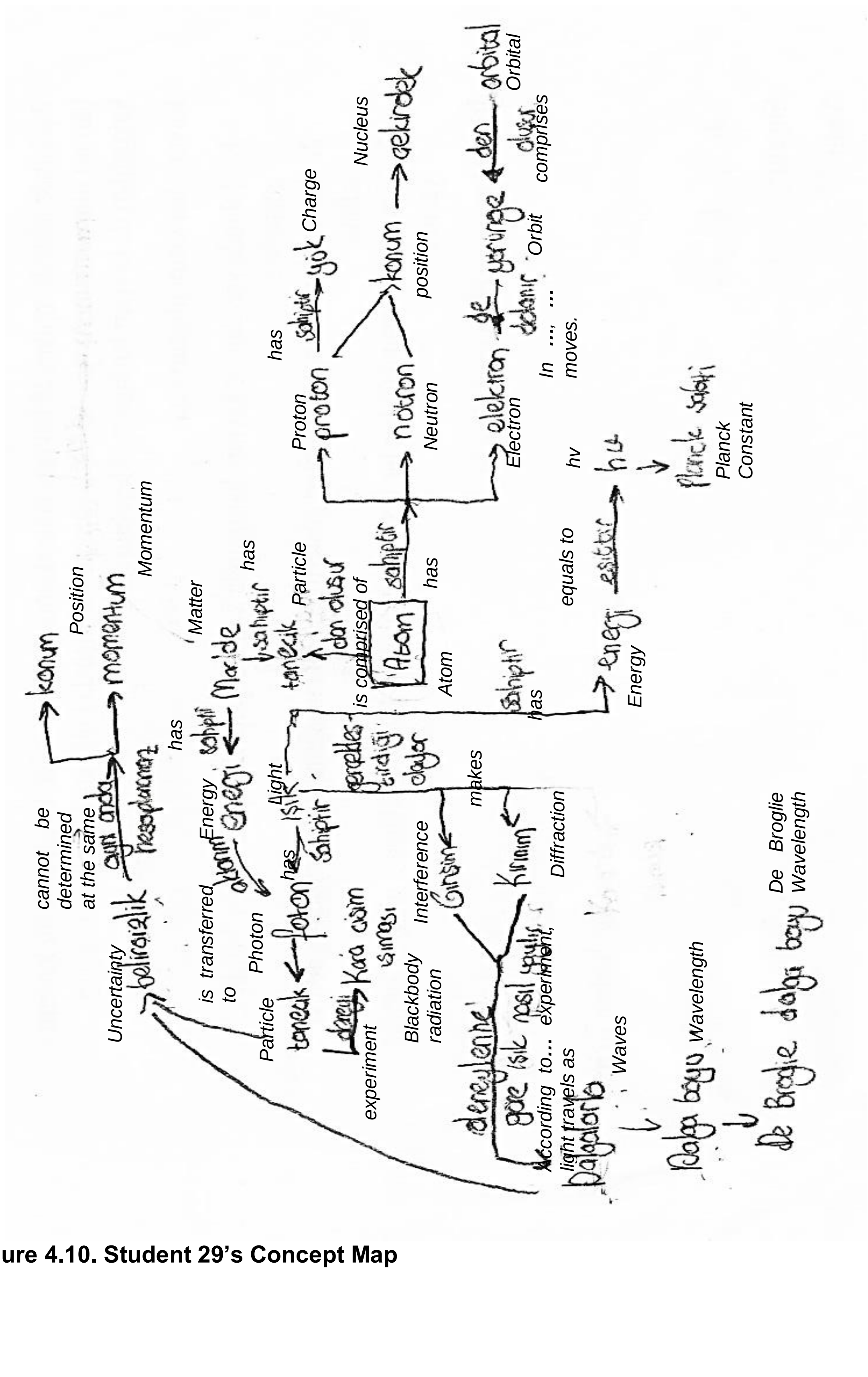

Figure 4.10. Student 29's Concept Map

4.3. Analysis Results of Group 1 Students' Concept Maps

Group 1 involved 28 students. As mentioned earlier, they were given 16 concepts. Their concept maps were analyzed in terms of four key concepts: atom, electron, light, and photon. Same or similar propositions with related frequencies were determined for each concept. All propositions are not included in the tables. Instead, propositions written by at least 3 out of all 28 students were presented in the tables.

To begin with, as seen in Table 4.1, there are 8 concepts used by more than 10% of the students for the atom concept. For example, 53.6% of the students connected orbit to the atom and stated "Atom has orbits". Besides that, students linked the nucleus concept in two different ways. 14 students wrote "Atom has a nucleus" while 11 students stated "Nucleus is found at the center of an atom." At this point, it can be concluded that 25 students believed that a nucleus exists inside the atom.

Table 4.1: Group 1 Students' Propositions for the "Atom" Concept

Related Concept	*Proposition*	*Frequency*	*Percentage*
Orbit	Atom has orbits.	15	53.6%
Nucleus	Atom has a nucleus.	14	50.0%
	Nucleus is found at the center of an atom.	11	39.3%
Mass	Atom has mass.	10	35.7%
Atomic Model	Atom is explained by atomic model.	9	32.1%
	Atom has atomic models.	5	17.8%
Electron	Atom has electrons.	8	28.6%
Particle	Atom has particles.	7	25.0%
Proton	Atom consists of protons.	6	21.4%
Neutron	Atom consists of neutrons.	6	21.4%

Similarly, half of the students wrote propositions about the relationship between atomic model and the atom. While nine students explained the role of atomic model by stating "Atom is explained by atomic models", the remaining students expressed that there are several models of the atom. Table 4.1 also represents how other concepts such as particles, electron, and proton were connected to the atom.

In Table 4.2, students' propositions related to the electron concept are given. When the first linkages were analyzed, it was found that the number of concepts linked to electron is less than the ones connected to the atom concept. There are certainly three concepts students connected to the electron: orbit, position, and charge. For instance, 89.3% of the students used orbit concept and wrote a semi classical idea in their concept maps: “Electron moves in orbits”. It is also evident from the Table 4.1 that students insisted on using orbit concept in their maps.

Table 4.2: Group 1 Students’ Propositions for the “Electron” Concept

Related Concept	*Proposition*	*Frequency*	*Percentage*
Orbit	Electron moves in orbits.	25	89.3%
Position	Electron’s position cannot be determined.	11	39.3%
Charge	Electron has a negative charge.	6	21.4%
	Electron has charge.	3	10.7%

In addition, 39.3% of the students believed that position of an electron is not determined. At this point, I wondered how many students wrote both propositions related to orbit and position concepts. A follow-up analysis revealed that the number of students is 10. There is only one student who did not relate orbit to electron; however, that student linked it to the atom and stated “Atom has orbits”.

In Figure 4.11, a sample concept map illustrates how a student linked a pair of concepts: electron - orbit, and electron - position in his map.

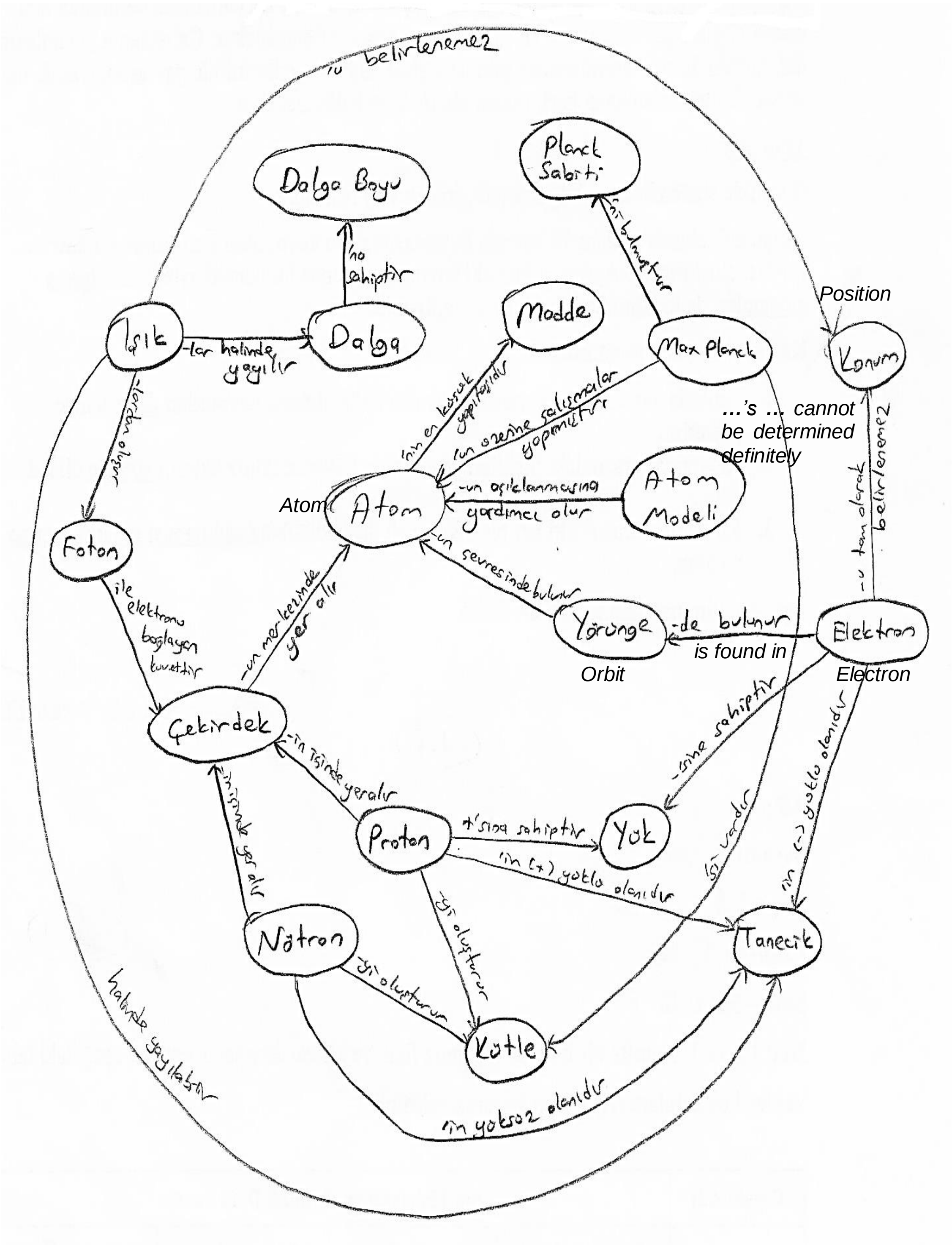

Figure 4.11. Student 2's Concept Map

In Table 4.3, propositions are listed for concept of light. For example, there are 10 students who wrote "Light is composed of photons". Moreover, 25% of the students wrote "Light travels in waves" in their maps. From another aspect, there are only three students who stated "Light travels in particles." Moreover, 25% of the students attributed wavelength as a feature that light possesses.

Table 4.3: Group 1 Students' Propositions for the "Light" Concept

Related Concept	*Proposition*	*Frequency*	*Percentage*
Photon	Light is composed of photons.	10	35.7%
Wave	Light travels in waves.	7	25.0%
	Light has a wave structure.	3	10.7%
Wavelength	Light has a wavelength.	7	25.0%
Particle	Light travels in particles.	3	10.7%

For the photon concept, there are not any propositions written by at least three students. Nonetheless, in their concept maps, two students wrote "photon has a particulate structure."

During the analysis of concept maps, it was found that some students clustered the concepts into two groups. While one cluster includes concepts related to the structure of the atom like nucleus, electron, and proton etc., another cluster includes concepts such as light, photon, wave, and wavelength. A representative concept map is given in Figure 4.12 below.

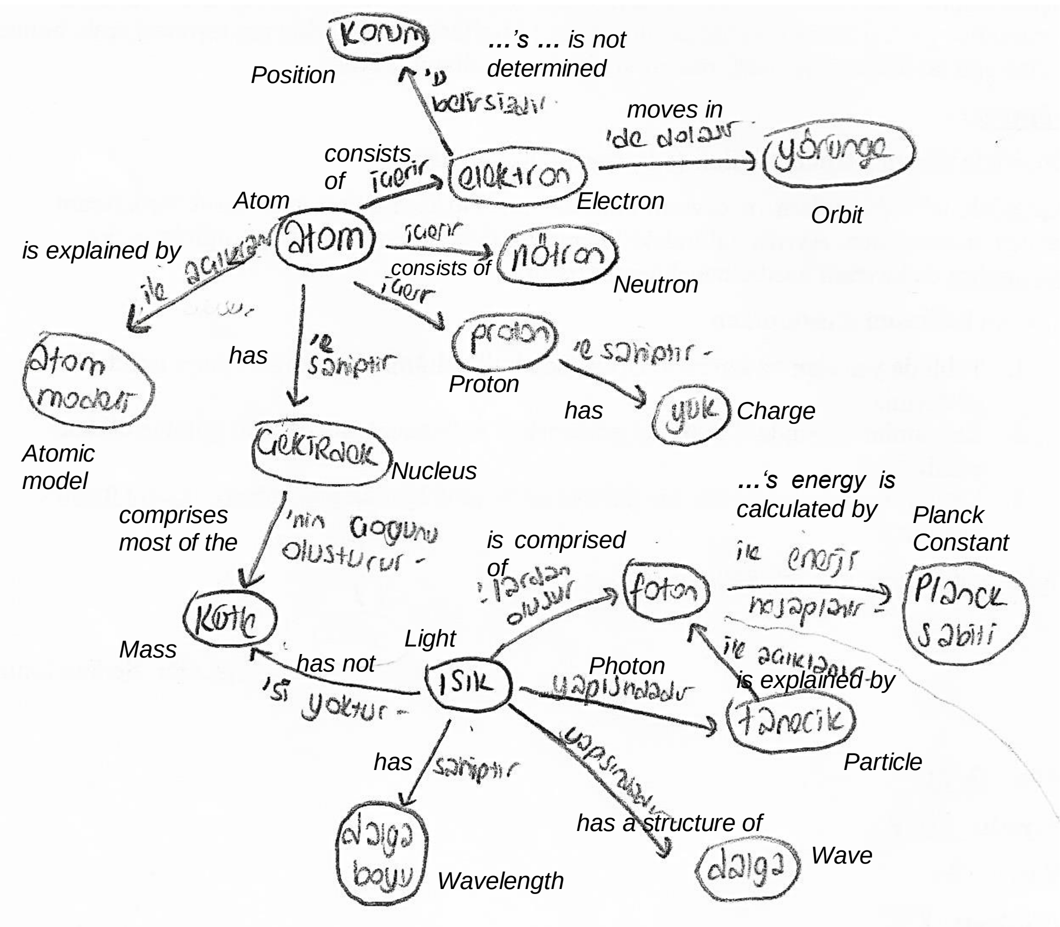

Figure 4.12. Student 10's Concept Map

As seen in the figure, Student 10 used all sixteen concepts; however, she did not include any extra concepts in her map. When the structure of the map is analyzed, it is very clear that she formed two clusters. The ‘mass’ is the only concept that joins the clusters. For the cluster at the top, the atom seems to be the central concept. For the cluster at the bottom, the light seems to be the central concept.

4.4. Analysis Results of Group 2 Students’ Concept Maps

As stated previously, students in Group 2 were given 23 concepts when implementing the concept mapping tool. There are 9 students involved in the analysis. For the sake of brevity, propositions written by at least two students are presented in the tables.

To begin with, the analysis of nine students’ concept maps for the atom concept revealed 8 propositions. As seen in Table 4.4, it is inferred that students focused on the structure of the atom and wrote several propositions. For instance, more than half of the students linked three fundamental particles (electron, proton, and neutron) to the atom concept. Furthermore, four students wrote “Atom is comprised of a nucleus” in their maps. Table 4.4 also presents other propositions related to concepts like particle, mass, and atomic model.

Table 4.4: Group 2 Students’ Propositions for the “Atom” Concept

Related Concept	***Proposition***	***Frequency***	***Percentage***
Electron	Atom consists of electrons.	6	66.6%
Proton	Atom consists of protons.	5	55.5%
Neutron	Atom consists of neutrons.	5	55.5%
Nucleus	Atom is comprised of a nucleus.	4	44.4%
Particle	Atom is comprised of particles.	3	33.3%
Mass	Atom has mass.	3	33.3%
Atomic model	Atom has atomic models.	3	33.3%
	Atom is explained by atomic models.	2	22.2%

When students’ maps were analyzed in terms the electron concept, there are five different concepts connected to the electron by at least two students. The list of the propositions is presented in Table 4.5.

Table 4.5: Group 2 Students' Propositions for the "Electron" Concept

Related Concept	*Proposition*	*Frequency*	*Percentage*
Orbital	Electron is found in orbitals.	7	77.7%
Orbit	Electron moves in orbits. / Electron is found in orbits.	6	66.6%
Photoelectric effect	Electron is removed as a result of the photoelectric effect.	5	55.5%
Charge	Electron has charge.	3	33.3%
	Electron's charge is negative.	2	22.2%
Position	Electron's position is not determined.	2	22.2%

Firstly, in their concept maps, most of the students reflected a quantum understanding by connecting concept of orbital to the electron. However, the orbit concept was still used by two third of the students. Again, I re-analyzed their maps to find out how many of the seven students having used the orbital concept also linked orbit to the electron. I found that 4 out of 7 students' maps involved both propositions given in the table above. However, there are also three remaining students who did not link orbit to the electron. While one student did not use that concept at all, two students linked it to the orbital, and each student wrote one of the following propositions in his/her map:

- Orbitals are found in orbits.
- Orbit consists of orbitals.

In Figure 4.13, an illustrative concept map of a student who linked both orbit and orbital concepts to the electron.

Figure 4.13. Student 34's Concept Map

Furthermore, there are also 5 students who focused on the relationship between the photoelectric effect experiment and electron by stating "Electron is removed as a result of the photoelectric effect". The other propositions are also given in Table 4.5.

For the light concept, students used various concepts to generate propositions. In fact, propositions can be grouped into two, each of which representing the particle and wave characteristics of light, respectively. To illustrate, there are 10 propositions related to the particle characteristics of light. For instance, five students stated "Light is composed of photons". Furthermore, three students wrote

“Light exhibits particle characteristics”, and besides, two students wrote “Light makes blackbody radiation”. On the other hand, four students wrote propositions by using interference and diffraction concepts. In addition, the wave concept was related to light in two ways: three students wrote “Light exhibits wave characteristics”, and two students stated “Light is a wave”. The propositions and related frequencies are given in Table 4.6.

Table 4.6: Group 2 Students’ Propositions for the “Light” Concept

Related Concept	***Proposition***	***Frequency***	***Percentage***
Photon	Light is comprised of photons.	5	55.5%
Interference	Light makes interference.	4	44.4%
Diffraction	Light makes diffraction.	4	44.4%
Particle	Light exhibits particle characteristics.	3	33.3%
Wave	Light exhibits wave characteristics.	3	33.3%
	Light is a wave.	2	22.2%
Blackbody Radiation	Light makes blackbody radiation.	2	22.2%

For the photon concept, there is only one proposition written by two students. The proposition is “Photon is a particle”. Nevertheless, students wrote a few propositions like “Photon is wave”, “Photon is radiated as waves”, and “Photoelectric effect is a phenomenon where photon collides with an electron”.

Similar to the Group 1 students, I found that some students in Group 2 also constructed clusters when drawing their maps. In this respect, Figure 4.13 is a good example. A critical look reveals the existence of clusters in student’s map. If atom, electron, light, and wave are all assumed to be a central concept, this map can be divided in four parts. For example, electron, orbit, orbital, position, momentum, charge, and photoelectric effect can be grouped together and they construct a cluster. Moreover, the concepts (except light) linked to the wave concept construct another cluster.

It should also be noted that the clusters are connected to each other with a link only. Furthermore, it may be thought that the clusters involving atom and electron concepts may form a large cluster related to atomic structure, while clusters consisting of light and wave concepts may form another large cluster related to light concept.

Figure 4.14 represents another student's concept map in which a more distinct clustering of concepts can be observed.

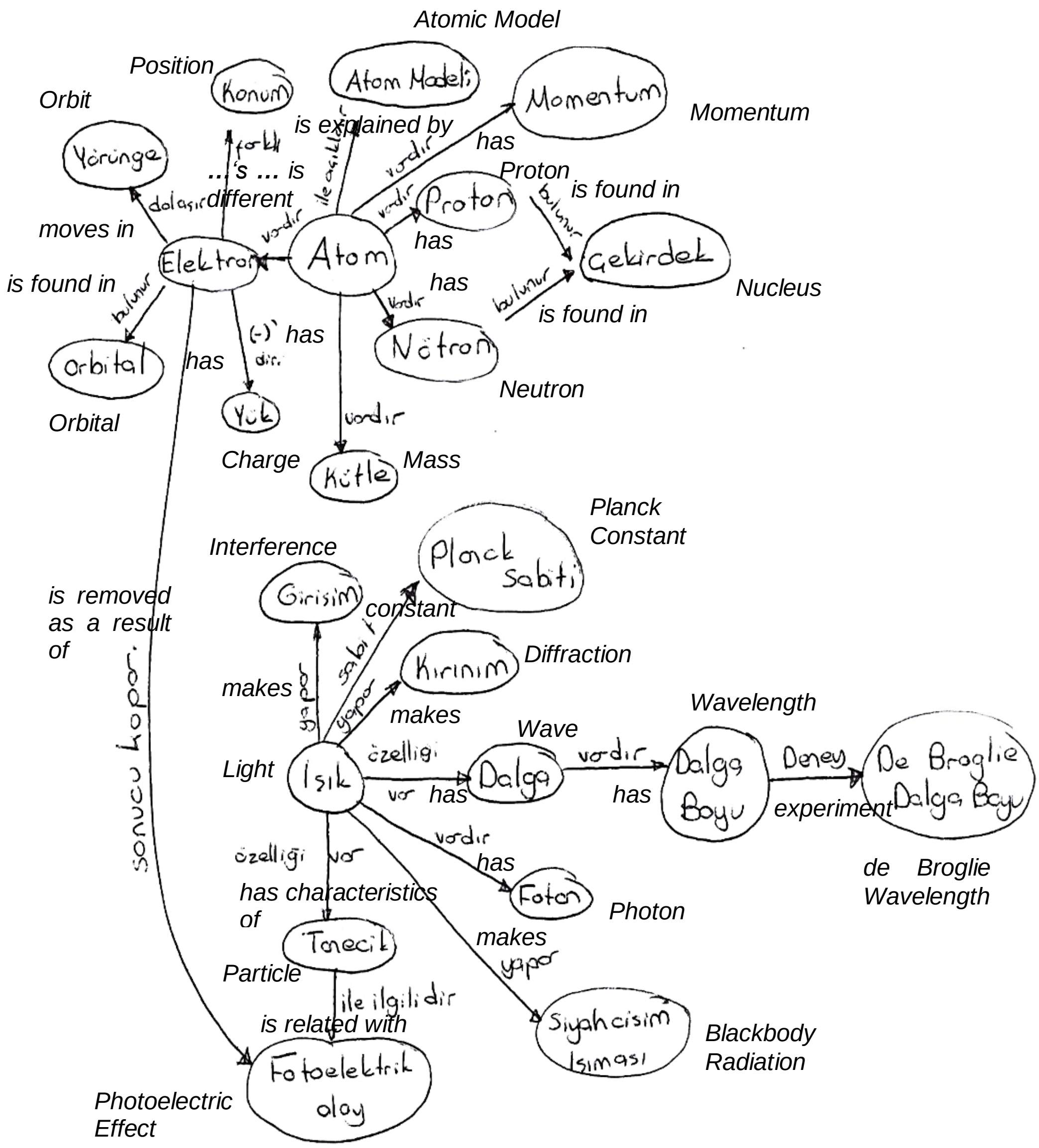

Figure 4.14. Student 33's Concept Map

It can be stated that the concepts can be divided into three clusters. The central concepts are atom, electron, and light in each cluster, respectively. The figure illustrates that Student 33 was not able to draw many links between the clusters. For instance, there is only one link between the electron cluster and light cluster.

5. DISCUSSION

This chapter involves four sections. Firstly, I will give a summary of the study. Then, I will discuss the main results of the study. After that I will talk about the limitations of the study. At the end of the chapter, I will give some suggestions for future research.

5.1. The Summary of the Study

This study mainly aimed to investigate 12th grade high school students' cognitive structures about the atom concept. For this purpose, students from five different schools participated in the study. To gather data from the students, three assessment tools were used; these are concept mapping, semi structured interview, and drawing. To administer the concept mapping, firstly, I conducted an analysis of high school chemistry and physics curricula of grades 9, 10, and 11. Based on the analysis, two concepts lists were developed (see Table 3.5 and Table 3.6). I gave the list in Table 3.5 to 249 students studying at four different schools (School A, B, C, and D). I also gave the list in Table 3.6 to 50 students studying at School E. After analyzing students' concept maps, 28 students from the first four schools and 9 students from the school E were randomly selected. Then, all students were involved in semi structured interviews. At the end of the interviews, they also drew an image of an atom.

The analysis was threefold. First, I analyzed 28 and 9 students' concept maps separately. I determined the first links for each key concept (atom, electron, light, and photon), and then I counted the related frequencies of each proposition. Secondly, I analyzed all students' interview responses and categorized them with respect to four distinct models. In the third step, students' drawings of an atom were analyzed by using the coding scheme described in Section 3.4.3. The results of the data analysis were presented in Chapter 4, and I will discuss them in the next section.

5.2. Discussion of the Results

I believe that restating the research questions will be a good starting point before discussing the major results of the study.

1. Considering grade 12 students' responses to the semi structured interview questions, how do they conceive the atom's structure?
2. Considering grade 12 students' drawings of an atom, how do they conceive the atom's structure?
3. Does the comparison between grade 12 students' interview responses and their drawings reveal any similarities or differences? If so, what are these?
4. Considering grade 12 students' concept maps,
   4.1. Which concepts do students link to the 'atom' concept?
   4.2. Which concepts do students link to the 'electron' concept?
   4.3. Which concepts do students link to the 'light' concept?
   4.4. Which concepts do students link to the 'photon' concept?

To begin with, students' interview responses were investigated to find answer(s) for the first research question. The results indicated that more than half of the students in Group 1 had classical and/or semi classical models. During the interviews, it was observed that these students did not reflect any ideas related to the quantum model of atom; instead they held classical and/or semi classical ideas strongly. This result is in agreement with previous findings reported in several studies (Cros, et al., 1986; Petri & Niedderer, 1998; Tsaparlis & Papaphotis, 2009). I think, there are several possible reasons that might explain this result. For example, having taken limited hours of chemistry and physics courses in grades 10 and 11, Group 1 students did not have opportunity to study some concepts/subjects that are directly related with the modern structure of the atom. The analyses results of both chemistry and physics curricula serve a good example for this. For example, there are seven extra concepts (see Table 3.5 and Table 3.6) that the students Group 1 did not study in both chemistry 'and' physics courses. However, concepts such as de Broglie wavelength, orbital, and momentum describe the important aspects of the quantum model. For that reason, as the results implied, it was a demanding task for the students to understand the basics of the modern theory of atom.

For students in Group 2, the results indicated that they had more knowledge about the quantum model of the atom than the first group. One of the probable reasons might be that second group students have taken more hours of chemistry and physics courses in grades 10 and 11. In addition, they have studied the extra concepts - as just mentioned above - in both chemistry ‘and’ physics curricula. However, it is possible to argue that having taken more hours of both chemistry and physics could not have a significant contribution on their understanding of the quantum model because the analysis results of their responses to the interview questions showed that they still used classical and/or semi classical ideas when describing the atomic structure; for instance, two third of the students held hybrid models in the interviews.

Secondly, findings related to students’ drawings provided answers to the second research question. The results revealed that students did not draw an electron cloud; most of the students in both groups tended to draw a classical or semi classical model of an atom. One possible reason might be that curricula, textbooks, instructors, and media generally represent the structure of atom in terms of the classical models; there is a nucleus at the center, there are also electrons, which are represented as point particles, move in orbits. Besides this, it should be admitted that drawing the modern structure of an atom is much more difficult than drawing a classical atom. Therefore, it is not very surprising that similar representations were observed in students’ drawings. It is suggested that it could be more appropriate not to ask students to draw images of sub-microscopic ‘objects’ since they do not make sense them in their everyday life. It was also detected that almost all students visualized the atom in three-dimensional and tried to draw it on paper; however, they explicitly stated that they could not draw a three dimensional picture on the paper.

Thirdly, the comparison of the data obtained from two instruments (i.e. semi structured interview and drawing) provided important findings. For instance, in Group 1 and Group 2, some students’ interview responses indicated that they visualized the atom by using the ideas of quantum model; however, they drew a classical/semi classical image of an atom. The reason might be the strong effect of the classical representations of the atom, especially the Bohr model, on students’ cognitive structures. As stated earlier, another reason might be that representing classical models of the atom is simpler than representing the electron cloud model. These findings suggest that drawing of an atom could force students to describe it as a classical object. As a result, students' drawings may probably lead researchers and teachers to overlook other important aspects of students' knowledge structures related to atom's structure. As was done in the present study, to have more complete information about their knowledge structures, multiple assessment tools should be used in the studies.

The last research question is about students' concept maps. Actually, it consists of four sub questions, each of which dealt with a key concept.

For the first sub question, both groups connected many concepts to the atom and described the structure of an atom. In this respect, the current study has similar findings with previous concept mapping study (Sen, 2002) where students also linked similar concepts to the atom. However, the result that fifteen students in Group 1 linked orbit concept to the atom showed the existence of Bohr model in their cognitive structure.

For the second sub question, the results revealed that almost all students in Group 1 connected orbit to the electron. The reason why students were highly inclined to draw such a relationship between these concepts might be due to the Bohr model. One explanation for this might be that the Bohr model was frequently introduced when students were learning concepts and subjects related to atomic structure.

The analysis of Group 1 students' first links for the electron concept revealed another finding that has not been reported before. It was found that 35.7% of the students linked both orbit and position to the electron and stated "Electron moves in orbits" and "Electron's position cannot be determined" Although the second proposition may imply that the students had some knowledge about the Heisenberg uncertainty principle, their explanations in the semi structured interviews showed that they did not actually have an accurate knowledge about this principle. Generally, students thought that electrons' positions could not be determined due to the fact that they were moving very fast in orbits. Since they misinterpreted this principle, they continued to use the concept of orbit in their explanations, concept maps, and drawings. For that reason, it is not surprising that the students wrote both conflicting propositions.

For Group 2, the results indicated that more than half of the students drew a link between orbital and electron and stated that electrons were found in orbitals.

However, more than half of those students also drew a link between orbit and electron. Thus, they mixed the semi classical model with the quantum model. As Ekinci and Şen (2014) revealed, the emphasis of the Bohr model in the curricula and textbooks might be a possible reason for this result; thus, students were not able to abandon the orbit concept easily. Another reason might be due to the fact that students used orbit and orbital concepts interchangeably. Students' explanations in the interviews also exemplify this. Similar results were also observed in previous studies (Cervellati & Perugini, 1981; Harrison & Treagust, 2000; Nakiboğlu, 2003).

For the third sub question, students' propositions were analyzed in terms of the concept of light and the results were summarized in Table 4.3 for Group 1 and Table 4.6 for Group 2. For both groups, it is clear that some students linked several concepts representing both particle and wave nature of light. It could be concluded that the students attributed the particle and wave properties to light. On the other hand, it should also be pointed that the analysis did not reveal similar results for the electron. It is evident from Table 4.2 and Table 4.5 that students did not draw links to concepts such as wave, wavelength, light, diffraction etc. In addition to these results, the students did not think that electrons have wave characteristics in the interviews. For instance, Olsen (2002) shed light on the wave and particles characteristics of light and electron, and found similar results. Moreover, the clusters observed in several students' concepts maps supported this result. It is suggested that teachers should help students construct meaningful connections between light and sub-atomic particles, especially electrons. To accomplish this, firstly, they should ascertain that their students have comprehended that light has a dual nature. Then, they should assist students to make a transition from light to sub-atomic particles in this aspect. As a result, it might be much easier for students to comprehend that sub-atomic particles have also wave characteristics.

Lastly, Group 1 and Group 2 students did not link many concepts to photon. Generally, they preferred photons when drawing a link to light and believed that photons comprise the light. Their limited knowledge about photons might be a probable reason why they did not write various propositions. The results of the current study were supported by a previous study (Mashhadi & Woolnough, 1999) in which more than half of the students stated that they did not have an image of photons.

Considering the discussions above, it could be concluded that although the students have taken many chemistry and physics courses in high school, they did not have an adequate knowledge related to modern structure of the atom. Besides this, the orbit concept had a strong influence on their conceptions about the structure of the atom. Moreover, the analyses of concept mapping data in terms of four key concepts suggest that it is a useful instrument for examining students' conceptual knowledge about this concept. Finally, by using multiple assessment tools in this study, it was possible to gain more insight into grade 12 students' understanding of the structure of atom. For that reason, it is suggested to use multiple instruments in future studies related to that concept.

5.3. Limitations of the Study

In the present study, students having studied the concept of atom in both chemistry and physics courses were involved. Students have encountered this concept at the very beginning of their chemistry course in 10^{th} grade, and at the end of their physics course in grade 11. It should be noted that introducing the last chapters is generally a problematic issue in Turkey. For that reason, students may not have adequately studied the concepts that belong to grade 11 physics curricula. For this reason, it may have had negative effects on the results of the study.

Students' interview responses and their drawings were examined in terms of four main categories. However, it could be possible to divide these categories into several sub categories so that a finer categorization process for the related data could be held. Nevertheless, in this study, I intended to discuss students' cognitive structures within a general framework.

5.4. Suggestions for Future Research

The results of the present study shed light on several important aspects of the atom concept with the help of three assessment tools, and in the light of these results, several suggestions can be made. Firstly, students may have obtained information about that concept from both formal and informal learning environments. Particularly, in formal learning environment, the atom concept is in focus in both chemistry and physics courses. In this framework, the related curricula of the courses were analyzed together in the current study; hence, it was possible to investigate their cognitive structures thoroughly. Therefore, it is suggested that future research should consider both chemistry and physics curricula/courses when dealing with this concept. Secondly, it is suggested that methodological triangulation of data should be used when collecting data from the participants of the study. Moreover, other instruments (e.g. mind mapping) that reveal students' cognitive structures can be integrated into research design. Lastly, future research may conduct similar concept mapping studies by making adjustments to the concept lists given in the present study.

REFERENCES

Adbo, K., & Taber, K. S. (2009). Learners' Mental Models of the Particle Nature of Matter: A study of 16-year-old Swedish science students. *International Journal of Science Education, 31*(6), 757-786.

Anderson, D., Lucas, K. B., & Ginns, I. S. (2000). Development of Knowledge about Electricity and Magnetism during a Visit to a Science Museum and Related Post-Visit Activities. *Science Education, 84*(5), 658-679.

Ausubel, D. P. (1968). *Educational Psychology: A cognitive View.* New York: Holt, Rinehart, and Winston, Inc.

Ausubel, D. P., & Robinson, F. G. (1969). *School Learning: An Introduction to Educational Psychology.* New York: Holt, Rinehart, and Winston, Inc.

Beiser, A. (2003). *Concepts of Modern Physics* (6th ed.). New York: McGraw-Hill.

Cervellati, R., & Perugini, D. (1981). The Understanding of the Atomic Orbital Concept by Italian High School Students. *Journal of Chemical Education, 58*(7), 568-569.

Cokelez, A. (2012). Junior High School Students' Ideas about the Shape and Size of the Atom. *Research in Science Education, 42*(4), 673-686.

Cros, D., Maurin, M., Amouroux, R., Chastrette, M., Leber, J., & Fayol, M. (1986). Conceptions of first-year university students of the constituents of matter and the notions of acid and bases. *European Journal of Science Education, 8*(3), 305-313.

Eisberg, R., & Resnick, R. (1974). *Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles.* New York: John Wiley & Sons.

Ekinci, S., & Şen, A. İ. (2014). *Atom Kavramının Öğretim Programları ve Ders Kitaplarındaki Yeri*. EJER Congress 2014. İstanbul, 24-26 Nisan 2014. [Çevrim-içi: http://ejercongress.org/pdf/EJERCongress2014-BildiriKitabi.pdf], Erişim Tarihi: 2 Şubat 2015.

Erlandson, D. A., Harris, E. L., Skipper, B. L., & Allen, S. D. (1993). *Doing Naturalistic Inquiry: A Guide to Methods.* Newbury Park, California: SAGE Publications, Inc.

Eryılmaz, A. (1996). *The Effects of Conceptual Assignments, Conceptual Change Discussions, and a CAI Program Emphasizing Cognitive Conflict on Students' Achievement and Misconceptions in Physics.* Unpublished PhD Dissertation, Florida Institute of Technology, Melbourne, Florida.

Fischler, H. (1999). *Introduction to Quantum Physics-Development and Evaluation of a New Course.* Research on Learning and Teaching Quantum Mechanics: Papers presented at the annual meeting National Association for Research in Science Teaching, [On-line: https://web.phys.ksu.edu/papers/narst/qm_papers.pdf#page=34], Date accessed: February 2nd, 2015.

Fischler, H., & Lichtfeldt, M. (1992). Modern physics and students' conceptions. *International Journal of Science Education, 14*(2), 181-190.

Fishbane, P. M., Gasiorowicz, S. G., & Thornton, S. T. (2005). *Physics for Scientists and Engineers with Modern Physics* (3rd ed.). New Jersey: Pearson Education Inc.

Francisco, J. S., Nakhleh, M. B., Nurrenbern, S. C., & Miller, M. L. (2002). Assessing Student Understanding of General Chemistry with Concept Mapping. *Journal of Chemical Education, 79*(2), 248-257.

Garnett, P. J., & Treagust, D. F. (1992). Conceptual Difficulties Experienced by Senior High School Students of Electrochemistry: Electrochemical (Galvanic) and Electrolytic Cells. *Journal of Research in Science Teaching, 29*(10), 1079-1099.

Garnett, P. J., Garnett, P. J., & Hackling, M. W. (1995). Students' Alternative Conceptions in Chemistry: A Review of Research and Implications for Teaching and Learning. *Studies in Science Education, 25*(1), 69-95.

Griffiths, A. K., & Preston, K. R. (1992). Grade-12 Students' Misconceptions Relating to Fundamental Characteristics of Atoms and Molecules. *Journal of Research in Science Teaching, 29*(6), 611-628.

Halloun, I. A., & Hestenes, D. (1985a). The initial knowledge state of college physics students. *American Journal of Physics, 53*(11), 1043-1055.

Halloun, I. A., & Hestenes, D. (1985b). Common sense concepts about motion. *American Journal of Physics, 53*(11), 1056-1065.

Harrison, A. G., & Treagust, D. F. (1996). Secondary Students' Mental Models of Atoms and Molecules: Implications for Teaching Chemistry. *Science Education, 80*(5), 509-534.

Harrison, A. G., & Treagust, D. F. (2000). Learning about Atoms, Molecules, and Chemical Bonds: A Case Study of Multiple-Model Use in Grade 11 Chemistry. *Science Education, 84*(3), 352-381.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force Concept Inventory. *The Physics Teacher, 30*, 141-158.

İngeç, Ş. K. (2009). Analysing Concept Maps as an Assessment Tool in Teaching Physics and Comparison with the Achivement Tests. *International Journal of Science Education, 31*(14), 1897-1915.

Ireson, G. (2000). The quantum understanding of pre-university physics students. *Physics Education, 35*(1), 15-21.

Jones, M. G., Carter, G., & Rua, M. J. (2000). Exploring the Development of Conceptual Ecologies: Communities of Concepts Related to Convection and Heat. *Journal of Research in Science Teaching, 37*(2), 139-159.

Justi, R., & Gilbert, J. (2000). History and philosophy of science through models: some challenges in the case of 'the atom'. *International Journal of Science Education, 22*(9), 993-1009.

Ke, J.-L., Monk, M., & Duschl, R. (2005). Learning Introductory Quantum Physics: Sensori-motor experiences and mental models. *International Journal of Science Education, 27*(13), 1571-1594.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic Inquiry.* Newbury Park, California: SAGE Publications Inc.

Markow, P. G., & Lonning, R. A. (1998). Usefulness of Concept Maps in College Chemistry Laboratories: Students' Perceptions and Effects on Achievement. *Journal of Research in Science Teaching, 35*(9), 1015-1029.

Mashhadi, A., & Woolnough, B. (1999). Insights into students' understanding of quantum physics: visualizing quantum entities. *European Journal of Physics, 20*(6), 511-516.

McKagan, S. B., Perkins, K. K., & Wieman, C. E. (2008). Why we should teach the Bohr model and how to teach it effectively. *Phys. Rev. ST Phys. Educ. Res., 4*(1), 010103-1-010103-10.

Müller, R., & Wiesner, H. (2002). Teaching quantum mechanics on an introductory level. *American Journal of Physics, 70*(3), 200-209.

Nakiboğlu, C. (2003). Instructional Misconceptions of Turkish Prospective Chemistry Teachers about Atomic Orbitals and Hybridization. *Chemistry Education: Research and Practice, 4*(2), 171-188.

Nakiboğlu, C. (2008). Using word associations for assessing non major science students' knowledge structures before and after general chemistry instruction: the case of atomic structure. *Chemistry Education Research and Practice*(9), 309-322.

Nakiboğlu, C., & Ertem, H. (2010). Atom ile İlgili Kavram Haritalarının Yapısal, İlişkisel ve Öneri Doğruluğu Puanlaması Analiz Sonuçlarının Kıyaslanması. *Türk Fen Eğitimi Dergisi, 7*(3), 60-77.

Novak, J. D. (2010). *Learning, Creating, and Using Knowledge: Concept Maps as Facilitative Tools in Schools and Corporations* (2nd ed.). New York: Routledge.

Novak, J. D., & Gowin, D. B. (1984). *Learning How to Learn.* Cambridge: Cambridge University Press.

Novak, J. D., Gowin, D. B., & Johansen, G. T. (1983). The Use of Concept Mapping and Knowledge Vee Mapping with Junior High School Science Students. *Science Education, 67*(5), 625-645.

Olsen, R. V. (2002). Introducing quantum mechanics in the upper secondary school: A study in Norway. *International Journal of Science Education, 24*(6), 565-574.

Özgün-Koca, S. A., & Şen, A. İ. (2006). The beliefs and perceptions of pre-service teachers enrolled in a subject-are dominant teacher education program about "Effective Education". *Teaching and Teacher Education, 22*(7), 946-960.

Pankratius, W. J. (1990). Building an Organized Knowledge Base: Concept Mapping and Achievement in Secondary School Physics. *Journal of Research in Science Teaching, 27*(4), 315-333.

Park, E. J., & Light, G. (2009). Identfying Atomic Structure as a Threhold Concept: Student mental models and troublesomeness. *International Journal of Science Education, 31*(2), 233-258.

Patton, M. Q. (2002). *Qualitative Research & Evaluation Methods* (3rd ed.). Thousand Oaks, California: Sage Publications, Inc.

Petri, J., & Niedderer, H. (1998). A learning pathway in high-school level quantum atomic physics. *International Journal of Science Education, 20*(9), 1075-1088.

Pozo, R. M. (2001). Prospective teachers' ideas about the relationships between concepts describing the composition of matter. *International Journal of Science Education, 23*(4), 353-371.

Rebello, N. S., & Zollman, D. (1999). *Conceptual Understanding of Quantum Mechanics After Using Hands-on and Visualization Instructional Materials.* Research on Learning and Teaching Quantum Mechanics: Papers presented at the annual meeting National Association for Research in Science Teaching, [Online: http://didaktik.physik.uni-bremen.de/niedderer/download/181999na.PDF#page=4], Date accessed: February 2nd, 2015.

Ruiz-Primo, M. A., & Shavelson, R. J. (1996). Problems and Issues in the Use of Concept Maps in Science Assessment. *Journal of Research in Science Teaching, 33*(6), 569-600.

Sanger, M. J., & Greenbowe, T. J. (1999). An Analysis of College Chemistry Textbooks As Sources of Misconceptions and Errors in Electrochemistry. *Journal of Chemical Education, 76*(6), 853-860.

Sen, A. I. (2002). Concept Maps as a Research and Evaluation Tool to Assess Conceptual Change in Quantum Physics. *Science Education International, 13*(4), 14-24.

Steinberg, R., Wittmann, M. C., Bao, L., & Redish, E. F. (1999). *The Influence of Student Understanding of Classical Physics When Learning Quantum Physics.* Research on Learning and Teaching Quantum Mechanics: Papers presented at the annual meeting National Association for Research in Science Teaching, [Online: http://didaktik.physik.uni-bremen.de/niedderer/download/181999na.PDF#page=43], Date Accessed: February 2nd, 2015.

Şen, A. İ. (2002). Fizik Öğretmen Adaylarının Kuantum Fiziğinin Temeli Sayılan Kavram ve Olayları Değerlendirme Biçimleri. *Balıkesir Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 4*(1), 76-85.

Taber, K. S. (2001a). The Mismatch between Assumed Prior Knowledge and the Learner's Conceptions: A typology of learning impediments. *Educational Studies, 27*(2), 159-171.

Taber, K. S. (2001b). When the analogy breaks down: modelling the atom on the solar system. *Physics Education, 36*(3), 222-226.

Tsaparlis, G., & Papaphotis, G. (2009). High-school Students' Conceptual Difficulties and Attempts at Conceptual Change: The case of basic quantum chemical concepts. *International Journal of Science Education, 31*(7), 895-930.

Uzuntiryaki, E., & Geban, Ö. (2005). Effect of conceptual change approach accompanied with concept mapping on understanding of solution concepts. *Instructional Science, 33*(4), 311-339.

Vosniadou, S., & Brewer, W. F. (1992). Mental Models of the Earth: A Study of Conceptual Change in Childhood. *Cognitive Psychology, 24*(4), 535-585.

Zele, E. V., Lenaerts, J., & Wieme, W. (2004). Improving the usefulness of concept maps as a research tool for science education. *International Journal of Science Education, 26*(9), 1043-1064.

APPENDICES

A. APPROVAL OF ETHICS COMMISSION

T.C.
HACETTEPE ÜNİVERSİTESİ
Genel Sekreterlik

Yazı İşleri Müdürlüğü

Sayı : 88600825 / 431-113

14 Ocak 2014

Konu :

EĞİTİM FAKÜLTESİ DEKANLIĞINA

İlgi: 19.12.2013 tarih ve 4895 sayılı yazınız

Fakülteniz Orta Öğretim Fen ve Matematik Alanlar Eğitimi Bölümü Fizik Eğitimi Anabilim Dalı öğretim üyesi **Prof. Dr. Ahmet İlhan ŞEN**'in danışmanlığında **Arş. Gör. Dr. Serkan EKİNCİ**'nin hazırladığı **"Sınıf Öğrencilerinin Atom Kavramı ile İlgili Bilişsel Yapılarının Farklı Ölçme Araçları Kullanılarak Araştırılması"** başlıklı çalışması Üniversitemiz Senatosu Etik Komisyonunun 24 Aralık 2013 tarihinde yapmış olduğu toplantıda incelenmiş olup, etik açıdan uygun bulunmuştur.

Bilgilerinizi ve gereğini saygılarımla rica ederim.

Prof. Dr. Ömer UĞUR
Rektör a.
Rektör Yardımcısı

Ek: Tutanak

Hacettepe Üniversitesi Genel Sekreterlik, Yazı İşleri Müdürlüğü, 06100 Sıhhiye-Ankara
Telefon: 0 (312) 305 1008 - 1039 • Faks: 0 (312) 310 5552
E-posta: yazimd@hacettepe.edu.tr

Ayrıntılı Bilgi için:

B. DOCUMENT OF RESEARCH CONSENT

T.C.
ANKARA VALİLİĞİ
Milli Eğitim Müdürlüğü

Sayı : 14588481/605.99/12664 02/01/2014
Konu: Araştırma İzni
(Serkan EKİNCİ)

HACETTEPE ÜNİVERSİTESİNE
(Genel Sekreterlik)

İlgi : a) MEB Yenilik ve Eğitim Teknolojileri Genel Müdürlüğünün 2012/13 nolu genelgesi
b) 24/09/2013 tarih ve 5062 sayılı yazınız.

Üniversiteniz Eğitim Fakültesi Orta Öğretim Fen ve Matematik Alanlar Eğitimi Bölümü, Fizik Eğitimi Anabilim Dalı Araştırma Görevlisi Serkan EKİNCİ'nin "Sınıf Öğrencilerinin Atom Kavramı ile İlgili Bilişsel Yapılarının Farklı Ölçme Araçları Kullanılarak Araştırılması" konulu tez önerisi kapsamında uygulama yapma isteği Müdürlüğümüzce uygun görülmüş ve araştırmanın yapılacağı İlçe Milli Eğitim Müdürlüğüne bilgi verilmiştir.

Anketlerin uygulama yapılacak sayıda çoğaltılması ve çalışmanın bitiminde iki örneğinin (CD ortamında) Müdürlüğümüz Strateji Geliştirme-1 Şube Müdürlüğüne gönderilmesini arz ederim.

Müberra OĞUZ
Müdür a.
Şube Müdürü

Güvenli Elektronik İmzalı
Aslı ile Aynıdır.
03/01/2014

Yaşar SUBAŞI
Şef

Bu belge, 5070 sayılı Elektronik İmza Kanununun 5 inci maddesi gereğince güvenli elektronik imza ile imzalanmıştır.
Evrak teyidi http://evraksorgu.meb.gov.tr adresinden e85b-e9db-3a7c-b7e5-f1d7 kodu ile yapılabilir.

Emniyet Mh. Alparslan Türkeş Cd. No: 4/A Yenimahalle/ANKARA
www.ankara.meb.gov.tr
istatistik06@meb.gov.tr

Ayrıntılı bilgi için: Murat YILMAZER
Tel: (0 312) 212 36 00
Faks: (0 312) 212 02 16

C. A SAMPLE CONCEPT MAPPING INSTRUCTION – 1

Değerli Arkadaşlar,

Atom kavramı ile ilgili 12. Sınıf öğrencilerinin algı ve düşüncelerini araştırmayı amaçlayan yüksek lisans tezi kapsamında atom kavramına ilişkin size verilen kavramları kullanarak bir kavram haritası oluşturmanız beklenmektedir. Oluşturduğunuz kavram haritalarından elde edilecek verilerin öğrencilerin bu kavramı daha iyi anlamalarını sağlayacak sonuçların ortaya çıkarılmasına, ayrıca bu kavram ile ilgili öğrenci başarısını geliştirmeye yönelik ileride yapılacak çalışmalara katkıda bulunacağı düşünülmektedir. Bu çalışmada verdiğiniz tüm kişisel bilgiler gizli tutulacak ve başka kişilerle paylaşılmayacaktır. Çalışmanın yayımlanması durumunda da sizi tanımlayacak şekilde kişisel bilgileriniz kesinlikle paylaşılmayacak, bunun yerine sizi tanımlamayan harf, rakam vb. ifadeler kullanılacaktır.

Yönerge:

Öncelikle sizden istenen bilgileri (adı, soyadı vb.) belirtiniz.

Aşağıdaki tabloda toplam 16 kavram bulacaksınız. Bu kavramları kullanarak bir kavram haritası oluşturunuz. Ayrıca, tablodaki kavramlar dışında kullanmak istediğiniz başka kavramları da kavram haritanıza ekleyebilirsiniz.

Kavram haritasını oluştururken

1. Tabloda yer alan ve kavram haritasında kullandığınız kavramları daire içinde gösteriniz.
2. Kavramlar arasındaki ilişkileri gösterirken kullanacağınız okların yönüne dikkat ediniz.
3. Kavramlar arasındaki her bir ilişkiye ait düşündüğünüz açıklamayı okların üzerine yazınız.

İlgi ve katılımınız için teşekkür ederim.

Arş. Gör. Serkan Ekinci

Adı:

Soyadı:

Yaşı:

Cinsiyet:

Sınıf – Şube:

Not: 10. ve 11. sınıfta bir haftada aldığınız fizik ve kimya ders saati sayısını aşağıdaki tabloda verilen boş kutulara (**X**) işareti koyarak belirtiniz.

Dersin Adı	Sınıf Seviyesi ve Haftalık Ders Saati			
	10. Sınıf - 2 saat	10. sınıf - 3 saat	11.sınıf - 2 saat	11. sınıf - 4 saat
Fizik				
Kimya				

Kullanılacak Kavramlar

Atom	Dalga Boyu	Konum	Proton
Atom Modeli	Elektron	Kütle	Tanecik
Çekirdek	Foton	Nötron	Yörünge
Dalga	Işık	Planck Sabiti	Yük

D. A SAMPLE CONCEPT MAPPING INSTRUCTION – 2

Değerli Arkadaşlar,

Atom kavramı ile ilgili 12. Sınıf öğrencilerinin algı ve düşüncelerini araştırmayı amaçlayan yüksek lisans tezi kapsamında atom kavramına ilişkin size verilen kavramları kullanarak bir kavram haritası oluşturmanız beklenmektedir. Oluşturduğunuz kavram haritalarından elde edilecek verilerin öğrencilerin bu kavramı daha iyi anlamalarını sağlayacak sonuçların ortaya çıkarılmasına, ayrıca bu kavram ile ilgili öğrenci başarısını geliştirmeye yönelik ileride yapılacak çalışmalara katkıda bulunacağı düşünülmektedir. Bu çalışmada verdiğiniz tüm kişisel bilgiler gizli tutulacak ve başka kişilerle paylaşılmayacaktır. Çalışmanın yayımlanması durumunda da sizi tanımlayacak şekilde kişisel bilgileriniz kesinlikle paylaşılmayacak, bunun yerine sizi tanımlamayan harf, rakam vb. ifadeler kullanılacaktır.

Yönerge:

Öncelikle sizden istenen bilgileri (adı, soyadı vb.) belirtiniz.

Aşağıdaki tabloda toplam 23 kavram bulacaksınız. Bu kavramları kullanarak bir kavram haritası oluşturunuz. Ayrıca, tablodaki kavramlar dışında kullanmak istediğiniz başka kavramları da kavram haritanıza ekleyebilirsiniz.

Kavram haritasını oluştururken

4. Tabloda yer alan ve kavram haritasında kullandığınız kavramları daire içinde gösteriniz.
5. Kavramlar arasındaki ilişkileri gösterirken kullanacağınız okların yönüne dikkat ediniz.
6. Kavramlar arasındaki her bir ilişkiye ait düşündüğünüz açıklamayı okların üzerine yazınız.

İlgi ve katılımınız için teşekkür ederim.

Arş. Gör. Serkan Ekinci

Adı:

Soyadı:

Yaşı:

Cinsiyet:

Sınıf – Şube:

Not: 10. ve 11. sınıfta bir haftada aldığınız fizik ve kimya ders saati sayısını aşağıdaki tabloda verilen boş kutulara (**X**) işareti koyarak belirtiniz.

Dersin Adı	Sınıf Seviyesi ve Haftalık Ders Saati			
	10. Sınıf -2 saat	10. sınıf - 3 saat	11.sınıf - 2 saat	11. sınıf - 4 saat
Fizik				
Kimya				

Kullanılacak Kavramlar

Atom	Elektron	Kırınım	Planck Sabiti
Atom Modeli	Fotoelektrik Olay	Konum	Proton
Çekirdek	Foton	Kütle	Tanecik
Dalga	Girişim	Momentum	Yörünge
Dalga Boyu	Işık	Nötron	Yük
De Broglie Dalga Boyu	Kara (Siyah) Cisim Işıması	Orbital	

E. ORIGINALITY REPORT (TURNITIN – FIRST PAGE)

Investigating 12th Grade Students' Cognitive Structures About the Atom Concept Using Different Assessment Tools

ORIGINALITY REPORT

14%	12%	11%	7%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	etd.lib.metu.edu.tr Internet Source	1%
2	ejercongress.org Internet Source	1%
3	www.earli2011.org Internet Source	<1%
4	perg.phys.ksu.edu Internet Source	<1%
5	Alan K. Griffiths. "Grade-12 students' misconceptions relating to fundamental characteristics of atoms and molecules", Journal of Research in Science Teaching, 08/1992 Publication	<1%
6	Georgios Tsaparlis. "High-school Students' Conceptual Difficulties and Attempts at Conceptual Change: The case of basic quantum chemical concepts", International Journal of Science Education, 2008 Publication	<1%

F. ORIGINALITY REPORT (TURNITIN – LAST PAGE)

152	Publication	<1%
153	Ibrahim Bilgin. "Promoting Pre-service Elementary Students' Understanding of Chemical Equilibrium through Discussions in Small Groups", International Journal of Science and Mathematics Education, 11/01/2006 Publication	<1%
154	Keith Taber. "Conceptual Resources for Learning Science: Issues of transience and grain-size in cognition and cognitive structure", International Journal of Science Education, 6/2008 Publication	<1%

EXCLUDE QUOTES OFF
EXCLUDE BIBLIOGRAPHY OFF
EXCLUDE MATCHES OFF

CURRICULUM VITAE

Personal Information

Name Surname	Serkan Ekinci
Birthplace	Elazığ / TURKEY
Birthdate	25.07.1987

Educational Background

High School	Söke Hilmi Fırat Anadolu Lisesi	2005
BSc	Middle East Technical University – Physics Education	2011
MSc	Middle East Technical University – Physics Education	2011
Foreign Language	English: Reading (Perfect), Writing (Good), Speaking (Good)	

Work Experience

Work Experience	Hacettepe University - Department of Secondary Science and Mathematics Education	2012 -

Academic Studies

Publications

Ekinci, S., Şen, A., İ., "Lise Fizik Ders Kitaplarında Yer Alan Bağlamların Cinsiyet Değişkenine Göre İncelenmesi", I. Ulusal Fizik Eğitimi Kongresi, Ankara, 12-14 Eylül 2013.

Şen, A., İ., Ekinci, S., "1st Grade Primary School Children's Conceptions about the Atom Concept", 21st Century Academic Forum Conference at Harvard University, Boston, USA, March 17-18, 2014.

Ekinci, S., Şen, A., İ., "Atom Kavramının Öğretim Programları ve Ders Kitaplarındaki Yeri", EJER Congress 2014, İstanbul, 24-26 Nisan 2014.

Şen, A., İ., Ekinci, S., "Investigating 12th Grade High School Turkish Students' Cognitive Structures about the Atom Concept Using Concept Mapping Tool", GIREP-MPTL 2014 International Conference, Palermo, Italy, July 7-12, 2014.

Eryılmaz, Ö., Ekinci, S., Şen, A., İ., "Cumhuriyet'ten Günümüze Ortaöğretim Düzeyindeki Öğretim Programlarında Modern Fiziğin Yeri", XI. Ulusal Fen Bilimleri ve Matematik Eğitimi Kongresi, Adana, 11-14 Eylül 2014.

Ekinci, S., Şen, A., İ., "Pre-service Physics Teachers' Learning Difficulties and Misconceptions About the Atom", iSER 2014 World Conference, Kapadokya, Turkey, October 29- November 2, 2014.

Contact

e-mail address	serkanekinci@hacettepe.edu.tr

Date of Jury	February 3rd, 2015