

A COMPARISON BETWEEN STUDENTS' MENTAL MODELS OF ATOMIC
STRUCTURE AND VISUALIZATIONS IN TEXTBOOKS FOR THE CONCEPT OF
ATOM

by

Zeynep Polat

B.S., Integrated B.S. and M.S. Program in Teaching Chemistry,

Boğaziçi University, 2010

Submitted to the institute for Graduate Studies in
Science and Engineering in partial fulfillment of
the requirements for the degree of
Master of Science

Graduate Program in Secondary School Science and Mathematics Education

Boğaziçi University

2012

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APPROVED BY:

Sevil Akaygün, Ph.D.
(Thesis Supervisor)

Assist. Prof. Emine Adadan

Prof. İlknur Doğan

DATE OF APPROVAL: 30.01.2012

ACKNOWLEDGEMENTS

First, a very special thank you goes to my thesis supervisor Sevil Akaygün, for giving me extra support and encouragement throughout my master years and throughout my thesis. I'm very grateful for her guidance, patience and understanding. I wish have the many years of working with her.

I would also like to thank my supervisor committee, Assist. Prof. Emine Adadan Prof. İlknur Doğan and for all of their guidance and assistance.

I gratefully thank to Prof. Ali Baykal for the very helpful contributions to the analysis part of this study.

I have furthermore to thank Assist. Prof. Buket Güzel who has helped me with her courses at the master program and for her support in my decision of academic life.

I would like to thank Gülşen Pekcan for her assistance and to Füsün Şahin and Mustafa Bozkurt for their support and understanding to complete my thesis.

I would have very special thanks to my best friend Nurseda Altinkaynak with her endless support for me. Without her assistance in my analyzing part, I wouldn't complete my thesis in the right time. I am very lucky that I have a friend like you.

I would like to my family, especially my caring mother, for their love and support during my difficult times throughout my life.

Finally, I would like to express my endless love to my fiancé, Yaseen, who has made me the person I am today with his patience, encouragement and love. I look forward to sharing the rest of life with you.

ABSTRACT

A COMPARISON BETWEEN HIGH SCHOOL STUDENTS' MENTAL MODELS OF ATOMIC STRUCTURE AND VISUALIZATIONS IN TEXTBOOKS FOR THE CONCEPT ATOM

This study was designed for two major goals which are to describe students' mental models about atom concept from 6th to 11th grade and to compare students' mental models of atomic model with visual representations of atom in textbooks. In order to analyze the comparison of students' mental models from their drawings and textbook visuals Chi-square analyses were used. Descriptive statistics were also used to describe students' mental models and textbook visual representations. The data was collected as qualitatively (*Mental Model Atom Test*) with 4 open ended questions including also drawings and quantitatively (*Evaluation Rubric for Atomic Model Representations*). The study was implemented in 2 elementary schools and 3 high schools with 180 students. In addition, 525 visuals from the Ministry of Education textbooks were evaluated in the study. The results indicated that Bohr's Atomic Model were seen as the most frequent model in both the student's drawings and textbook atom visuals. The consistency with textbook visuals and students' drawings were not established statistically because of the 6th grade students and 10th grade students' drawings. The results obtained by qualitatively can show that motion was not seen frequently in students' drawings similarly textbooks visuals. Finally, the results stated that students are very stable to draw their previous model even though they can encounter with the new atom model.

ÖZET

ÖĞRENCİLERİN ATOM KONUSUNDAKİ ZİHİNSEL MODELLERİ İLE DERS KİTAPLARINDAKİ ATOM GÖRSELLERİNİN KARŞILAŞTIRILMASI

Öğrencilerin atom konusundaki zihinsel modellerini tanımlamak ve öğrencilerin zihinsel modellerini ders kitaplarındaki atom görselleriyle karşılaştırmak çalışmanın başlıca iki amacıdır. Öğrencilerin zihinsel modellerini belirlemek amacıyla öğrencilere 2 tanesi çizim olmak üzere 4 tane açık uçlu soru içeren *Zihinsel Model Atom Testi* uygulandı. Öğrencilerin atom konusundaki zihinsel modelleri nitel olarak toplandıktan sonra *Atom Modellerini Değerlendirme Ölçeğinde* hem öğrenci çizimleri hem de Milli Eğitim Bakanlığı ders kitapları nicel olarak değerlendirildi. Ders kitaplarındaki görseller ile öğrencilerin zihinsel modellerini karşılaştırmak için de Chi-square analizi kullanıldı. Çalışmada toplam 180 öğrenci ve 525 atom görseli yer almaktadır. Çalışmanın sonuçlarına göre hem öğrenci çizimlerinde hem de ders kitaplarındaki görsellerde en çok kullanılan atom modeli Bohr Atom Modelidir. Öğrenci çizimleri ve öğrencilerin kullanmış oldukları ders kitaplarındaki görseller arasında istatistiksel olarak uyum bulunamamasına rağmen bu durum 6. sınıf ve 10. sınıf öğrencilerinin çizmiş olduğu modellerden kaynaklanmaktadır. Ayrıca nitel analiz sonuçlarına göre, öğrencilerin çizimlerinde neredeyse hiç denilebilecek kadar az hareketli çizim vardır. Son olarak da, sonuçlar gösteriyor ki öğrenciler yeni atom modelleriyle karşılaşsalar bile önceden zihinlerinde var olan modeli yeni değiştirmeme konusunda ısrarcı davranmaktadırlar.

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LIST OF SYMBOLS

D	Dimensional
Df	Degree of Freedom
e	Electron
-	Negative Charge
n	Neutron
+	Positive Charge
p	Proton
Sig.	Significance

LIST OF ACRONYMS/ABBREVIATIONS

Approx.	Approximate
Asymp. Std. Error	Asymptotic Standard Error
MEB	The Ministry of Education Press
RQ1	Rubric Question 1
RQ2	Rubric Question 2
RQ3	Rubric Question 3
RQ4	Rubric Question 4
RQ5	Rubric Question 5
RQ6	Rubric Question 6
S	Student Drawings
T	Textbook Visual
TMMA	Test of Mental Models of Atom

1. INTRODUCTION

Science, especially chemistry is often regarded as a difficult subject for many students because understanding chemistry relies on making sense of the invisible and untouchable world. In the literature, what sets difficulty of chemistry from the other sciences is that chemistry is presented in three levels as macroscopic, symbolic and submicro (molecular) level (Johnstone, 1993). Macroscopic level involves observable chemical phenomena; symbolic level explains chemical phenomena that have been translated into different symbols (mathematical formulae, graphs etc.) and submicro level represents what atoms and molecules do during physical and chemical changes (Bowen, 1998; Johnstone, 1999). Students are required to represent and translate chemical problems between these levels, and thinking in molecular level and explaining in submicro level (Harrison and Treagust, 2000; Ben-Zvi, Eylon, and Silberstein, 1986). However, many research shows that students cannot explain chemical phenomena at the submicro level instead students use symbols without understanding the meaning of the chemical concepts (Abraham, Grybowski, Renner, and Marek, 1992; Bowen, 1998; Harrison and Treagust, 1996; Lee, 1999; Nurrenbern and Pickering, 1987).

A good understanding of the atomic model is required for an understanding of structural properties of matter but many students have alternative conceptions about the atom concept (Ben-Zvi, Eylon, and Silberstein, 1988). One of the difficulties with learning about the atom model is that molecular world is different from the more familiar world which students already know (Taber, 2003). The atomic model plays a crucial role in the study of chemistry because it is given in early grades in many countries such as United Kingdom, United States of America and it is given in the 7th grade in the science curriculum in Turkey. The image of atom needs to be simple, accurate and also accessible for students because it is the basis of the understanding of the molecular world (Wright, 2003). In this respect, textbooks play an important role because students generally use textbooks by themselves, and they present different atomic models for students.

Models, in general, are valuable tools because they can be used to make sense of invisible, untouchable and abstract science concepts such as the structure of atom (Pringle,

2004). Teachers use 2D or 3D models and representations to help students in constructing their mental models. Especially, teaching atoms and atomic structure to elementary and high school students can be really challenging because it is hard to imagine how atoms look like. When things are too small to be seen with eye or too big, models provide the visual representations to the learners (Pringle, 2004). Atoms cannot be seen with the naked eye because they are smaller than the wavelengths of visible light. Therefore, for the concept of atom, modeling is the essence of thinking and working scientifically (Harrison, 2001).

One of the roles of a science teacher is to facilitate learning as meaningful and textbooks can be helpful in this sense. Many teachers have to make use of textbooks for planning the content and instruction in their classes, in other words they use textbooks to follow the curriculum. Actually, textbooks should provide the necessary scaffolding to help students to overcome conceptual barriers especially for abstract and fundamental chemical concepts like atomic models (Park and Light, 2008). Therefore, choosing textbooks should be carefully considered in the curriculum design because textbooks differ widely in the way they use scientific models.

Mental models are visual or abstract representations of reality that people develop as a result of their own observations or experiences (Craik, 1943). Students' mental models can be different from the scientific model or the expressed models which are accepted by scientific community (Osborne, 1983). Therefore, describing and understanding of students' mental models, understanding the visualization of students in chemical changes or in chemical events play significant roles to improve effective teaching strategies and learning environments. Coll and Treagust (2002) aimed to gain an understanding of secondary school, undergraduate and graduate level learners' mental models of chemical bonding. The study showed that all students showed a preference for simple models to explain chemical bonding but there were noticeable differences in the levels of understanding according to their academic grade levels. Actually, the study concluded that describing students' mental models are challenging, and these models are just the students' "own explanations." Rapp (2005) states that mental models are not just based on students' individual understanding and not always permanent or reliable, instead they can be tentative in the time being. in other words, students mental models can change in different

grades like the results of Coll and Treagust's (2002) study, therefore, students' mental models can be determined in each grade to see the academic grade level differences. Rapp also clarifies that students' mental models are abstract structures or schemas which are combination of personal perceptions, physical, and conceptual features of students' experiences. Greca and Moreira (2000) explain that mental models are personal and built in the basis of students' interactions with the world. In order to understand their surrounding world students will allow explaining and predicting their mental models.

Harrison and Treagust (1996) studied about Grades 8-10 students' mental models of atoms and molecules. In Taylan's (2006) study, the mental models of primary and secondary school students were described in atomic structure, and how the analogical and historical models of atom have impact on students' mental models were investigated.

More importantly, up to date, no research studies on the comparison of students' mental representations (mental models) of atom and the visuals of atomic models in textbooks has been reported in the literature. The comparison of the visuals in textbooks and the students' mental models will be examined in this study.

2. REVIEW OF LITERATURE

Understanding chemistry relies on making sense of the invisible and untouchable world; therefore, it is a difficult subject for students to understand. The level of abstraction of chemical concepts such as chemical bonding, atomic theory, molecules or subatomic particles makes it also difficult to get conceptual understanding for students. In addition, dynamic nature of chemistry is not directly observable to illustrate, dynamic nature of equilibrium requires representing and translating the chemical problems between macroscopic, symbolic and submicro levels (Harrison and Treagust, 2000; Johnstone, 1991, 1993). Links between the macroscopic, symbolic, and submicro levels are necessary for an improved understanding in chemistry (Gabel, 1993; Johnstone, 1993; Lee, 1999).

Johnstone (1993) defines the multilevel thought in chemistry. Macrochemistry is observable (tangible, edible and visible); submicro level in chemistry includes molecular, atomic and dynamic views; symbolic chemistry consists of symbols, equations, and mathematical equations. According to Johnstone, instruction should include connections between these levels and students should think in the combination of macroscopic, molecular and symbolic levels. Gabel (1993) also studied about the link between these three levels in chemistry. In their instruction, worksheets and transparencies are used to emphasize the particulate nature of matter. Results showed that students' test scores on the particulate nature of matter and also overall achievement scores increased with Gabel's instruction. According to Sanger's study (2000), students who get instruction including molecular representations were better able to answer conceptual questions that were molecular particulate in nature.

2.1. Atomic Models

The atomic model plays a central role in the study of chemistry (Ben-Zvi, Eylon and Silberstein, 1986) because atomic structure has been pointed out in many studies (Akyol, 2009; Ben-Zvi, Eylon and Silberstein, 1986; Çokelez and Duman, 2004; Harrison and Treagust, 1996; Just, 2000; Park and Light, 2009; Pringle, 2004; Robinson, 2000; Yıldız, 2006;) due to abstract nature of the submicro world of atoms; students have difficulty

understanding these concepts (Harrison and Treagust, 1996). In this proposed study, an attempt was made to define students' mental models about the concept of atom and a comparison between textbooks' representations of atomic models and students' mental models was examined.

There are many studies about atomic structure. Some of them have highlighted learning difficulties and alternative conceptions relating to atomic structure and the particulate nature of matter because atomic concept is one of the most difficult concepts (Harrison and Treagust, 1996) to understand conceptually by students. Atoms are not observable by naked eye or under the microscope. Park and Light (2009) made an attempt to better understanding for conceptual barriers to learn atomic structure. Their study aimed to explore the troublesome nature of this fundamental scientific concept. Learning difficulties and alternative students' models through the identification of the main structure of the threshold of understanding of atomic structure indicate that the atomic structure is a threshold concept (Park and Light, 2009). In end of the study, they suggested that atomic structure was a possible threshold concept for further study in science. Despite many studies attempting to understand the reasons of difficulties in learning atomic structure, it is still not clear that how best to teach atomic molecular structure to students (Bent, 1984; Berry, 1986; Hawkes, 1992; Park and Light, 2009; Shiland, 1995). In the study of Taber (2003), importance of pre-knowledge on new learning concepts is discussed. Taber concentrated on the relationship of students' alternative concepts and previous knowledge in learning the "orbital" model of atomic and molecular structures. Fifteen college students between ages 16-18 years were interviewed in a semi-structured format and analysis of the results suggested that previous knowledge was a link for developing new ideas or an obstacle resulting in alternative understanding shortly; and previous knowledge is a requirement of meaningful learning.

Another study about alternative conceptions of atoms is Ben-Zvi, Eylon, and Silberstein's (1986) study. Students often display misconceptions while explaining the particulate nature of atoms and molecules. According to Ben-Zvi, Eylon, and Silberstein (1986), students have continuous and instinctive model of matter instead of scientific or particle model of matter. The authors gave a questionnaire about atomic model, structure, and properties of matter to 10th-grade 300 Israeli students. About half of the students

(42.7%) had difficulty to differentiate between properties of substance and properties of a single atom, in other words they think that substance and the single atom of it have the same properties. In addition, 63.3 % of students stated that atoms have different properties in different phases. According to their results, Ben-Zvi *et al.* implemented a new program including historical review of atomic theory, and this program was explaining a correct view of the atom in a developing model. Results of the study showed that students who were taught by the new program developed better understanding of nature of atom and structure of matter than the students in control group. The authors recommended that a method giving the development of atomic model in scientific history is effective in preventing misconceptions about development of atomic model.

Many other studies also examined students' misconceptions and pre-existing knowledge about atoms and molecules (Garnett, Garnett and Hacking, 1995; Griffiths, 1994; Herron, 1978; Janiuk, 1993). According to the results of these studies, students' misconceptions stem from incorrect teaching, lack of prerequisite knowledge, and absence of relevant concepts in long term memory (Park and Light, 2009).

There are some studies directly related to understanding atomic models. According to the study done by Harrison and Treagust (1996) students generally used the terms "the atom as a sphere", "solar system atom", "neutral atom", and "the atom as a nucleus surrounded by an electron cloud" to describe atomic models. and many students (87.5%) represented an atom as a simple circle within a large circle. In addition, the usage of solar system and neutral atomic models were found as 41% and 48% respectively by students in the Charlet-Brehelin's (1998) study. In another study, some students showed as the same number of electron, protons, and neutrons for a given atom (Tsai, 1998). Tsaparlis and Papaphotis (2002) resulted that 12th grade Greek students had greater difficulties in understanding the concept of atomic orbital.

Cokelez and Dumon (2004) aimed to describe the students' representations and misconceptions concerning with the atom and molecule for the 10th to 12th grade secondary school French students. 930 students from upper secondary schools were included in this study. Diagnostic questionnaire with open ended questions that included drawings and explanations were used to collect data. According to study results, spherical atom model

was favored through their years of study but the choice of that drawn diagrams decreased from 10th to 12th grade in the more likely to Lewis representation. The use of the solar system model of atom is went up from grade 10 to 12 was a surprising result. Finally, from 10th to 12th grade some students still had confusion between atom and molecule and between model and reality.

in Turkey, Akyol's (2009) study investigated basic scientific concepts taught in the atom and identified learning difficulties. Students' ideas about the shape, description and size of the atom were defined with an open ended questionnaire related with the 10th grade curriculum. It is applied to 295 pre-service science teachers from Dokuz Eylül University, in addition, this 30 students were interviewed about their mental models of atom. The results showed that pre-service science teachers have a sufficient pedagogical background about atoms because of secondary school curriculum but their mental models was closely similar to Rutherford's atom. In addition, students' ideas for atomic size focused more on comparison with a known dimension instead of numeric values. They also found that students' imaginations of atom were concrete.

2.2. Mental Models

A model can be considered as a representation of an idea, object, event, process, or system (Gilbert and Boulter 1995). The role of the modeling and models in science is debated because models are abstract entities (Giere, 1990). Models have an intermediate role between scientific theory and the world we are living. According to constructivism, each individual constructs his/her own mental model with preexisting cognitive structures or observations or interactions of the real world (Bodner, 1986). Gilbert (year) states that "The precise nature of the models' role depends on how one interprets the meaning of 'theory', 'model' and 'the world-as-experienced.'"

Mental models "refer to a special kind of mental representation, an analog representation which individuals generate during cognitive functioning" and mental models are created on the spot to deal with the demands of specific situations (Vosniadou, 1994, 2001). According to Gentner and Stevens (1983), a mental model is produced is at the heart of the cognitive science perspective on learning. However, mental models cannot

be directly identified, only inferred from the major modes of human communication: gesture, speech, and writing (Justi and Gilbert, 2010). Therefore, describing and understanding of students' mental models, understanding the visualization of students in chemical changes or in chemical events play significant roles to improve effective teaching strategies and learning environments.

Studies concerning with the mental models of students takes place in the literature. Coll and Treagust (2002) aimed to gain an understanding of secondary school, undergraduate and graduate level learners' mental models for chemical bonding. The study showed that all the students showed a preference for simple models such as chemical formulas or ball and stick models to explain chemical bonding but there were noticeable differences in the levels of understanding according to their academic grade levels. in spite of different understanding levels, students at higher grade levels more clearly remembered simple bonding models rather than advanced models. According to research consequences, it was seen that students failed to follow shifts between the theory and the use of the model. Therefore, it was recommended that teachers should provide clear links between the models related to their introduction and experimental data and more details about the limitations of the model as well as the particular circumstances in which to use a given model.

When mental models take place into the public area through any mode of representation they turn out to be expressed models (Gilbert and Boulter, 1995). Those expressed models which are accepted by society and followed by community of scientists become scientific models. Scientific models can be consensus models when they are at the forefront of research at any time (Justi and Gilbert, 2010). A scientific model includes a specific context, "but which has been superseded at the cutting edge of science" may be termed as a historical model (Justi, 1997). Finally, a curricular model is simpler version of any consensus or historical model which takes place in science curriculum in the education system (Justi and Gilbert, 2010). Textbooks also represent curricular models; in this study textbooks' representations of atomic models will be analyzed. However, students may appear to be inconsistent in the use of scientific concept model, instead they may hold an internally consistent alternative which is the synthetic model (Vosniadou, 2002). When the new information proceeds contrary to existing conceptual structures, simply presenting the

new information as a fact may not be adequate for the consistency of the existing structure. In this case, the results are most probably becomes a synthetic model (Vosniadou *et al.*, 2001). Synthetic models (or misconceptions) can be integration of the new and existing knowledge in students' mind. In this study, the integration of different atom models in the students' mental models was called the synthetic model (Vosniadou, 2002).

2.3. Mental Models in Atomic Model Concept

There are some studies for the mental models of students concerning with the atomic concept. Harrison and Treagust (1996) reported that a descriptive study of Grades 8-10 students' mental models of atoms and molecules. They reported that most students at this age preferred models of atoms and molecules as "discrete, concrete structures" and they observed significant relationship between many students' mental images on atoms and the reality from the interviews. According to these outcomes, they concluded that many students of this age lack both experience with scientific modeling and requisite intellectual maturity to successfully interpret multiple models. Harrison and Treagust (2000) also reported a year-long study following 10 Grade 11 chemistry students' understanding in atoms, molecules, and chemical bonds. Their results favored the importance of proving students with analogical models and opportunities for exploring them on conceptual understanding and intellectual development.

The alternative mental models of students on atomic structure are identified by Park and White (2007). They analyzed the conceptual development of atomic structure during an introductory college chemistry course. According to the results of study, only a few students reached target level of understanding, and the study revealed the existence of conceptual barriers for learning atomic structure. Identification and exploration of students' learning barriers provide a guideline to develop curriculum for helping students to overcome chemical problems such as understanding the abstract concepts and for preparing appropriate instruction.

in Taylan's (2006) study, the mental models of primary and secondary school were determined in concerned with atomic structure and whether there is a relationship among them or not has been investigated. in this study, the impacts of analogical and historical

models of atom on students' mental models were examined. The sample of this study was 441 students from 7th and 8th grade and 479 students from high school in Balıkesir. In the first part of the study, grade 6th to 10th students' mental models, concerning atomic structure, between the years of 2003 and 2006 were determined and grouped according to historical models of atom and the analogical models used in teaching. In result of this grouping, it was concluded that mental models of students were affected by both the analogical and historical models but Modern Atomic Theory, which is the valid and recent one, has not yet been structured in their minds. This result actually is also supported in the literature Ruis (1988) suggested that the Quantum mechanical model shouldn't be taught in the beginning chemistry texts because students don't have enough mathematical skills to understand the Quantum atomic model and according to Gold (1988) Quantum numbers and orbital shapes are too abstract for high school chemistry. In the second part, the primary and secondary school students' mental models were compared. At the end of that investigation, it was found that mental models of primary and secondary students were parallel in terms of atom concept.

2.4. Textbooks

Textbook is a basic source of idea and information. Textbooks have been designed to perform on function supplying course of study (Chasnoff, 1964). It represents materials in an organized sequence, and is graded for reading skills and can be used to stimulate many kinds of curricular activities such as science experiments (Foshasy, 1997). Typically, a textbook is organized as course of a study so that the chapters to be studied are in sequence (Cronback, 1984). Generally, earlier chapters are prerequisites of the later chapters in textbooks.

The majority of teachers rely on textbooks when teaching subject matter that is available in textbooks (Sánchez and Valcárcel 1999). More than 90% of secondary school science teachers rely on textbooks to organize and deliver instruction and assign homework (Fouad Abd-El-Khalick, 2007). Teaching by largely depending on and following textbook content is the textbook-based approach, in contrast with an inquiry approach. In other words, textbook-based teaching has been associated with direct instruction (Scruggs and Mastropier, 1993).

Both in teaching and in textbooks, it is important that scientific concepts are easily reached to students in a number of different ways so that each student finds out his or her own best approach to studying and learning (Ahtivena, 2005). This is important because students need to discover an approach that is well –matched with their individual worlds of experience. The teaching methods should enlarge or change student’s horizon in mental states in the result of instruction. Usages of textbooks are one of the common instruction methods which are used by teachers to follow the sequence of topics and curriculum. Therefore, textbooks can differ greatly in how they translate the goals into teaching-learning activities and in how they structure different kinds of documents. As a consequence, by including particular content and activities and excluding others, textbooks can influence students’ opportunity to learn (Bakker, Panhuizen and Kolovou, 2009). in this study, textbooks will be analyzed in aspect of visuals of atom models and these visuals will be compared students’ mental models in the same chemical concept to see whether textbooks can influence students’ mental models or not.

In a textbook, knowledge is typically presented and integrated in the text and then applied in examples and exercises. The structure of knowledge may be evaluated on the basis of how coherently the knowledge and related key concepts are presented in the textbook, and whether model examples are provided with accompanying pictures and examples. The text, pictures, examples and exercises explain knowledge (Ahtineva, 2005). These are the criteria that may be used to study the key concepts of a textbook from the viewpoints of integration within the subject: integration between two or more subjects, pictures accompanying concepts, and examples or exercises clarifying concepts.

2.4.1. General Textbook Analysis

An extensive textbook analysis procedure has been developed within the frame of the AAAS Project 2061, based on seven main categories. First one is: providing a sense of purpose which is a part of planning a consistent curriculum. Second one is taking account of student ideas which examines whether the material contains specific suggestions for identifying and relating to student ideas. The third one is engaging students with phenomena in terms of small number of principles or ideas; forth one is developing and using scientific ideas to determine whether the material attempts to provide links between

phenomena and ideas to demonstrate the usefulness of the ideas in different contexts. The fifth criterion is promoting student reflection to determine whether the material suggests how to help students express, think about, and restructure their ideas to make better sense of the world. The sixth criterion is assessing progress to evaluate whether the material includes a variety of goal-relevant assessments. The last criterion is enhancing the learning environment such as to help the teachers in encouraging students' curiosity and creating a classroom community where all can succeed or can provide materials for scientific accuracy or attractiveness (AAAS, 2005).

There are other textbook studies focused on questioning styles (Lowery and Leonard, 1978), readability levels (Chiang-Soong and Yager, 1992), attention to controversial and social issues (Levin and Lindbeck, 1979; Rosenthal, 1984), inclusion of evolutionary theory (Skoog, 1984, 1979), and the treatment of specific subject matter content (Anderson, 1990; Lloyd, 1990; Staver and Lumpe, 1993) of secondary biology and/or chemistry textbooks.

2.4.2. Science Textbooks Analysis

Science textbooks are the major component of science instruction (Harms, 1981). Science textbooks contain much of the scientific information students receive, which influences how students perceive science (Factor and Kooser, 1981). Science textbooks are used as the primary organizer of subject matter at all levels of schooling and given that they are a prominent component of curriculum, "they should reflect reform recommendations" (Kahveci, 2003). They provide more instructional support than the teacher because students can use textbooks by themselves and spend more time with them (Mayer, 1983). Therefore, science textbooks need to be designed in ways that promote learning through and about inquiry, develop deep understanding of science concepts, and address diverse student populations.

There are some different studies and criteria about science textbooks' analysis. Here there are the main criteria for the science textbooks from relevant studies. Thiele and Treagust (1994) described the analogy classification framework used with ten high school chemistry textbooks. The framework took into consideration of past research into analogies

in science education to allow for a systematic classification of textbook analogies based upon nine criteria including chemistry content area. 93 described analogies were classified and many of these analogies include abstract chemistry concepts such as atomic structure and bonding but according to his study the common use of simple analogies are likely to create learning problems for students. In addition, in some books the authors use margin spaces to include more analogies and these kinds of analogies often contained a pictorial component. The Analogy Classification Framework was used in this study to classify 93 analogies from ten chemistry textbooks:

- (i) the content of the target concept - what aspect of chemistry is being considered by the target concept;
- (ii) the location of the analogy through the textbook - at what stage of the curriculum is the analogy being presented;
- (iii) the analogical relationship between analog and target - whether the analog and target share structural or functional attributes;
- (iv) the presentational format - whether the analog is verbal or pictorial-verbal;
- (v) the condition or level of abstraction of the analog and target concepts - whether they have an abstract or concrete cognitive level;
- (vi) the position of the analog relevant to the target - whether it is before, during, or after the presentation of the target, or whether it is presented in the margin;
- (vii) the level of enrichment - to what extent is the mapping between analog and target domains done by the author;
- (viii) the pre-topic orientation - is there evidence of further analog explanation of the analog domain and/or have the authors included any strategy identification that will indicate that the text has an analogical nature;
- (ix) the presence of any stated limitations or warning which highlights to the students where possible attribute mis-matches may occur.

In addition, in the Ahtineva (2005) analysis one upper secondary level course of chemistry instruction involved the use of a learning strategy: classification of the central concepts and a classification of activities based on task difficulty. In the study, four criteria: integration within the subject, integration between two or more subjects, pictures accompanying concepts, and examples or exercises clarifying concepts were used to

analyze text, pictures, examples. The study also attempted to find out the goodness of fit between the national curriculum and the textbook chemistry course. The national objectives concerned the content of knowledge, social significance, emphasis on experimental chemistry, and inspiring students for further study. In the strategy classification for concept learning, textbooks describe links between real world phenomena and scientific theories (Ahtineva, 2005).

A quantitative approach by itself may be limiting in such respects; however, it can potentially depict textbook profiles in a more reliable way. Past and also up-to-date evaluations of science textbooks involve various analyses from certain perspectives, such as representations of gender and sexuality (Snyder and Broadway, 2004), gender equity (Elgar, 2004), questioning level (Pizzini *et al.*, 1992), science vocabulary load (Groves, 1995), content accuracy (Hubisz, 2003; Shilan 1997; Gabel, 1983), physical appearance of science textbook (Crosby, 1986); or the inclusion of the nature of science aspects in biology (Chiappetta and Fillman, 2007; Irez, 2009) and chemistry (Abd-El-Khalick, Waters, and Le, 2008; Niaz, 2005) textbooks. These evaluations are thematically-based as compared to other scale-based analyses involving criterion items to be scored (Chiappetta and Collette, 1989; Ogan-Bekiroglu, 2007). By nature, thematically based evaluations allow for a narrower, yet in-depth focus on a certain theme (i.e., gender equity), and do not necessarily utilize scales. Here are the some mentioned studies about the above criteria.

Science textbooks were analyzed in the aspect of the existed questions to recall more complex mental levels. Science textbooks questions are the important study aid used to assist students in attaining understanding of science concepts, principles and facts (Holiday, 1981; Leonard, 1987). Pizzini (1992) analyzed eight commonly used middle school science textbooks to determine the cognitive level of questions as well as the locations of these questions within chapters. They found that input level questions, which are low level cognitive questions, dominated the textbooks, and concluded that for higher order thinking skills more, higher level cognitive questions would have been desirable. In textbooks, examples and activities are used to teach reasoning skills. The demands of reasoning skills may be evaluated on the basis of the width and depth of the knowledge needed in managing tasks. Four-level classification was used by Mikkilä (1992) and Nurrenbern and Robinson (1998). The lowest level of the processing hierarchy, the recall

task level, is represented by tasks which either require rote learning of the material or mechanic transfer of knowledge from a table format to a note format. The learner is much less active in carrying out repetitive tasks than in performing tasks at the next level of the hierarchy. The next level tasks are more demanding, as required the application of knowledge or the transformation of knowledge. Finally, the highest level, the fourth level, contains tasks that can be described as extensively activating, because they frequently involve the use of material and the application of information that have to be derived from sources other than the textbook.

Elgar's (2004) work involved analyzing a series of three lower secondary science textbooks used in Bruneian schools in terms of how equally females and males were represented in both illustrations and text. The result of analysis had showed a clear gender balance in text and illustrations in favor of males.

Abd-El-Khalick *et al.*'s (2008) nature of science (NOS) analysis of US high school chemistry textbooks revealed persisting inadequate representations of the NOS aspect with little change occurring in the past four decades. Niaz (2005) examined to this line of research by examining US general chemistry textbooks and emphasizing the need for inclusion of history and philosophy of science components for conceptual understanding. Irez (2009) investigated Turkish high school biology textbooks and underlined serious problems with the way NOS was portrayed.

Niaz (1998) and Rodriguez and Niaz (2002) analyzed 23 college freshman chemistry textbooks based on criteria derived from recent developments in history and philosophy of science (HPS). He found that most textbooks lacked an HPS framework and failed to deal with the conceptual basis for the development of this chemical theory.

Hubisz (2003) conducted a follow-up study of the 5 physical science textbooks used particularly in North Carolina's middle schools. He concluded that the most popular physical science textbooks used in US schools were content-wise inaccurate, consisted of errors, and unacceptable. Gönen and Kocakaya (2006) surveyed high school physics teachers and found that most of them perceived physics textbooks as insufficient in terms

of subject. However, many science teachers rely heavily on textbooks which give students not correct ideas about the nature of science (Chipetta, 1991).

Actually, content is one the most important part in textbooks not to get incorrect knowledge. Shiland (1997) analyzed the content of eight secondary chemistry textbooks according to four elements by reference to a 'learning as conceptual change' model: dissatisfaction, intelligibility, plausibility, and fruitfulness. None of the conditions of these criteria were met. The inadequacies of the Bohr's atomic model were presented in an abbreviated fashion (low dissatisfaction), the Quantum atomic model requires several pages to present (low intelligibility), there were no visuals as to how the Quantum mechanical model was able to correct these inadequacies (low plausibility), and there were few applications that required the use of the Quantum atomic model in the text or in the problems (low fruitfulness). According to results, textbooks should be modified to include conceptual change elements but Shiland (1997) also explained that the chemistry teachers emphasize the above classification beyond the presentations in their textbooks.

Another study about the content is Gabel's study. Gabel (1983) analyzed the content of a best-selling secondary chemistry textbook between the years of 1958 and 1978. According to the results, the chapters on atomic structure, chemical bonding, and the periodic law were more theoretical and mathematical. Her aim was modifying the textbooks to help students to learn chemistry in the balance content according to the aims of the "National Science Teachers Association: societal needs, personal needs, career education, and salient knowledge". However, she didn't mention about a specific learning model or the textbooks led to memorization instead of understanding.

Crosby (1986) analyzed the chemistry texts comprehensively; chemistry textbooks have changed significantly in content, style, format, appearance, ancillary materials over the past years. Chemistry textbooks have become thicker with more quantitative and theoretical materials, oriented towards greater emphasis on vocabulary, more relevant to the lives of students (Crosby, 1986).

Finally, textbooks are resources that support teachers in planning and delivering science instruction to meet local and national curricular standards. However, it is an undeniable reality that in the larger majority of classrooms, textbooks become the

curriculum and determine, to a much larger extent than desired by science educators, what is taught and learned about science in the classrooms. Science textbook analyses have mainly focused on representations of scientific literacy themes (Chiappetta, 1991) and the historical accuracy of the treatment of specific science concepts (Brito, Rodriguez, and Niaz, 1995) but any of analysis focus on the only one chapter which is atomic models and its relation with students' mental models.

2.5. Visuals in Textbooks

Visualization is “a forming a mental image and to make something visible to the eye” according to the Oxford Dictionary definition. Visualizations can extend the visual memory and thinking processes of chemists by providing dynamic images of virtual worlds (Shepard and Cooper, 1982). In addition, the research has showed that the visuals in textbooks facilitate students' understanding of concepts. Levie and Lentz (1982) assessed 46 studies that had compared learning from illustrated text to learning from text without pictures. They reported "an overwhelming advantage for the inclusion of pictures". Levin and Lesgold (1978) examined research on the impacts of pictures on learning from text when the text was presented orally and visuals were more effective in learning. However, in many textbooks, visuals are not scaffolds for learning plus the text and visuals are not related with each other (Bean *et al.*, 1990; Reid 1990).

in Biology textbooks visuals also play an important role especially for the invisible concepts such as cells, microorganism. Özay and Hasenekoğlu (2007) aimed that whether Biology textbooks which are used by public schools have proper visualization or not. They analyzed 11th grade Biology textbooks in terms of two criteria: the consistency of visuals with each other and logic and motion of the visuals which comes back to back. The results showed that there are insufficient and incompatible visual representations. in addition, visuals were not related with each other, the components of visuals were not proportional (Güneş, 2002) with other component in the same visual. The examined biology textbooks should be revised in terms of visuals and the necessity of more effective textbooks were appeared for students. Textbooks should not be just collection of information instead; they should be effective education tools to facilitate students' learning (Özay and Hasenekoglu, 2007).

There are some other studies about the usage of textbooks. Holliday's (1990) study explained that today's textbooks include many visual aids that facilitate to teach difficult scientific concepts. Unfortunately, many textbooks including visuals or colorful photographs have more for commercial aims not for educating students. In addition, some decorative color photographs are useful because of simulating and motivating students. He tried to examine the real value of such visuals in aspect to misconceptions, text format, publishers and teacher views.

Pozzer and Roth (2003) studied to investigate the function and structure of photographs in high school science textbooks. They tried to explain whether students can learn from textbooks when they study visuals or not. They analyzed four Brazilian biology textbooks and focus on the use of photographs and the relation among them focus on" the use of photographs and the relation among them, various types of texts, and the subject matter presented." The result of study showed that the relations of the structural elements of text, caption and visuals of textbooks are different across textbooks even within the same book.

Textbooks which have important impacts on students' education are insufficient in aspect of education aims and visuals (Dündar, 1995). Her study revealed that the pictures or photographs in the fundamental classes of elementary school textbooks are not significantly related with the content of text and the sequences of visuals are not designed in a logical way. In addition, the pictures were not found attractive for students.

A number of studies have focused on different aspects of the content, structure, curriculum design features, and disciplinary emphases of high school science textbooks, but none, to the best of our knowledge, have specifically targeted the visuals of atomic models in textbooks and also none mentioned the comparison of visuals in textbooks and students' mental models.

3. STATEMENT OF THE PROBLEM

According to literature review there are some studies (Ben-Zvi, Eylon and Silberstein, 1986; Wright; Harrison and Treagust, 1996; Pringle, 2004; Just,2000; Robinson, 2000; Çokelez and Duman, 2004; Yıldız, 2006; Akyol, 2009; Park and Light,2009) about students' understanding of atomic models. Atomic model and its subatomic particles play a central role in the study of chemistry and those are usually introduced early (7th grade) in the school curriculum. The science educators identified a wide range of alternative conceptions in the studies (Ben-Zvi, Eylon, and Silberstein, 1988, Garnett, Garnett and Hacking, 1995; Griffiths, 1994; Herron, 1978; Janiuk, 1993) about atom. Most science educators agree that learners' prior knowledge highly influences how they construct new knowledge (Ausubel, 1978). Prior knowledge may stem from instructional methods, textbooks, curriculum or the combination of these factors. When we focus on textbooks' usage, we see that teachers often use them for planning study programs and the content of their lessons (Sanchez and Valcarcel, 1999). Especially, for the abstract and nonobservable concepts like atom, models are utilized in textbooks. Again from literature, number of recent research studies has pointed out that science textbooks about content, language, visuals, readability levels, questioning style (Bazler and Simonis, 1991; Bennetta and Lerner, 1988; Brincones and Otero, 1994; deBerg and Treagust, 1993; Eltinge and Roberts, 1993; Jeffery and Roach, 1994; Staver and Lumpe, 1993; Stinner, 1992; Strube, 1989). A number of additional studies have examined chemistry textbooks with respect to content (Chiappetta, Sethna, and Fillman, 1991; Gabel, 1983; Gold, 1988; Pauling, 1983; Ruis, 1988), and also a number of studies examined visuals (Leive and Lents, 1982; Bean *et al.*, 1990; Reid 1990; Holliday, 1990; Lord, 2001; Pozzer and Rath 2003; Dündar, 1995) but there is not any study which is pointed out only one concept and its related visuals in textbooks. Since students generally use textbooks by themselves, textbooks play an important role to determine their mental models by presenting a variety of visuals.

The present study has two major purposes: first to describe students' mental models on the concept of atom from 6th to 11th grades. Second is to compare the students' mental models of atomic model with visual representations of atom in textbooks.

3.1. Research Questions

The following questions will be investigated in this study:

- (i) What features do students' mental models for atomic structure have in their grade (6th to 11th) levels?
- (ii) How do science textbooks describe atomic models with visualizations in each grade (6th to 10th) level?
- (iii) What are the similarities between the textbook visualizations of atomic model and students' mental models of atom?

3.2. Variables and Operational Definitions

3.2.1. Criterion variables

The criterion variable is the variable being predicted. Actually criterion variable is a dependent variable. The criterion variable of this study is the students' mental models for the atom concept from 6th to 11th grade.

Students' mental models for the atom concept were measured with the "Test of Mental Models of Atom" which was prepared by the researcher.

3.2.2. Reference variables

Reference variable can associate with different values at different times. It is also called independent variable. The references variable of the study is the atom visuals which take place in science and technology textbooks in elementary school and chemistry textbooks in high school. The visuals were measured with the "Evaluation Rubric for Students' Atomic Model Representations".

4. METHODOLOGY

This research is a descriptive and comparative research design which determines and describes the way things are and also compares the subgroups such as different grade levels. It involves collecting data to answer questions about students' opinions on the atom concept. This study is a cross sectional descriptive study because the data were collected from the selected students in a single time of the period but collecting data took time (Gay and Airasian, 1996). This study involves collecting data to answer questions on the students' mental models about atom concept and comparing them with textbook atom visuals.

4.1. Sample

The population of the study is elementary and high school students from 6th to 11th grade and elementary school science and technology and secondary school chemistry textbooks.

The students in the first semester of the year 2011-2012 were involved in this study by convenient sampling. There were totally 180 students and each 30 students were 6th, 7th, 8th, 9th, 10th and 11th grade students from the schools which are located in Istanbul. Students were chosen from two elementary schools named as Türkan Şoray Primary School (Elementary School 1) and Hasan Ali Yücel Primary School (Elementary School 2) and three high schools named as Mecidiyeköy Anatolian High School (High School 1), Behçet Kemal Çağlar High School (High School 2) and Etiler High School (High School 3). The chosen schools are located in Istanbul within Şişli, Sarıyer, Beşiktaş districts. The permission for the application of mental model test in schools was supplied by the Ministry of Education. In addition, 44.6% of whole sample is male and 55.4% is female students. The sample of the study is shown in Table 4.1. The percentage distribution according to the gender in each grade is given in Table 4.2 and in Figure 4.1.

Table 4.1. Sample of the study.

		School					Total
		Elementary School 1	Elementary School 2	High School 1	High School 2	High School 3	
Grade	6	30	0	0	0	0	30
	7	30	0	0	0	0	30
	8	9	21	0	0	0	30
	9	0	0	16	14	0	30
	10	0	0	24	6	0	30
	11	0	0	12	0	18	30
Total		69	21	52	20	18	180

Table 4.2. The percentage distribution of sample by grade level.

		Gender %		Total
		Male	Female	
Grade	6	54%	46%	100%
	7	37%	63%	100%
	8	40%	60%	100%
	9	43%	57%	100%
	10	43%	57%	100%
	11	50%	50%	100%
All percentage in the sample		44.6%	55.4%	100%

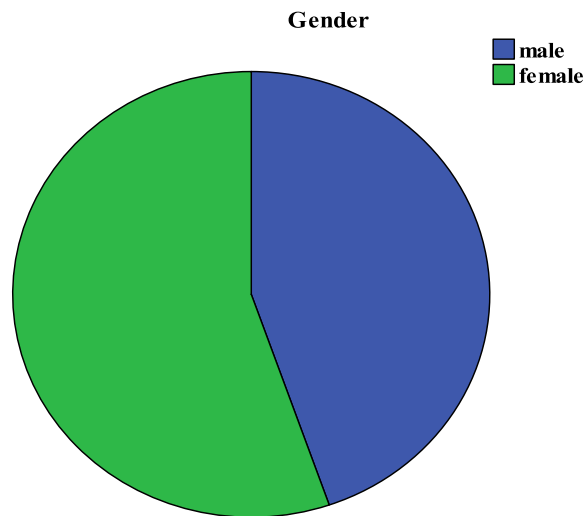


Figure 4.1. The percentage distribution of sample by grade.

Elementary school science and technology textbooks and high school chemistry textbooks are the other sample of the study. There are totally 525 visuals of atom in science and technology and chemistry textbooks from 6th to 10th grade. The percentage distribution of visuals in textbooks according to grade levels are given in Table 4.3

Table 4.3. Sample of the study by textbooks.

		Frequency	Percent %
Valid	Grade 6 textbook	89	17%
	Grade 7 textbook	87	16.6%
	Grade 8 textbook	75	14.3%
	Grade 9 textbook	156	29.7%
	Grade 10 textbook	118	22.5%
	Total	525	100%

4.2. Design and Procedure

There are three parts in this study. Firstly, students' mental models were determined; secondly visuals of atoms in textbook were evaluated according to the same criteria. Finally, students' drawings and textbook visuals were compared.

First, students' mental models of structure of atom in different grade levels from 6th to 11th were identified. For this reason, "Test of Mental Models of Atom" (APPENDIX A) was administered to identify students' mental models of atom.

The second part of the study includes analysis of visualizations of atomic models in elementary school science and technology and secondary school chemistry textbooks. The visual representations of atomic models and how the text mentions about the atom models were examined by using the "Evaluation rubric for atomic model representations" (APPENDIX B) which was also developed by the researcher based on the previous research results (Akyol 2009; Harrison and Treagust, 2000; Park and Light, 2009; Taylan, 2006).

The schools in Turkey apply the national curriculum which is prepared by the Ministry of Education. Therefore, The Ministry of Education Press (MEB) science and

technology and chemistry textbooks were analyzed in this study. The concept of atom firstly takes places in the 6th grade Chapter 3 “Particulate Nature of Matter”. in the 7th grade Chapter 4: “The Structure and Properties of Matter”, and in the 8th grade Chapter 3: “The Structure and Properties of Matter” includes the concept of atom and atom models in MEB publication textbook. The 9th grade MEB textbook includes atoms and Lewis structure in the Chapter 2: “Compounds”. In the 10th grade chemistry textbook Chapter 1 is “The Structure of Atom” including Quantum atomic theory. Finally, atom concept is not mentioned in the 11th grade textbooks. Therefore, in this grade mental model test results can show the students’ mental models after they completed all chapters including motion.

In the last part of the study, the students’ mental models and textbook visuals were compared and the similarities were investigated for the concept of atom in each evaluated grade level. The “Evaluation Rubric for Atomic Model Representations” was the same rubric that was used to evaluate students’ mental model drawings and explanations.

The similarities and differences between students’ drawings and visuals in textbooks were determined by using Chi-square analysis to see whether there were statistically significant differences or not.

4.2.1. Instruments

4.2.1.1. Test of Mental Models of Atom (TMMA). Test of Mental Models of Atom which was prepared by the researcher includes 4 open-ended questions. While preparing the “Test of Mental Models of Atom” instrument, the results of other studies (mental models of atom and molecules, Harrison and Treagust, 1996; scientific models, Justi, 2000; mental model of students, Taber, 2003; students representatives for atom and molecule, Çokelez and Duman, 2004; mental model of students, Taylan, 2006; learning difficulties in atom, Akyol 2009) were examined, and the questions were written in the light of the results of these studies. The validity of the instrument was established qualitatively. The content validity of the questions was achieved by asking experts. The experts are the two university professors from chemistry education, one university professor from chemistry department in the university and also one chemistry teacher. First and third questions asked the drawings or pictorial representations of atomic structure of Sodium and Neon atoms. Sodium was

chosen because it was a common example in each grade of textbooks. Neon was chosen because it was a noble gas, students did not need to think about ions form from this atom, and its atomic structure was not usually given in the textbooks. The second and forth questions ask the written explanations of their drawings asked in questions 1 and 3. The explanation part provides them to explain the things which they really want to draw (APPENDIX A).

4.2.1.2. Evaluation Rubric for Students' Atomic Model Representations. To assure the reliability of the “Evaluation Rubric for Students' Atomic Model Representations”, the students’ responses were evaluated by one researcher and one teacher. Reliability is related to the consistency of scoring the test (Gay and Airasian, 1996). For the students’ answers and textbook visuals, inter-rater reliability was counted separately. inter-rater reliability is necessary for a test to address the consistency of the implementation of a rating system. If there is no consistency between the scores, the scoring rubric should be discussed and a final agreement between the scorers should be reached. in order to determine inter-rater reliability a chemistry teacher scored randomly 20% of selected responses of students in each grade who took “Test of Mental Models of Atom”. Two scorers agreed in about 90%, when a disagreement occurred in evaluation, it was discussed in detail and an agreement was reached. The percentage agreement between the two scorers; in other words the inter-rater reliability was found to be 96.73%. There is another method to calculate inter-rater reliability. When two binary variables are attempted by two individuals to measure the same thing, Cohen’s Kappa is used as a measure of agreement between the two individuals. Cohen’s Kappa coefficient was found 0.838 which has been accepted as very good agreement. Statistics information about these analyses was given in the Table 4.4.

Table 4.4. Cohen's Kappa coefficients of two rater’s scores for evaluation rubric.

		Value	Asymp. Std. Error	Approx. T ^b	Approx. Sig.
Measure of Agreement	Kappa	0.838	0.034	21.011	0.000
N of Valid Cases		612			
a. Not assuming the null hypothesis.					
b. Using the asymptotic standard error assuming the null hypothesis.					

The evaluation rubric consists of six criteria for both students' drawings and textbook visuals. When it is used to evaluate textbooks and students' drawings, first criterion is to determine which *types of atomic models* are frequently used in the textbooks or students' drawings. The second criterion is to determine the location, representation, charge and number of *subatomic particles*; proton, neutron and electron. Location has three subcategories which are in the nucleus, in the orbital or in the other place. Representation has four subcategories which are dots, symbol with charge and wording. The third one is about *ion charge*. Fourth one is for *orbitals* in aspect to shape and number. Shape has six subcategories: solid circles, dash lines, clouds, half lines, elliptical in different orientations and s, p orbital shapes. Fifth one is about the *nucleus* in respect of charge, shape, including in it, the nucleus shape has two sub criteria which are solid and solid circle and including of nucleus has six subcategories: proton, neutron, electron, positive charge, negative charge and both positive & negative charges. The sixth criterion is about the existence of *motion in drawings*. These mentioned six criteria that were determined for the visuals in the textbooks. The seventh criterion is the *consistency of explanations with the drawings* (APPENDIX B).

From 6th to 10th grades, a total of 5 textbooks were evaluated by using the prepared rubric, 20% of the all visuals in textbook were evaluated by two researchers for inter-rater reliability. The percent of inter-rater reliability between the two scorers was found to be 92.64%. Cohen's Kappa was also used as a measure of agreement between the two individuals. Cohen's Kappa coefficient was found to be 0.801 which has been accepted as very good agreement. Statistics information about these analyses was given in Table 4.5.

Table 4.5. Cohen's Kappa coefficients of two rater's scores for textbook visuals.

		Value	Asymp. Std. Error ^a	Approx. T ^b	Approx. Sig.
Measure of Agreement	Kappa	0.801	0.015	37.978	0.000
N of Valid Cases		2159			
a. Not assuming the null hypothesis.					
b. Using the asymptotic standard error assuming the null hypothesis.					

5. DATA ANALYSIS AND RESULTS

In this section, results of the statistical analyses and descriptive results of the research questions were given separately.

Evaluation rubric for atomic model representations was used to evaluate both students' mental models of atom and visual representations of atom in science and technology textbooks of elementary school and chemistry textbooks of high school. The scores of students' obtained from TMMA (APPENDIX A), the evaluations of textbook visualizations were in nominal level.

As it is mentioned in the methodology section, there were two elementary schools and three high schools where the study was conducted. In each grade 30 students (from 6th to 11th) completed the Test of Mental Models of Atom (TMMA) (APPENDIX A). The scores in these tests were evaluated according to the "Evaluation Rubric for Atomic Model Representations" (APPENDIX B). In addition, the visual representations of atom in elementary school science and technology textbooks (6th, 7th and 8th grade) and high school chemistry textbooks (9th and 10th grade) were evaluated according to 17 criteria determined in the evaluation rubric (APPENDIX B). The results of these analyses were given in detail under each research question.

5.1. Students' mental models of an atom

Research Question 1: What features do students' mental models for atomic structure have for different grade (6th to 11th) levels?

Descriptive statistics were carried out in order to answer the corresponding research question after the Test of Mental Models of Atom (APPENDIX A) was administered to the students. Students' answers were evaluated according to 17 criteria which took place in the "Evaluation Rubric for Atomic Model Representations" (APPENDIX B).

The atomic bomb was shown by 6th grade students with the highest frequency as 15 drawings out of 30 followed by 9 Synthetic, 2 Dalton, and 2 Rutherford's atomic model in Table 5.1. In other words, the 50% of the 6th grade students drew was atomic bomb picture and 30% of the 6th grade students' drawings were the synthetic model which was created by students. In the 7th grade Dalton model had the largest number among other models with 26 students' drawings followed by 2 synthetic models, 1 atomic bomb and 1 Rutherford's atomic model. When these numbers were given by percentages the 81.3% of students drew Dalton's atomic model, 9.4% of students created their own models which were called synthetic model. In the 8th grade, Bohr's atomic model has extremely large number with 25 students; it is the 83.3% of the 8th grade students' drawings. in the 8th grade, 4 students' drawing could not be categorized as exactly any of the scientific atom model because they created their own models by integrating different models. in other words, synthetic models took place 13.3% among the 8th grade students' drawings. in the 9th grade, there is a similar pattern like the 8th grade students' drawings for their mental atom models. Except 1 synthetic model, 29 students drawing was the Bohr's atomic model. Namely, the 96.7% of 9th grade students' drawings were the Bohr's atomic model. in the 10th grade, again the largest number of atom models shown by students was Bohr's atomic model with 24 students which is the 76.7% of 10th grade students followed by 3 synthetic model which is the 10% of the students, 2 Rutherford which is the 6.7% of students, 1 Thomson which is the 3.3 % of students and 1 Quantum atomic model which is again the 3.3% of students. In the 11th grade students' drawing, again Bohr's atomic model took place the largest number in the other atom model with 18 drawings and 60% of students. In addition 20% of 11th grade students' drawings were Rutherford's atomic model with 6 students. The remaining 20% of the students drew the integrated models were categorized as synthetic models. The distribution of students' atom models in respect to grade is also shown in Figure 5.1.

Table 5.1. Students' mental models of atomic structure in each grade level.

		RQ1								TOTAL
		NONE OF THE MODEL	DALTON	THOMSON	RUTHERFORD	BOHR	QUAN TUM	OTHER: ATOMIC BOMB	SYNTHETIC MODEL	
Grade	6	2	2	0	2	0	0	15	9	30
	7	0	26	0	1	0	0	1	2	30
	8	0	1	0	0	25	0	0	4	30
	9	0	0	0	0	29	0	0	1	30
	10	0	0	1	2	23	1	0	3	30
	11	0	0	0	6	18	0	0	6	30
Total		2	29	1	11	95	1	16	25	180

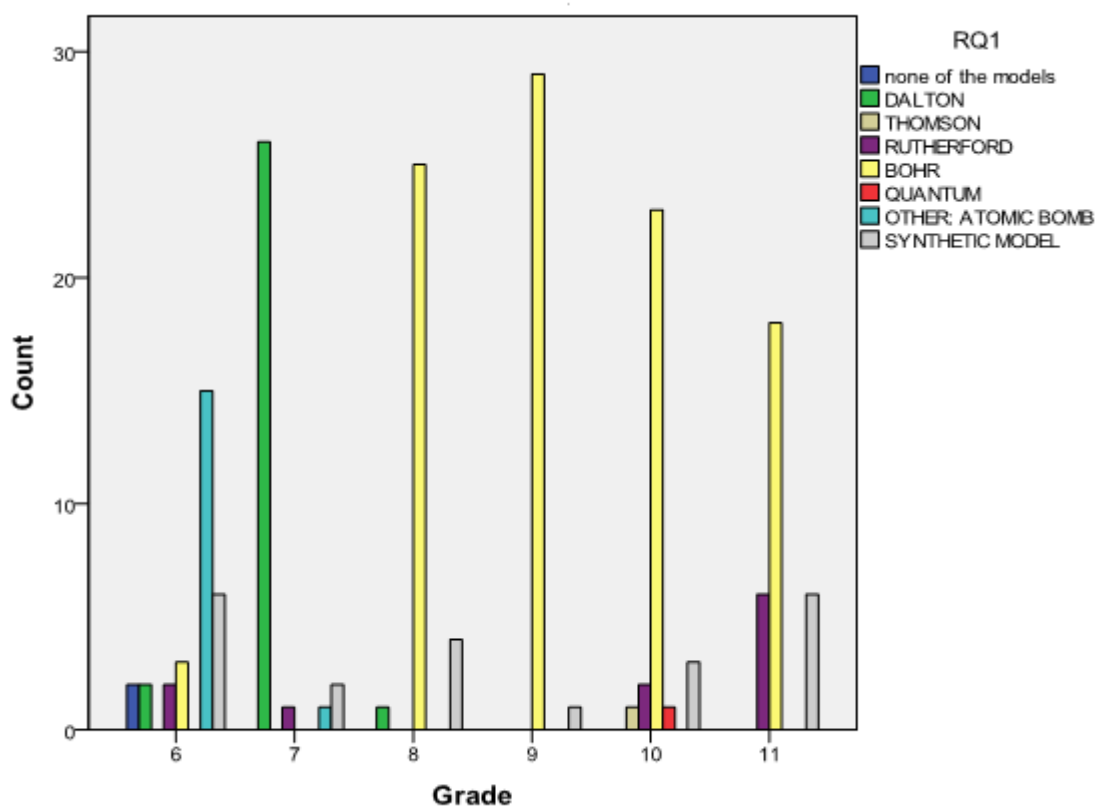


Figure 5.1. Students' mental models of atomic structure in each grade level.

Some examples from students' drawings for the atomic models are also given in Figure 5.2-10:

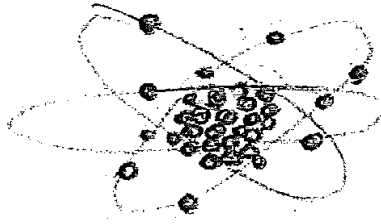


Figure 5.2. 11th grade, Rutherford's atomic model.

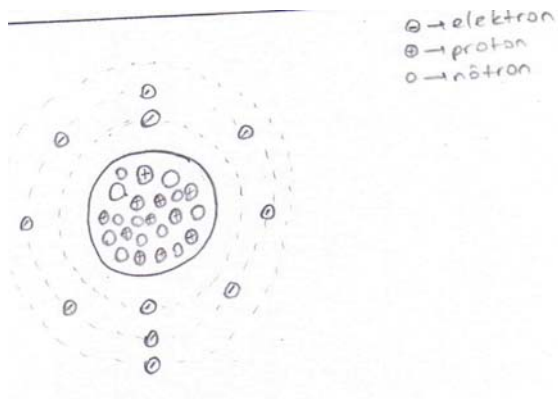


Figure 5.3. 10th grade, Bohr's atomic model.

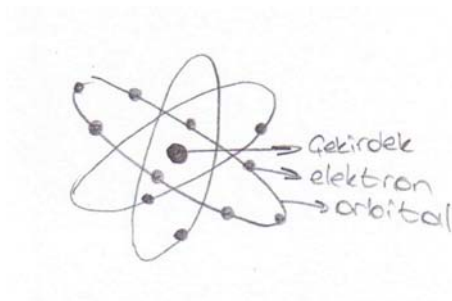


Figure 5.4. 10th grade, Rutherford's atomic model.

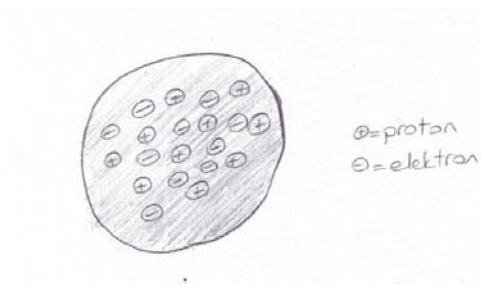


Figure 5.5. 10th grade, Thomson's atomic model.

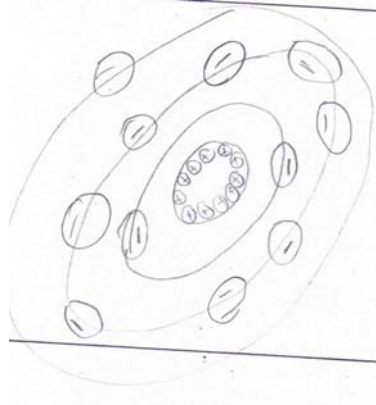


Figure 5.6. 9th grade, Bohr's atomic model.

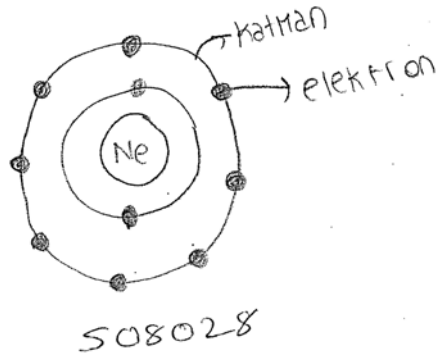


Figure 5.7. 8th grade, Bohr's atomic model.

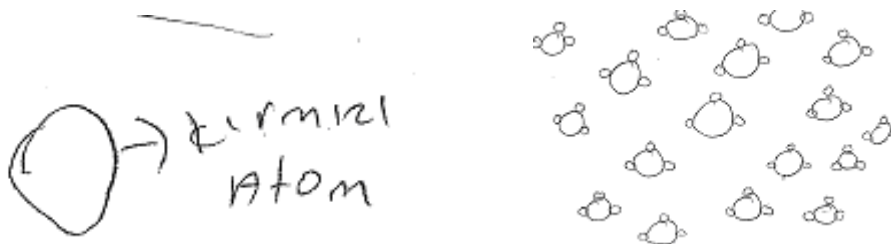


Figure 5.8. 7th grade, Dalton's atomic models.

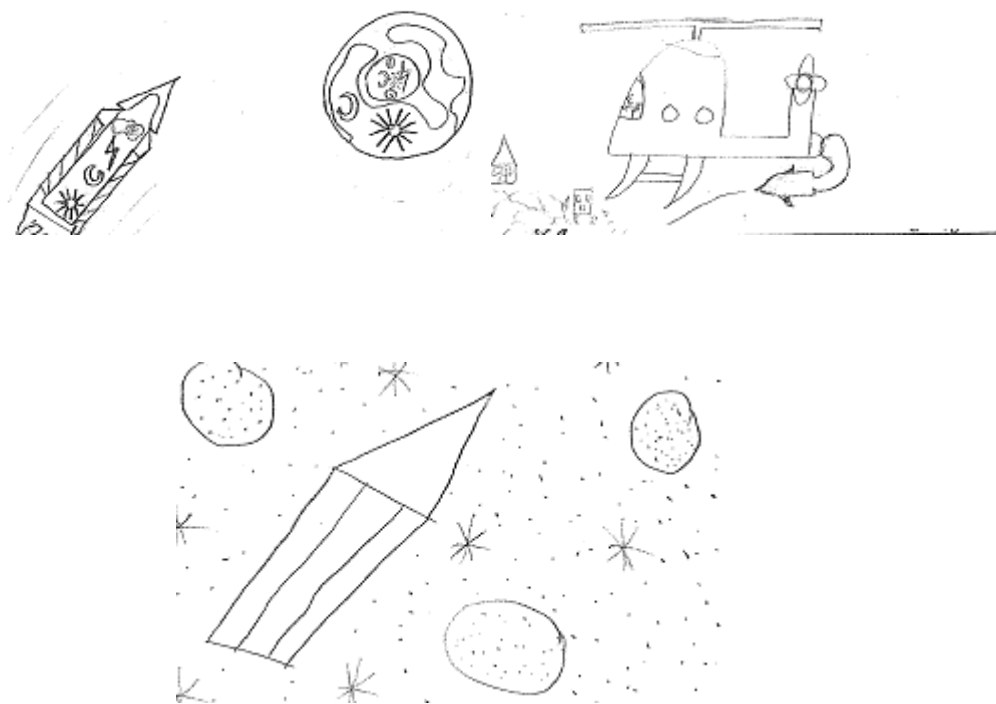


Figure 5.9. 6th grade, atomic bomb models.

The percentage distribution of students' drawings according to atom models is given in Table 5.2. When the all students are thought as a whole, 53.3% of students drew the Bohr's atomic model. Dalton's atomic model was drawn by the 15.6% of students; synthetic model was shown the by the 13.9% of the all students, atomic bomb model was shown by 8.9% of all students, Rutherford's atomic model was represented by 6.1% of all students followed the Thomson's and Quantum atomic model which were 0.6% of all students.

Table 5.2 The percentage of students' mental models of atomic structure.

		RQ1							
		NONE OF THE MODELS	DALTON	THOMSON	RUTHERFORD	BOHR	QUANTUM	OTHER: ATOMIC BOMB	SYNTHETIC MODEL
Grade	6	6.7%	6.7%	0%	6.7%	0%	0%	50%	30%
	7	0%	81.3%	0%	3.1%	0%	0%	3.1%	9.4%
	8	0%	3.3%	0%	0%	83.3%	0%	0%	13.3%
	9	0%	0%	0%	0%	96.7%	0%	0%	3.3%
	10	0%	0%	3.3%	6.7%	76.7%	3.3%	0%	10%
	11	0%	0%	0%	20%	18%	0%	0%	20%
All percentage distribution		0.01%	15.6%	0.6%	6.1%	53.3%	0.6%	8.9%	13.9%

5.1.1. Synthetic atomic models of students

The percentage of synthetic models which were drawn by students was coming after Bohr and Dalton's atomic models with the 13.9%. Some examples for the synthetic models from each grade are given from Figure 5.10 to Figure 5.20. In the Figure 5.10, the orbitals are integrated from the Rutherford's atomic model but the negative particles in the orbitals are coming from the Bohr's atomic model and the nucleus doesn't have any particles and positive charges inside of it. Therefore, this model couldn't be categorized either Rutherford's or Bohr's atomic model. The model which is seen in the Figure 5.11 looks like Thomson's atomic model but there is a nucleus in it. In addition, student showed the motion with arrows like the Quantum atomic model. Therefore, this model was also categorized as synthetic model which was the integration of different models.



Figure 5.10. 11th grade, synthetic model.

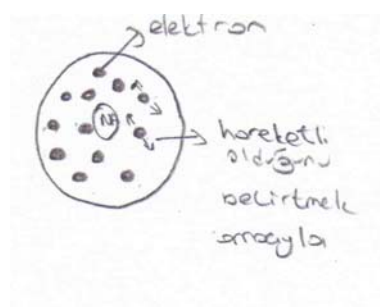


Figure 5.11. 10th grade, synthetic model-1.

In the Figure 5.12, student's drawing is looking like a Bohr's atomic model because of the regular orbitals and the distribution of the electrons but all of the orbitals are in a certain solid sphere like the Thomson's atomic model. In the figure 5.13, student's drawing is looking like a Dalton's atomic model but there is a nucleus in the centre of the atom, and also there are 2 orbitals with the number of electron. Therefore, these two models were also called as synthetic models.



Figure 5.12. 10th grade, synthetic model-2.

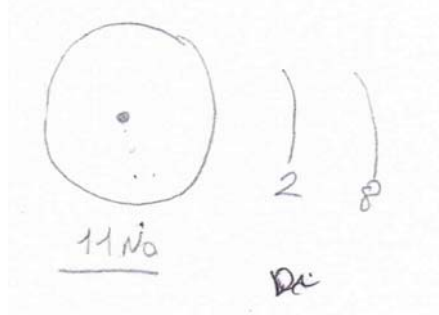


Figure 5.13. 9th grade, synthetic model.

In the Figure 5.14, the 1st orbital of atom is similar to the Bohr's atomic model but there are also different oriented orbitals so it is also similar to Rutherford. The atom model in the Figure 5.15 is a kind of Rutherford's atomic model but it does not show the positive ions in the centre of the atom. Therefore, these two atom models were also synthetic models.



Figure 5.14. 8th grade, synthetic model-1.

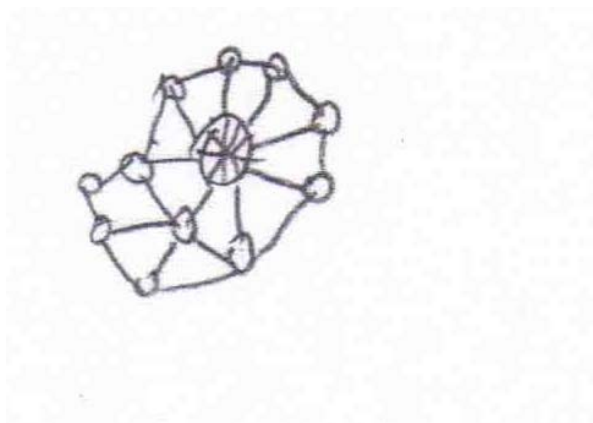


Figure 5.15. 8th grade, synthetic model-2

The 7th grade students' drawings are given in the Figure 5.16 and 5.17. Figure 5.17 has 7 solid circles. These solid circles can be the separate atoms like the Dalton's atomic models or can be the number of sub atomic particles in different oriented orbitals. The model in the Figure 5.17 is a kind of Dalton's atomic model with the Rutherford orbitals. Therefore, these two students' drawings were also called as synthetic models.

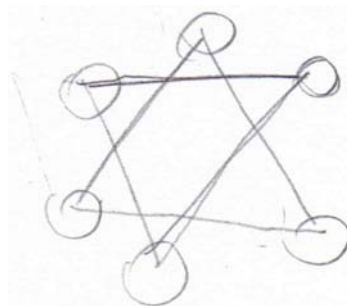


Figure 5.16. 7th grade, synthetic model-1

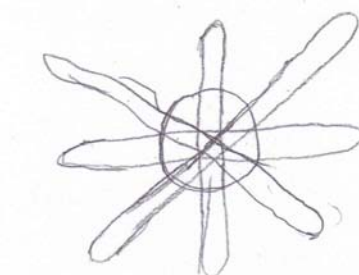


Figure 5.17. 7th grade, synthetic model-2

6th grade students' synthetic models are given in the Figure 5.18-20. Figure 5.18 is looking like Bohr's atomic model but the sub atomic particulates are distributed in the atom like the Thomson's atomic model. Figure 5.19 is a combination of Thomson's atomic

model because of the distribution of the sub atomic particles. However, it is not exactly the Thomson's atomic model because there are many different spheres in the atom. Figure 5.20 is a kind of Dalton's atomic model with the different oriented orbitals like the Rutherford's atomic model. Therefore, these three drawings are also categorized as the synthetic models of students.

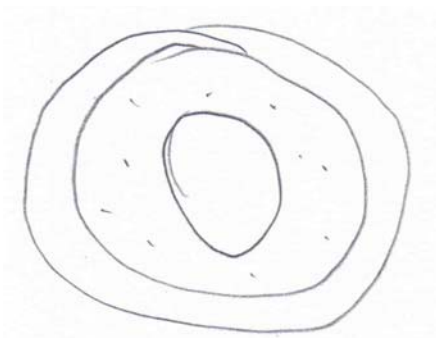


Figure 5.18. 6th grade, synthetic model-1.

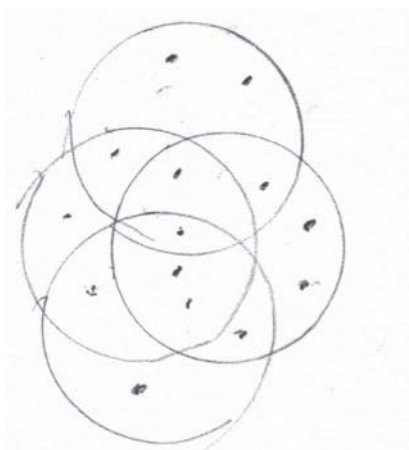


Figure 5.19. 6th grade, synthetic model-2.

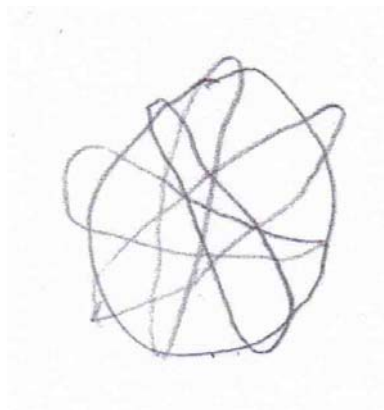


Figure 5.20. 6th grade, synthetic model-3.

5.1.2. Subatomic species in the students' drawings

As shown in Table 5.3, generally students in all grades did not show the charge of the proton in their drawings. In the 6th and 7th grade none of the students showed the charge of proton in their drawings. In the grade 8, two students; in grade 9 and grade 11, 1 student showed the charge of proton as a positive which is expected. In the 10th grade ten students showed the proton charge as a positive. Finally, 92% of all students didn't show the charge of proton in their drawings.

Table 5.3. Proton charges shown by students at each grade level.

		RQ2pCharge		Total
		not shown	Positive	
Grade	6	30	0	30
	7	30	0	30
	8	28	2	30
	9	29	1	30
	10	20	10	30
	11	29	1	30
Total		166	14	180

As shown in Table 5.4, 6th and 7th grade students did not draw protons in their drawings. Whereas in the 8th grade 6, 9th grade 10, 10th grade 19, and 11th grade 7 students located proton in the nucleus or centre of the atom. Only one student in the grade 9 drew the proton in the orbital. While, 24% of students showed the proton in their drawings, 95% of these students showed the proton in the centre or in the nucleus of the atom.

Table 5.4. Location of protons by students at each grade level.

		RQ2pLocation				Total
		not shown	in the nucleus/centre	in the orbital	other: atomic number place	
Grade	6	30	0	0	0	30
	7	30	0	0	0	30
	8	24	6	0	0	30
	9	19	10	1	0	30
	10	11	19	0	0	30
	11	22	7	0	1	30
Total		136	42	1	1	180

The way of the representation of proton by students is shown in Table 5.5. 6th and 7th grade students did not represent the proton as it was seen in Table 5.4. Table 5.5 shows that 5 students from grades 8 and 10, 8 students from grade 9 represented the proton with symbol “p” with their drawings whereas 10 students from 10th grade represented proton with “+” charge. In addition, 1 student from 9th grade, 3 students from 10th grade and 6 students from 11th grade represented the proton as solid circle in their drawings. Finally, 3 students from 9th grade and 1 student from 11th grade represented the proton just with the proton numbers. Finally, 40 % of the all students who represent protons showed protons with symbol of “p” and 24% showed protons with charge and 22% of them showed the proton as solid circles. The frequency distribution of proton representation was also shown in the Figure 5.12.

Table 5.5. Representation of protons by students at each grade level.

		RQ2pRepresentation						Total
		not shown	Symbol	with charge	Words	solid circle	Number	
Grade	6	30	0	0	0	0	0	30
	7	30	0	0	0	0	0	30
	8	25	5	0	0	0	0	30
	9	17	8	1	0	1	3	30
	10	11	5	10	1	3	0	30
	11	22	0	0	1	6	1	30
Total		135	18	11	2	10	4	180

Table 5.6 shows that 5 students from 8th grade, 4 students from 9th grade, 9 students from 10th grade and 1 student from 11th grade total 19 students out of 180 showed the neutron location in their own drawings. Finally, 91% of all students didn't represent neutron in their drawings but 100% of the rest of the students representing neutron in their drawings showed the neutron in the nucleus or the centre of the atom.

Table 5.6. Location of neutrons by students at each grade level.

		RQ2nLocation		Total
		Not shown	in the nucleus/centre	
Grade	6	30	0	30
	7	30	0	30
	8	25	5	30
	9	26	4	30
	10	23	7	30
	11	29	1	30
Total		163	17	180

As seen in Table 5.7, 6th and 7th grade students did not show the neutron in their drawings, five students from 8th grade, three students from 9th grade 4 students from 10th grade represented neutron with the symbol “n”. One student from 9th, 10th and 11th grade showed neutron with wording as “neutron” and two students from 10th grade represented neutron as solid circle in their atomic mental model drawings. While 91% of all students didn’t represented neutron, the 71% of the students who represented neutron showed them with the symbol of “n”, and 18% of the students who represented neutron showed them with the words and 11% of the students who represented neutron showed them as solid circles.

Table 5.7. Representation of neutrons by students at each grade level.

		RQ2nRepresentation				Total
		not shown	Symbol	Words	solid circle	
Grade	6	30	0	0	0	30
	7	30	0	0	0	30
	8	25	5	0	0	30
	9	26	3	1	0	30
	10	23	4	1	2	30
	11	29	0	1	0	30
Total		163	12	3	2	180

Table 5.8 shows that the charge of electron represented in students’ mental model drawings. Two students from 8th and 9th grades, nine students from 10th grade, and 4 students from 11th grade showed the charge of electron as negative which was expected while 163 students out of 180 which is 91% of all students’ drawings didn’t show the charge of electron in their drawings of the atom.

Table 5.8. Representation of charge of electron by students at each grade.

		RQ2eCharge		Total
		not shown	Negative	
Grade	6	30	0	30
	7	30	0	30
	8	28	2	30
	9	28	2	30
	10	21	9	30
	11	26	4	30
Total		163	17	180

Table 5.9 shows the locations where students put the electrons in their drawings. In the previous table, it was clarified that 6th and 7th grade students didn't show the electrons in their mental models. In 8th grade, 8 students showed electrons in the nucleus which is incorrect whereas 19 students showed electrons in the orbital and 1 of the student showed around the nucleus. In 9th, 10th and 11th grade, there was a similar pattern in the location of electrons which were in the orbitals. Totally, while 63 students didn't show the electrons, 106 students which is the 59% of all students and 91% of the students who showed the electrons showed electrons in the orbitals in their drawings and 2% of students represented electrons around the nucleus.

Table 5.9. Location of electrons by students at each grade level.

		RQ2eLocation				Total
		not shown	in the nucleus/centre	in the orbital	around the nucleus	
Grade	6	30	0	0	0	30
	7	30	0	0	0	30
	8	2	8	19	1	30
	9	1	0	29	0	30
	10	0	0	28	2	30
	11	0	0	30	0	30
Total		63	8	106	3	180

As shown in Table 5.10, 104 students being 26 of them from 8th, 27 from 9th, 21 from 10th and 30 from 11th grade represent the electrons as a solid circle or dot in their mental model atom drawings. Six students showed electrons with charge, three students showed them with their electron numbers and only one student represented the electron as electron cloud. Finally, 90% of the students who showed the electrons in their drawings represented

the electrons as solid circles or dots and 5% of the students who showed the electrons in their drawings represented the electrons with negative charge.

Table 5.10. Representation of electrons by students at each grade level.

		RQ2eRepresentation						Total
		not shown	Symbol	with charge	solid circle/dot	numbers	probability in Clouds	
Grade	6	30	0	0	0	0	0	30
	7	30	0	0	0	0	0	30
	8	2	0	0	26	2	0	30
	9	1	0	1	27	1	0	30
	10	1	2	5	21	0	1	30
	11	0	0	0	30	0	0	30
Total		64	2	6	104	3	1	180

5.1.3. Ion charge in the students' drawings

Table 5.11 shows the representation of ion charge of atoms in students' representations at each grade. Even though, the ion or neutral atom was not mentioned in the Test of Mental Models of Atom (APPENDIX A), totally 3% of all students, two students from 8th and 10th grades showed the atom as ion and one student from 9th and one student from 11th grade showed ion charge by “-” symbol.

Table 5.11. Representation of ion charges by students at each grade level.

		RQ3ion_charge			Total
		nothing extra	Symbol	Ion	
Grade	6	30	0	0	30
	7	30	0	0	30
	8	28	0	2	30
	9	29	1	0	30
	10	28	0	2	30
	11	29	1	0	30
Total		174	2	4	180

5.1.4. Orbitals in the students' drawings

How students represented the orbitals in their representations was given in Table 5.12. In 6th grade, 22 students didn't draw any orbitals in their drawings. Four students drew the orbitals as solid circle and three students represented as elliptical drawings in different orientations in 6th grade. In 7th grade, while two students showed orbitals in elliptical drawings in different orientations and one student in dash line, 27 students didn't draw the orbitals for atoms. In 8th grade, all students represented the orbitals with 26 solid circles and 2 half lines. In 9th grade, again orbitals were existed in the all students' drawings with 28 as solid circles, one as dash line and 1 as half line. In 10th grade only one student didn't show the orbitals. 22 students represented the orbitals as solid circles, five students showed it with dash lines, one student with elliptical drawings in different orientations and one student with s, p, d orbitals. In the 11th grade again all students drew the orbitals and 18 students drew solid circles, three drew dash lines and nine showed elliptical drawings in different orientations. In the total, 50 students didn't show the orbital and highest number of orbital shape is solid circles with 98 drawings. Orbital shapes in terms of grades were also given as bar graph in the Figure 5.21 and percentage distribution of orbital shapes according to grades is given in the Table 5.13.

Table 5.12. Representation of orbitals by students at each grade level.

		RQ4OrbitalShape							Total
		orbitals don't exist	solid circles	dash lines	half lines	elliptical in different orientations	s,p,d Orbitals	Others	
Grade	6	22	4	0	0	3	0	1	30
	7	27	0	1	0	2	0	0	30
	8	0	26	0	2	0	0	2	30
	9	0	28	1	1	0	0	0	30
	10	1	22	5	0	1	1	0	30
	11	0	18	3	0	9	0	0	30
Total		50	98	10	3	15	1	3	180

Table 5.13. Percentage distribution of representation of orbitals by students at each grade level.

		RQ4OrbitalShape %							Total
		orbitals don't Exist	solid circles	dash lines	half lines	elliptical in different orientations	s,p,d orbitals	Others	
Grade	6	73%	13.3%	0%	0%	10%	0%	3.3%	100%
	7	90%	0%	3.3%	0%	6.7%	0%	0%	100%
	8	0%	87%	0%	6.7%	0%	0%	6.7%	100%
	9	0%	93.3%	3.3%	3.3%	0%	0%	0%	100%
	10	3.3%	73.3%	16.7%	0%	3.3%	3.3%	0%	100%
	11	0%	60%	10%	0%	30%	0%	0%	100%
Total		28%	54%	5.6%	1.7%	8.3%	0.7%	1.7%	100%

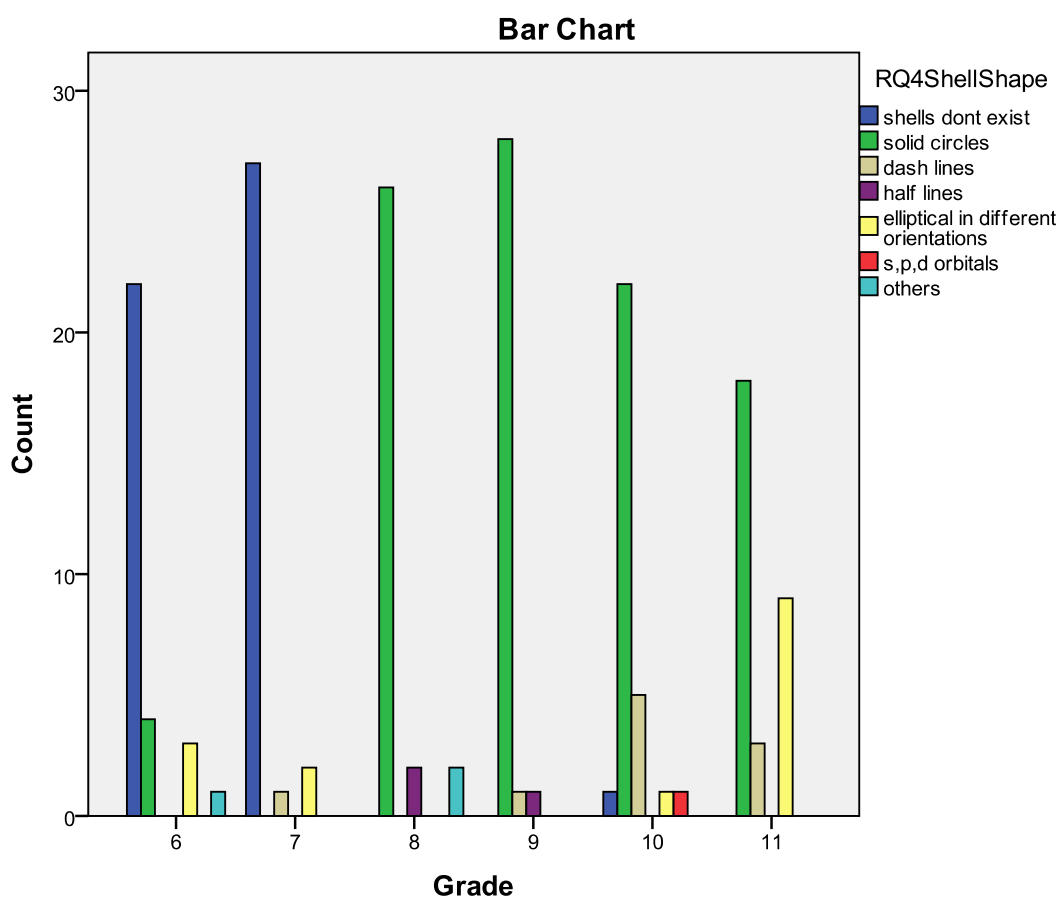


Figure 5.21. Representation of orbitals by students at each grade level.

Table 5.14 shows whether students drew the orbital number correctly or not. in the Table 5.11, it was seen that 50 students didn't draw the orbitals. In this table, it was seen

that 113 students being 26 of them from 8th grade, 29 from 9th grade and 28 from 10th grade drew the number of orbitals correctly. However, 17 students as being seven of them from 6th grade, two from 7th grade, four from 8th grade, one from 9th and 10th grade and two from 11th grade showed the wrong orbital numbers. Finally, while 63% of all students showed the orbitals in the correct number, 28% of all students didn't show any orbitals in the atoms and 9% of the students showed the orbitals incorrectly.

Table 5.14. Representation of number of orbitals by students at each grade level.

		RQ4OrbitalNumber			Total
		not shown	Shown	incorrect shown	
Grade	6	22	1	7	30
	7	27	1	2	30
	8	0	26	4	30
	9	0	29	1	30
	10	1	28	1	30
	11	0	28	2	30
Total		50	113	17	180

5.1.5. Nucleus in the students' drawings

As shown in Table 5.15, only 8% of all students with 15 students drew the nucleus with positive charge which is expected, and 11 of the 15 students took place in 10th grade. One student from 8th grade showed nucleus as neutral.

Table 5.15. Representation of charge of nucleus by students at each grade level.

		RQ5NucleusCharge			Total
		not shown	Positive	Neutral	
Grade	6	30	0	0	30
	7	30	0	0	30
	8	28	1	1	30
	9	28	2	0	30
	10	19	11	0	30
	11	29	1	0	30
Total		164	15	1	180

The representations for the shape of nucleus in students' drawings are seen in Table 5.16. While 48% of all students with the number of 86 out of 180 didn't draw the nucleus in their drawings being 26 of them from 6th and 7th grades, 12 from 8th grade, eight from

both 9th and 10th grade and six from the 11th grade. Half of the students drew nucleus as a solid circle being 4 from 6th and 7th grades, 18 from 8th grade, 22 from both 9th and 10th grade and 20 from 11th grade, and also four students from 11th grade drew the nucleus as an undefined shape. Finally, 50% of all students and 96% of the students who showed nucleus in their drawings represented the nucleus as a solid circle.

Table 5.16. Representation of the shape of nucleus by students at each grade level.

		RQ5NucleusShape			Total
		No defined nucleus	solid circle	other: no definite shape	
Grade	6	26	4	0	30
	7	26	4	0	30
	8	12	18	0	30
	9	8	22	0	30
	10	8	22	0	30
	11	6	20	4	30
Total		86	90	4	180

As shown in Table 5.17, 15 students out of 180 drew proton in the nucleus being 3 students from 8th and 11th grades, seven students from 9th grade, 2 students from 10th grade. Only 1 student from 8th grade drew just a neutron in the nucleus, eleven students put “+” symbol in the nucleus. They are 2 students from 9th grade, eight students from 10th grade and 1 student from 11th grade. In addition, 18 students put “+” symbol in the nucleus being four students from 8th grade, three students from 9th grade, nine students from 10th grade and two students from 11th grade. Eighteen students put proton and neutron in the nucleus with four students from 8th grade, 3 students from 9th grade, nine students from 10th grade and two students from 11th grade. With the largest number of 31 students put the symbol of element or the atom number in the nucleus with 6 students from 8th grade, nine students from 9th grade, three students from 10th grade and 13 students from 11th grade. Finally, 58% of the all students didn’t draw anything inside of the nucleus. However, 41% of the students who drew the things inside of the nucleus showed the element symbol in the nucleus or in the centre of the atom, 24% of these students put the p and 20% of them draw “p” in the nucleus.

Table 5.17. Representation of subatomic subatomic species included in nucleus by students at each grade level.

		RQ5 Species included in nucleus						Total
		Nothing	P	N	+	p n	symbol of element, or ion, number	
Grade	6	30	0	0	0	0	0	30
	7	30	0	0	0	0	0	30
	8	16	3	1	0	4	6	30
	9	9	7	0	2	3	9	30
	10	8	2	0	8	9	3	30
	11	11	3	0	1	2	13	30
Total		104	15	1	11	18	31	180

5.1.6. Motion in the students' drawings

As shown in Table 5.18, the motion of atoms didn't take place in students' drawings. Only 2% of all students with the number of one student from 10th grade and two students from 11th grade showed motion with arrows and symbols. In addition, only one student from 11th grade showed motion by with wordings. The Figures 5.22 shows the drawings of students including motion.

Table 5.18. Representation of motion of subatomic species by students at each grade level.

		RQ6Motion			Total
		Not shown	With symbols, arrows	with words	
Grade	6	30	0	0	30
	7	30	0	0	30
	8	30	0	0	30
	9	30	0	0	30
	10	28	1	1	30
	11	28	2	0	30
Total		176	3	1	180

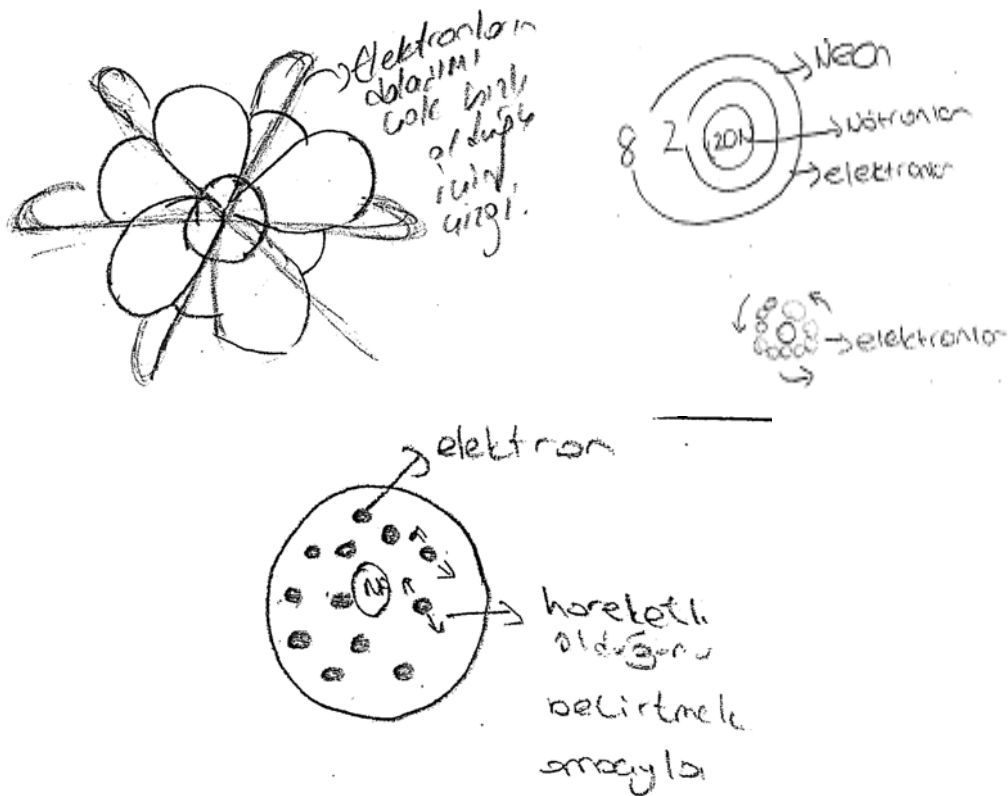


Figure 5.22. Students' drawings of atom including motion.

5.1.7. Explanations of the students' own drawings

As shown in Table 5.19, 54 students which is the 30% of the research sample didn't explain their drawings being 26 of them from 6th grade, 17 of them from 7th grade, 3 of them from 8th grade, one of them from 9th grade and 7 of them from 11th grade. In addition, explanations of 35% of the all students with the number of 63 students were consistent with their drawings with the largest number student 19 from 10th grade and lowest student number 3 student from 6th grade. 35 students added extra information to their explanations which were not asked in the question. These extra information included isotope atoms, nonmetal, metal, noble gases, stable atom, and octet rule. While none of the 6th grade student wrote extra information to their drawings, 20% of all sample with 1 student from 7th grade, 11 students from 8th grade, 12 students from 9th grade, 8 students from 10th grade and 3 students from 10th grade added extra information to their drawing explanations. Ten students forming 5.6% of all students chose symbol by explaining their drawings instead of writing. In addition, even though 2% of all students showed motion in their drawing from Table 5.16, 8 students' explanations were including motion, 4% of students' explanation, 4

from 7th grade, 2 from 8th grade and 2 from 9th grade, were wrong or inconsistent with their drawings. One student from 6th and 1 student from 7th grade mentioned about daily usage of the atoms in their drawings.

Table 5.19. Students' explanations given besides their representations at each grade level.

		RQ7Explanations							Total
		no explanation	consistent with drawing	extra info	with symbols	Motion	inconsistent with drawings	other: daily life usage	
Grade	6	26	3	0	0	0	0	1	30
	7	17	7	1	0	0	4	1	30
	8	3	11	11	1	2	2	0	30
	9	1	14	12	0	1	2	0	30
	10	0	19	8	0	3	0	0	30
	11	7	9	3	9	2	0	0	30
Total		54	63	35	10	8	8	2	180

5.2. Textbook visuals

Research Question 2: How do science textbooks describe atomic models with visualizations in each grade (6th to 10th) level?

in order to respond to the research question 2, each visual which takes place in the 6th, 7th, 8th, 9th and 10th grade textbooks were evaluated according to “Evaluation Rubric for Atomic Model Representations” (APPENDIX B). Descriptive statistics were carried out after the “Evaluation Rubric for Atomic Model Representations” (APPENDIX B) application to each atom visual in the evaluated textbooks.

As shown in Table 5.20, there were 525 atom visuals in the elementary and secondary school textbooks. In the 6th grade science and technology textbook, there were totally 89 visuals of atom being 88 of them representing Dalton's atomic model and 1 representation of atomic bomb. In the 7th grade science and technology textbook, there were 63 representations of Bohr's atomic model having the highest frequency followed by 20 Dalton's atomic models out of 87 atom model visuals in textbooks. In the 8th grade, science and technology textbook, the largest number of representation of atomic model

was Dalton's being 62 Dalton's atomic model representations; that were similar to the trend seen in visualization in 6th grade textbook. In addition, 10 representations out of 75 visuals were Bohr's atomic model in 8th grade science and technology textbook. The largest number of visuals related with the atom among all grade textbooks was found in the 9th grade textbook, 156 visuals. Among all the visualizations in the 9th grade, Lewis model with 79 visuals has the most frequency which was followed by Bohr with 60 visuals and 11 visuals were not categorized any of the atom models. There were also 6 visuals of Dalton's atomic model for the same grade. in the 10th grade chemistry textbook visual categorization, there were 118 visuals with 76 Dalton's atomic models, 21 Quantum atomic models which took place only in the 10th grade textbooks, 12 Lewis structure, 4 Bohr's atomic model and 2 Thomson's atomic model. Finally, the largest number of atom model among all the visual representations given in textbooks, was representation of Dalton's atomic model with 252 visuals followed by Bohr's atomic model with 137 visuals and Lewis with 91 visuals. Representations of Thomson's and Rutherford's atomic models had the lowest frequencies with 4 and 1 visual. Figure 5.23 shows the distribution of representations of atomic models given in textbooks for each grade by bar graph.

Table 5.20. Distribution of representations of atomic models given in textbooks for each grade level.

		RQ1								Total
		none of the models	DALTON	THOMSON	RUTHERFORD	BOHR	QUANTUM	LEWIS	OTHER: ATOMIC BOMB	
Grade	6	0	88	0	0	0	0	0	1	89
	7	0	20	2	1	63	1	0	0	87
	8	3	62	0	0	10	0	0	0	75
	9	11	6	0	0	60	0	79	0	156
	10	3	76	2	0	4	21	12	0	118
Total		17	252	4	1	137	22	91	1	525

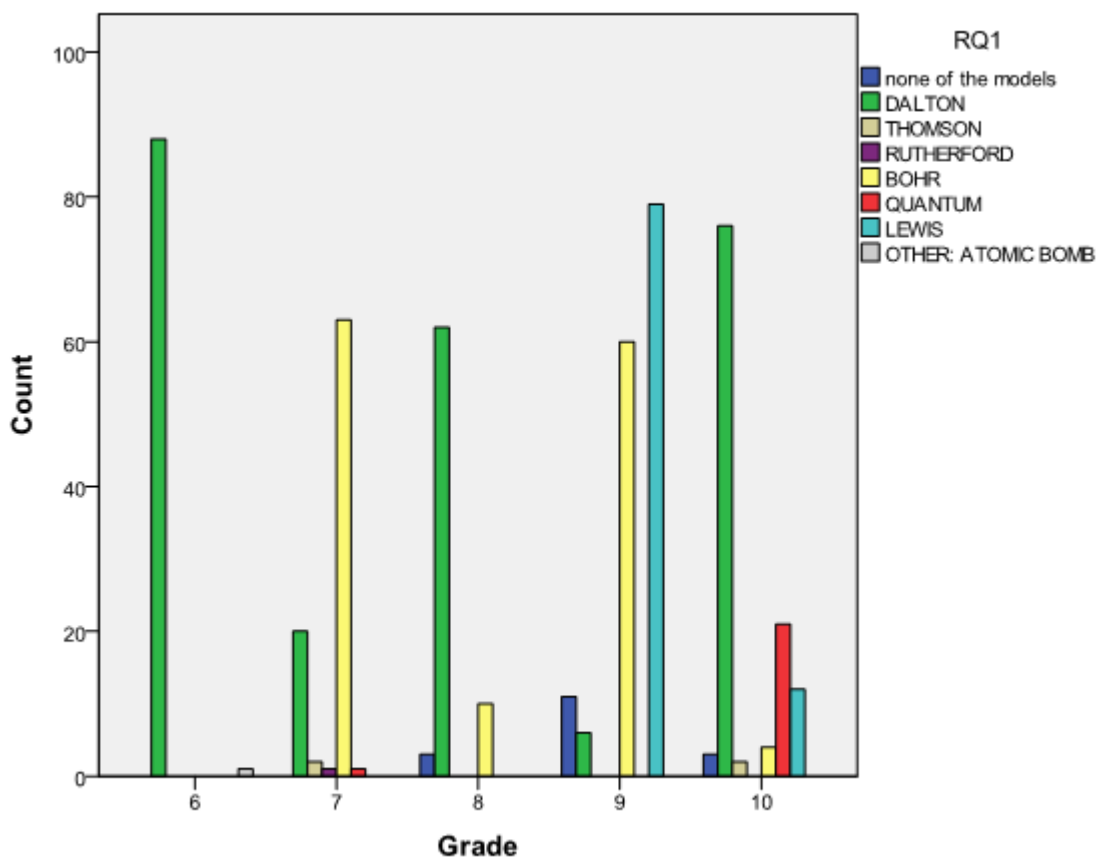


Figure 5.23. Distribution of representations of atomic models given in textbooks for each grade.

In addition, some examples of atom visuals in textbooks in each grade are given in Figure 5.24-5.25. In the 6th grade textbooks the 99% of the atom visuals were Dalton's atomic model and there was just one atomic bomb picture. Figure 5.24 shows the representation of Dalton's atomic model which was the most frequent in the 6th grade textbooks and the atomic bomb.

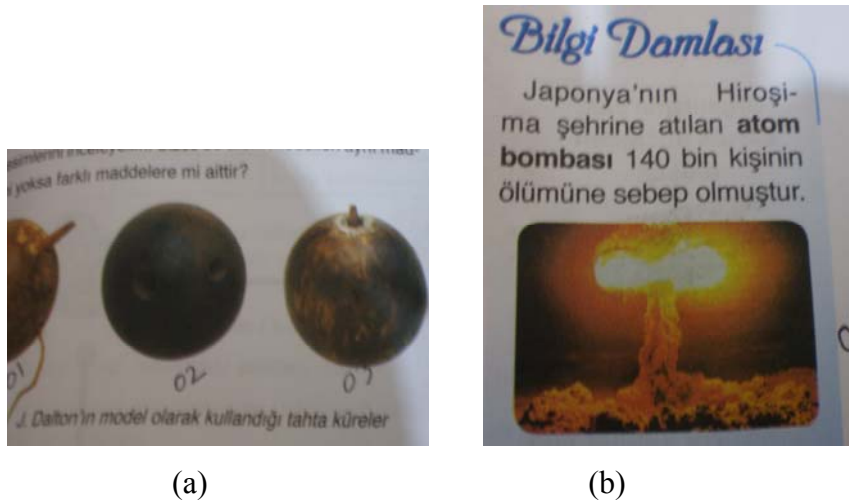


Figure 5.24. (a) Dalton's atomic model representation in 6th grade science and technology textbook (b) Atomic bomb representation in 6th grade science and technology textbook.

Figure 5.25 represents Dalton's atomic model, the Rutherford's atomic model and the Bohr's atomic model which was the most frequent in 7th grade textbook. In the 7th grade, 73% of visuals in textbooks represent the Bohr's atomic model and 23% of the visuals in textbooks represented the Dalton's atomic model. Rutherford's and Thomson's atomic models take only 1% 7th grade textbook. I observed that in the representation of Bohr's atomic model there were blue regions; but when the picture was small, students could not realize the region, they might realize them as a line instead of a region.

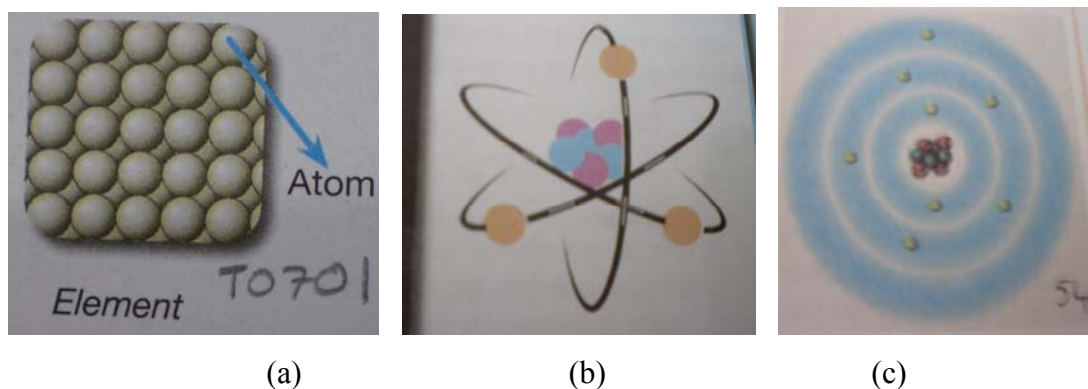


Figure 5.25. (a) Dalton's atomic model representation in 7th grade science and technology textbook. (b) Rutherford's atomic model representation in 7th grade science and technology textbook. (c) Bohr's atomic model representation in 7th grade science and technology textbook.

In the 8th grade science and technology textbook, 83% of the atom visuals were Dalton's atomic model and 13% of the atom visuals were the Bohr's atomic model. The most frequent representation of atom was the representation of Dalton's atomic model as seen in Figure 5.26.

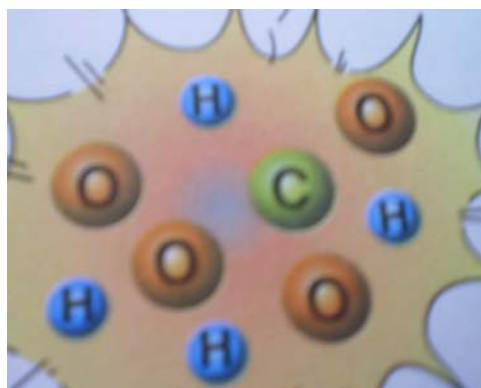


Figure 5.26. Dalton's atomic model representation in 8th grade science and technology textbook.

In the 9th grade chemistry textbook, there are largest numbers of representations were Bohr's atomic models similar to the 7th grade textbook. The 38% of the visuals in the 9th grade textbooks were the visuals of Bohr's atomic model and 51% of the atomic visuals were the Lewis dot structure. In addition, Figure 5.27 shows that the representation of Bohr's atomic model in the 9th grade is very similar to the one in the 7th grade science and technology textbook.

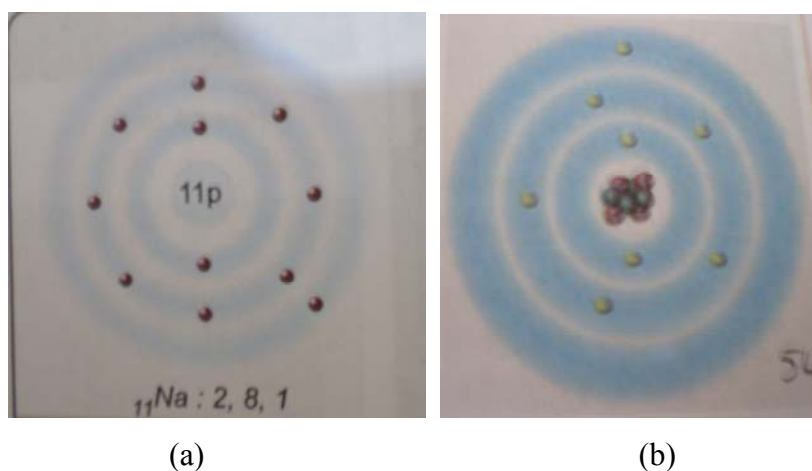


Figure 5.27. (a) Bohr's atomic model representation in 9th grade chemistry textbook. (b) Bohr's atomic model representation in 7th grade science and technology textbook.

Finally, Dalton's atomic model was seen the most frequent among the visual representations which are found in the 10th grade chemistry textbook. The 64% of the atomic structure in the 10th grade textbook were the Dalton's atomic model, 18% of the atom visuals in the 10th grade textbook the representation were Quantum atomic model and 10% of the atom visuals in the 10th grade textbook were Lewis dot structure. Some examples from these models are seen in Figure 5.28. in addition, the percentage distribution of atom models in textbooks for each grade is given in the Table 5.21.

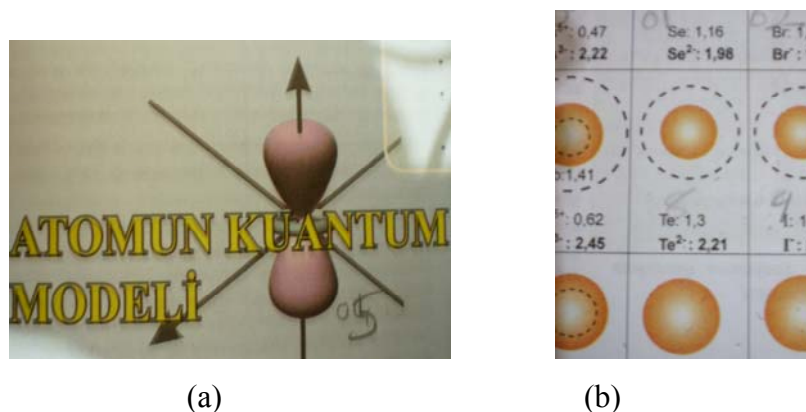


Figure 5.28. (a) Quantum atomic model representation in 10th grade chemistry textbook.
(b) Dalton's atomic model representation in 10th grade chemistry textbook.

Table 5.21. The percentage distribution of atomic models in textbooks for each grade level.

		RQ1								
		NONE OF THE MODEL	DALTON	THOM-SON	RUTHER-FORD	BOHR	QUAN-TUM	LEWIS	OTHER: ATOMIC BOMB	SYN-THETIC MODEL
Grade_ Visual Type	grade 6 textbook	0%	99%	0%	0%	0%	0%	0%	1%	0%
	grade 7 textbook	0%	23%	2%	1%	73%	1%	0%	0%	0%
	grade 8 textbook	4%	83%	0%	0%	13%	0%	0%	0%	0%
	grade 9 textbook	7%	4%	0%	0%	38%	0%	51%	0%	0%
	grade 10 textbook	3%	64%	2%	0%	3%	18%	10%	0%	0%

5.2.1. Subatomic species in the visual representation of textbooks

Proton charge was rarely shown in the textbook visuals. Only 0.7% of all visuals, just from the 7th grade, represented the proton charge as positive which was expected, the other visuals did not show the proton charge in the visuals. Table 5.22 shows that out of 525 atom visuals in the textbooks according to showing proton charge.

Table 5.22. Representations of charge of protons in the textbook visuals for each grade level.

		RQ2pCharge		Total
		not shown	positive	
Grade	6	89	0	89
	7	83	4	87
	8	75	0	75
	9	156	0	156
	10	118	0	118
Total		521	4	525

As shown in Table 5.23, while 73% of the atom visuals with the number of 381 visuals didn't show the location of protons, the 89% of the visuals showing proton located the proton in the nucleus or in the centre of atom. In the 6th grade textbook, the location of the proton was not indicated in the visuals. In the 7th grade textbook, proton's location was shown in the centre or inside the nucleus. In the 8th grade again the location of proton was not seen in any of the visuals. The 41% of the visuals in the 9th grade textbook included the location of proton in the centre or nucleus and 4% of them showed proton in the place where atomic number is written. Finally, in the 10th grade textbook, only 8% of the visuals indicated the proton's place which was the position of atomic number.

Table 5.23. Representations of location of protons in the textbook visuals for each grade level.

		RQ2pLocation			Total
		not shown	in the nucleus /centre	other: atomic number place	
Grade	6	89	0	0	89
	7	23	64	0	87
	8	75	0	0	75
	9	85	64	7	156
	10	109	0	9	118
Total		381	128	16	525

The representations of protons in the textbook visuals for each grade level are summarized in Table 5.24. The protons in total visuals of textbooks are represented with the symbol “p” in the textbooks in 91 visuals which was the 17% of the all textbook visuals, followed by solid circle with 33 visuals which was the 6% of all visuals in the textbooks. In the grade 7 textbook, 38% of visuals represented the proton as solid circle and 31% of visuals represented proton with symbol “p”. In the 9th grade textbooks, 41% of the visuals which was the highest percentage represented proton with the “p” symbol and 4% of visuals just wrote proton with proton numbers. In the 10th grade textbook, only 9 protons which were the 8% of 10th grade visuals were represented with the number of protons. In addition, 6th and 8th grade textbooks did not show the proton in the visuals of atom.

Table 5.24. Representations of protons in the textbook visuals for each grade level.

		RQ2pRepresentation					Total
		not shown	Symbol	With charge	solid circle	Number	
Grade	6	89	0	0	0	0	89
	7	23	27	4	33	0	87
	8	75	0	0	0	0	75
	9	85	64	0	0	7	156
	10	109	0	0	0	9	118
Total		381	91	4	33	16	525

As seen in Table 5.25, that only 7th grade textbooks visuals of atom showed neutrons in the nucleus or centre with 63 representations. in addition, as shown in Table 5.26, out of 63 representations of neutrons, 36 of them were represented as solid circle which is 61% of

the represented neutrons and 27 of them represented with the symbol “n” which is the rest 39% of the represented neutrons.

Table 5.25. Representations of location of neutrons in the textbook visuals for each grade level.

		RQ2nLocation		Total
		not shown	in the nucleus/centre	
Grade	6	89	0	89
	7	24	63	87
	8	75	0	75
	9	156	0	156
	10	118	0	118
Total		461	63	525

Table 5.26. Representations of neutrons in the textbook visuals for each grade level.

		RQ2nRepresentation			Total
		not shown	Symbol	solid circle	
Grade	6	89	0	0	89
	7	24	27	36	87
	8	75	0	0	75
	9	156	0	0	156
	10	118	0	0	118
Total		462	27	36	525

in Table 5.27, the analysis of whether the textbook visuals include the charge of electron charge or not is shown. It was observed that only 5 textbook visuals represented the charge of electron. Only 1% of the visuals in textbooks represented the charge of protons which were in the 7th grade textbook, 3, and only with 2 visuals in the 10th grade textbook.

Table 5.27. Representations of charge of electrons in the textbook visualizations for each grade level.

		RQ2eCharge		Total
		not shown	negative	
Grade	6	89	0	89
	7	84	3	87
	8	75	0	75
	9	156	0	156
	10	116	2	118
Total		520	5	525

As shown in Table 5.28, it was found that 6th grade textbooks did not show the electrons in their visuals of atom. in the 7th grade textbook, electrons were shown in the orbitals for the 75% of atom visuals; while 23% of visuals don't show the location of the electrons. In the 8th grade textbook, electrons were shown in the orbitals only in the 13% of visuals. The location of electrons is presented the most frequently in the 9th grade textbook, among the textbooks of other grades. The 55% of 9th grade visuals showed the electrons around the atom symbol such as Lewis and 41% of visuals represented the electrons in the orbital in the 9th grade textbook. in the 10th grade textbook, electrons were shown around the nucleus in 21 visuals which was the 18% of the 10th grade atom visuals, electrons were also shown around the atom symbol in 12 visuals which was the 10% of the 10th grade atom visuals and in the orbital in 3 visuals which was the 3% of the 10th grade atom visuals. Totally, 27% of the atom visuals represented electrons in the orbital, 19% of atom visuals represented electrons around the symbol of the atom, and 4% of atom visuals represented electrons around the nucleus.

Table 5.28. Representations of location of electrons in the textbook visuals for each grade level.

		RQ2eLocation					Total
		not shown	in the orbital	Other	around the atom Symbol	around the nucleus	
Grade	6	89	0	0	0	0	89
	7	20	65	2	0	0	87
	8	65	10	0	0	0	75
	9	6	64	0	86	0	156
	10	76	3	6	12	21	118
Total		256	142	8	98	21	525

As shown in Table 5.29, it was found that in the 228 visuals which were the 43% of, electrons were represented with solid circle or dot. The 28% of these visuals were found in the 7th grade textbook, 4% of them were found in the 8th grade textbook, 61% of them were seen in the 9th grade textbook, and 7% of them were observed in the 10th grade textbook. In addition, 2% of all visuals, all were found in the 9th grade textbook, represented electrons with numbers, and 5% of all visuals, all were found in the 10th grade textbook, represented electrons with electron clouds.

Table 5.29. Representations of electrons in the textbook visuals for each grade level.

		RQ2eRepresentation							Total
		Not shown	Symbol	with charge	Solid circle /dot	Numbers	Others	Probability in clouds	
Grade	6	89	0	0	0	0	0	0	89
	7	20	0	3	64	0	0	0	87
	8	65	0	0	10	0	0	0	75
	9	6	0	0	139	11	0	0	156
	10	73	2	0	15	0	1	27	118
Total		253	2	3	228	11	1	27	525

5.2.2. Ion charges in the visual representation of textbooks

Table 5.30, it is seen that totally, 49 visuals showed ion charge as ion which was the 89% of all visuals in textbooks and 6 visuals showed ion charge (1%) with symbol and two visuals showed ion charge (0.3%) with electron spectrum. The 15% of 8th grade visuals, 17% of the 9th grade visuals and 9% of 10th grade visuals represented the ion and the other grades' textbooks didn't show the in the atom visual representations.

Table 5.30. Representations of ion charges in the textbook visuals for each grade level.

		RQ3ion_charge				Total
		nothing extra	Symbol	Ion	e spectrum	
Grade	6	89	0	0	0	89
	7	85	2	0	0	87
	8	64	0	11	0	75
	9	125	4	27	0	156
	10	105	0	11	2	118
Total		468	6	49	2	525

5.2.3. Representations of orbitals in the visuals of textbooks

As shown in Table 5.31, different orbital shapes were represented in the different grades of textbooks. In the 6th grade textbook, orbitals were not shown in the visuals of atom. in the 7th grade textbooks, 55 visuals (63%) were represented in the clouds or electron regions and 7 visuals (8%) were represented as solid circles. in the 8th grade textbooks, 10 visuals (13%) were represented as solid circles. in the 9th grade textbooks, 38 visuals (24%) were represented as solid circles, 22 visuals (14%) were represented as electron clouds or regions. in the 10th grade textbook, 33 visuals of atom (28%) were represented by s, p, d orbitals.

Table 5.31. Representations of shape of orbital in the textbook visuals for each grade level.

		RQ4OrbitalShape							Total
		Orbitals don't Exist	Solid circles	Dash lines	Clouds/region	half lines	Elliptical in different orientations	S,p,d orbitals	
Grade	6	89	0	0	0	0	0	0	89
	7	22	7	2	55	0	1	0	87
	8	65	10	0	0	0	0	0	75
	9	92	38	0	22	4	0	0	156
	10	82	0	1	2	0	0	33	118
Total		350	55	3	79	4	1	33	525

In Table 5.32, it was summarized whether the number of orbitals was shown in the textbook visuals or not. While in the 6th grade textbook, number of orbitals was not shown in any visuals of atom, in the 7th grade textbook 61 visuals (70% of 7th grade visuals); in the 8th grade textbook, 10 visuals (13% of 8th grade visuals); in the 9th grade textbook, 71 visuals (46% of 9th grade visuals); and in the 10th grade textbook, 36 visuals (31% of 10th grade visuals) represented the number of orbital.

Table 5.32. Representations of the number of orbitals in the textbook visuals for each grade level.

		RQ4OrbitalNumber		Total
		not shown	Shown	
Grade	6	89	0	89
	7	26	61	87
	8	65	10	75
	9	85	71	156
	10	82	36	118
Total		347	178	525

5.2.4. Representation of nucleus in the visuals of textbooks

The representation of the charge of nucleus as positive or negative was summarized in Table 5.33. In the 7th grade textbook 4 visuals; in the 8 grade textbook, 3 visuals; and in the 10th grade textbook, 15 visuals showed the charge of nucleus as negative. In addition, only 3 visuals in the 8th grade textbook and 2 visuals in the 10th grade textbook showed that the nucleus had negative charges in the visuals. Totally, 95% of all visuals in textbooks didn't show the nucleus charge. In addition, 81% of the visuals which are showing nucleus charge represented correctly as positive charge.

Table 5.33. Representations of charge of nucleus in the textbook visuals for each grade level.

		RQ5NucleusCharge			Total
		Not shown	Positive	Negative	
Grade	6	89	0	0	89
	7	83	4	0	87
	8	69	3	3	75
	9	156	0	0	156
	10	101	15	2	118
Total		498	22	5	525

As shown in Table 5.34, in the 7th grade textbook 39 visuals (45% of the visuals in the 7th grade textbooks) represented nucleus as solid circle and in the 26 visuals (30% of visuals in the 7th grade textbooks), nucleus didn't have any definite shape. In the 8th grade textbook, 10 visuals (13% of the visuals in the 8th grade textbooks) represented nucleus as solid circle. in the 9th grade textbook, again 64 visuals (41% of the visuals in the 9th grade textbooks) represented nucleus as solid circle and 86 visuals (55% of the visuals in the 9th

grade textbook) represented nucleus by the symbol of the element. in the 10th grade textbook, nucleus was represented both by solid circle in 21 visuals (18% of the visuals in the 10th grade textbooks) and it was represented by the symbol of element in 12 visuals (10% of the visuals in the 10th grade textbook), in addition, it was not shown by a particular shape in 21 of the visuals (18% of the visuals in the 10th grade textbook). Totally, in the 47% of the all textbook visuals nucleus were not defined. In addition 26% of the textbook visuals represented the nucleus as solid circle, 9% of the textbook visuals represented the nucleus without any definite shape and 18% of the textbook visuals represented nucleus with the symbol of element.

Table 5.34. Representations of the shape of nucleus in the textbook visuals for each grade level.

		RQ5NucleusShape				Total
		no defined nucleus	solid circle	other: no definite shape	element symbol	
Grade	6	89	0	0	0	89
	7	22	39	26	0	87
	8	65	10	0	0	75
	9	6	64	0	86	156
	10	64	21	21	12	118
Total		246	134	47	98	525

Representations of species included in nucleus in the textbook visuals for each grade level are seen in Table 5.35. In the 6th grade visuals, nothing was seen inside of the nucleus. In the 7th grade textbook, 63 visuals (73% of the visual representations in the 7th grade textbook) included both the symbol of proton as “p” and neutron as “n”. In the 8th grade textbook, the symbol of element took place in the nucleus in 11 visuals (15% of the visual representations in the 8th grade textbook). In the 9th grade textbook, 71 visuals (46% of the visual representations in the 9th grade textbook) showed only “p” in the nucleus and 79 visuals (51% of the visual representations in the 9th grade textbook) included the symbol of element in the nucleus. Finally, in the 10th grade textbook, symbol of “+” took place in the atom visuals, six of the visuals (5% of the visual representations in the 10th grade textbook) showed the radius of atom inside of the atom, 33 visuals (28% of the visual representations in the 7th grade textbook) showed the radius of ions in nucleus, and 15 visuals (13% of the visual representations in the 10th grade textbook) showed the symbol of element in the nucleus.

Table 5.35. Representations of subatomic species included in nucleus in the textbook visuals for each grade level.

		RQ5 Species included n nucleus								Total
		nothing	P	E	+	p n	others: radius of atom	Symbol of element,	radius of Ion	
Grade	6	89	0	0	0	0	0	0	0	89
	7	23	0	0	1	63	0	0	0	87
	8	64	0	0	0	0	0	11	0	75
	9	6	71	0	0	0	0	79	0	156
	10	56	0	1	7	0	6	15	33	118
Total		238	71	1	8	63	6	105	33	525

5.2.5. Motion of atomic species in the visual representation of textbooks

As shown in Table 5.36, in 6th grade textbook, motion was not represented in the visuals. In the 7th grade textbook, there were 3 motion included in visuals; one of them showed visuals with symbols or arrows. In the 8th grade textbook, 31 visuals included motion and 20 of them showed motion with arrows or symbols. In other words, the arrows help to include motion in the 2 Dimensional visuals. In the 9th grade textbook, only four visuals included motion with arrows. Finally, in the 10th grade textbook visuals, 16 of them included motion. Half of the visuals showed motion with arrows or symbols and 7 visuals included wording about motion. Some examples from the representation of motion were shown in Figure 5.29 and 5.30. In the Figure 5.28, the motion is created by adding frames to the previous frame. The location of electrons are different in the each frame, it shows the motion. Finally, only 10% of the textbook visuals are including motion. The percentage distribution for the representations of motion in the textbook visualizations for each grade is given in the Table 5.34a. In addition, in the Figure 5.29, the positive ions are moving towards outside of the class because of the negative ions are in the outside. The negative ions such as oxygen are playing in the inside of the class. Helium is their teacher and angry to positive ions. Helium is telling that “why positive ions want to go outside rather than playing with their friends inside of class like the negative ions”. This picture also shows that ions are not stable; they are dynamic including motion.

Table 5.36. Representations of motion of atomic species in the textbook visuals for each grade level.

		RQ6Motion				Total
		not shown	With symbols, arrows	With words	Other	
Grade	6	89	0	0	0	89
	7	84	1	0	2	87
	8	44	20	0	11	75
	9	152	4	0	0	156
	10	102	8	7	1	118
Total		471	33	7	14	525

Table 5.37. The percentage distribution of the representations of motion of subatomic species in the textbook visuals for each grade level.

		RQ6Motion			
		Not shown	With symbols, arrows	With words	Other
Grade	6	100%	0%	0%	0%
	7	97%	1%	0%	2%
	8	59%	27%	0%	14%
	9	97%	3%	0%	0%
	10	86%	7%	6%	1%
Total		90%	6%	1%	3%

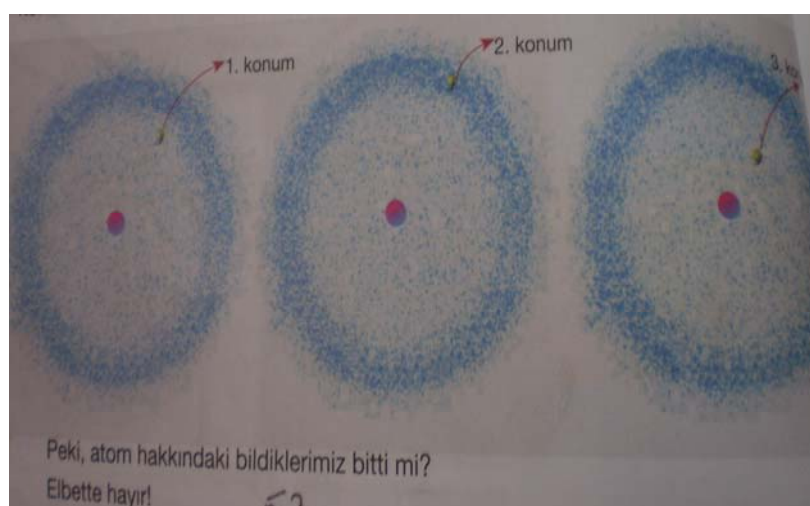


Figure 5.29 7th grade visual including motion.

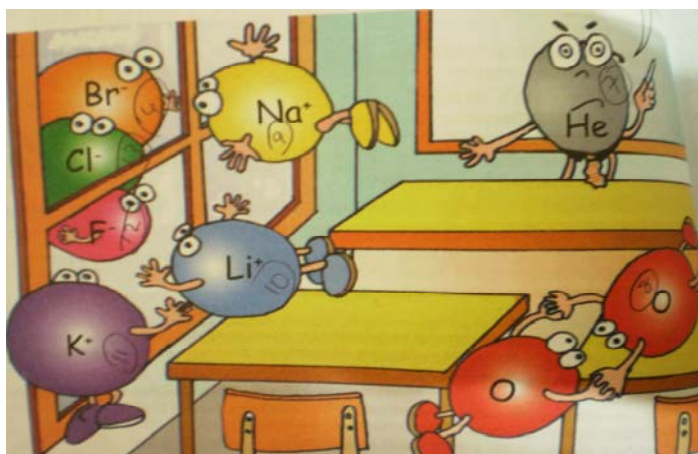


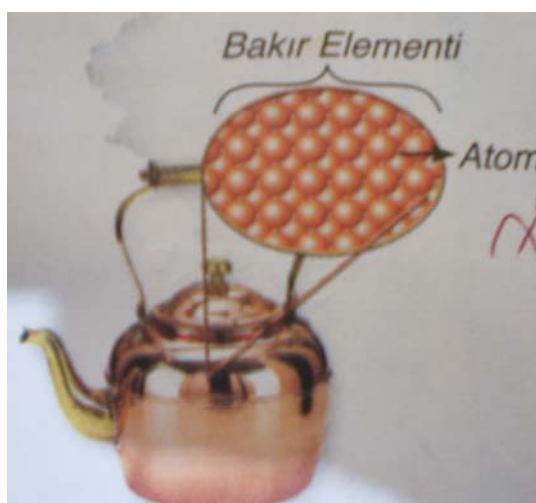
Figure 5.30 8th grade visual including motion.

5.2.6. Explanations in the visuals representation of textbooks

As shown in Table 5.38, 58 visuals (11% of all visuals) from textbooks did not include explanations which were parallel with the drawings. Specifically, 21 visuals of 6th grade textbook (24% of the 6th grade visuals), 20 visuals of 7th grade textbook (23% of the 7th grade visuals), 7 visuals of 8th grade textbook (9% of the 8th grade visuals), and 10 visuals of 10th grade textbook (8% of the 10th grade visuals) didn't include explanations. In addition, 367 visuals which are the 70% of the all visuals in textbooks were consistent with their drawings. The 92% of the 9th grade textbook visuals' and 82% of the 10th grade textbook visuals were consistent with their explanations. There was also extra information in the explanations part of the 7% of the textbook visuals. Totally, 4% of visuals' explanations with the number of 19 in the whole textbooks included motion. Motion was included in the 8 visual explanations for 8th grade and in the same number of visual explanations for 10th grade textbooks and there were also three explanations for the visuals of atom including motion in the 7th grade science and technology textbook. In the explanations of the atom visuals, totally 8% of the explanations with the number of 18 visuals from 6th and 8th grade and 5 visuals from 7th grade were including explanations with daily life connections. In addition one example about the daily life connected visuals was shown in Figure 5.31.

Table 5.38. Representations of explanations in the textbooks for each grade level.

								Total
		No explanation	Consistent with drawing	Extra info	Motion is included	Daily life usage	Other: spaces between atomic particles	
Grade	6	21	50	0	0	18	0	89
	7	20	25	19	3	18	2	87
	8	7	52	3	8	5	0	75
	9	0	143	13	0	0	0	156
	10	10	97	3	8	0	0	118
Total		58	367	38	19	41	2	525

Figure 5.31. Daily life connected visual in 8th grade textbook.

5.3. Comparison of students' representations of an atom and textbooks' visuals of an atom

Research Question 3: What are the similarities between the textbook visualizations of atomic model and students' mental models of atom?

As it is mentioned in the methodology section, in the last part of the study, students' mental models of atom and textbook visuals of atom were compared and the similarities were investigated for each grade level. The "Evaluation Rubric for Atomic Model

Representations” (Appendix B) was used to evaluate both students’ mental models represented by drawings and explanations and visualizations in the textbooks.

5.3.1. Consistency of students’ representation of a Sodium atom and textbooks’ visuals for a Sodium atom

The chi-square analysis was done to see whether the observed proportions for a categorical variable differ from hypothesized proportions. In this research, we wanted to test whether students’ mental models in our sample differed significantly from the textbook visuals in each grade from 6th to 10th. In the “Test of Mental Models of Atom” (Appendix A), there were four open-ended questions. The first two questions were related with the atomic structure of Sodium and last two questions were related with the atomic structure of Neon. To compare the consistency between the textbook visuals and students’ drawings for both Sodium and Neon, all Sodium and Neon visuals in textbooks were counted. In the 6th grade textbook, there were not any representations of atomic models of Sodium and Neon atoms. In the 7th grade textbook, there were eight visual representations of Sodium given as Bohr’s atomic model, 2 visuals of Sodium atom shown as Dalton’s atomic models and 1 visual representation of Neon as Bohr’s atomic model. In the 8th grade textbook, there were two visualizations of Sodium atom given as Dalton’s and Bohr’s atomic models, and one visualization of Neon atom represented as Bohr’s atomic model. In the 9th grade textbook, three representations of Bohr’s atomic model and one representation of Lewis model were recognized for Sodium atom, and three visual representations of Sodium atom were not categorized as any of the models in the 9th grade textbooks because they are just including symbol of Sodium with one electron so not can be categorized as Lewis and the other one is including half orbitals and electron are shown by numbers so it is not categorized for the any determined categorized models. In the textbook of the same grade level, there were two representations of Bohr’s atomic model and one representation of Lewis atomic model for Neon atom. In the 10th grade textbook, there were two visual representations of Sodium atom given as Dalton’s atomic models and one visualization of Neon atom is shown as Lewis model for the Neon visual in the textbook. The numbers of visual representations of Sodium and Neon atoms in the textbooks for each grade level are given in Table 5.39.

Table 5.39. Number of representations of sodium and neon atoms in the textbooks for each grade level.

		Textbook visuals		Total	
		Sodium	Neon		
Grade	6	0	0	0	
	7	8 Bohr	1 Bohr	11	
		2 Dalton			
	8	1 Bohr	1 Bohr	3	
		1 Dalton			
	9	3 Bohr	2 Bohr	10	
		1 Lewis			1 Lewis
		3 None			
	10	1 Dalton	1 Lewis	2	
	Total		20	6	26

After counting all the visual representations of Sodium and Neon atoms in the textbooks, they were categorized as consistent or inconsistent with students' drawings both for Sodium and Neon atoms in each grade level. These consistencies were determined by the help of university professors in the secondary school science and mathematics department. Firstly, the consistency of students' Sodium atom drawings with textbooks from each grade is given in the Table 5.40 according to grades. In the 6th grade textbook, there were no visual representations of Sodium but 88 atom visuals out of 89 visuals were Dalton's atomic models in the 6th grade textbook which is described in the Table 5.19. Therefore in the 6th grade if the students' drawings were Dalton's atomic models, they were coded as consistent with the textbook. In the 6th grade, 26 students' sodium drawings were not consistent with the textbook visuals only four students' drawings were consistent with 6th grade textbooks. In addition, there were one atomic bomb model and 17 students drew the atomic bomb model in their drawings in the "Test of Mental Models of Atom" (Appendix A). in the 7th grade, while 25 students' drawings were consistent with the textbooks' visuals, 5 visual representations for Sodium atom, drawn by students were not similar to the 7th grade textbook visuals because one student drew the atomic bomb model, one student drew the Rutherford's atomic model and three students drew the synthetic model among 7th grade students. In the 8th grade, there was a very similar pattern for the consistency of textbook visuals and students' drawing for sodium atom. Only four students' drawings are not consistent with the textbooks visuals which take place in the 8th grade textbook. In the 9th grade, except one drawing of a student, all students' drawings

were consistent with the visual representations found in 9th grade textbooks. As seen in Table 5.34 only 1 of the student drawings was found to be consistent with the visuals of atom in the 10th grade textbook. This situation was explained in the discussion section. in the 11th grade, there was no chapter including a visualization of atom, so for the evaluation of consistency, drawings of 11th grade students' were compared with the visual representations given in 9th and 10th grade textbooks. Then, 19 drawings of students were found to be consistent with the 9th and 10th grade chemistry textbook visuals. Totally, as 76 Sodium drawings of students which are 42% of all students' drawings, were inconsistent with the visualizations given in textbooks, 104 drawings of students which are 58% of all students' drawings, were consistent with the visuals found in the textbooks. It is also shown as the bar graph in Figure 5.32.

Table 5.40. Consistency between textbook visuals of sodium atom and students' mental models of sodium atom.

		Grade						Total
		6	7	8	9	10	11	
textbook_Na	not consistent with textbook visual	28	4	4	1	29	11	77
	consistent with textbook visual	2	26	26	29	1	19	103
Total		30	30	30	30	30	30	180

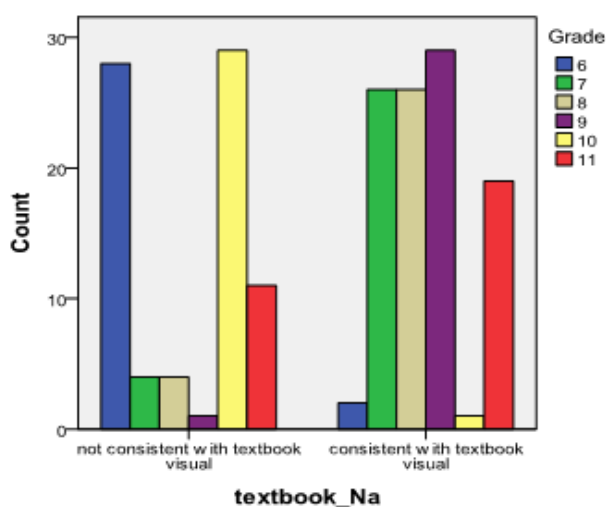


Figure 5.32. Consistency between textbook visuals of sodium atom and students' mental models of sodium atom.

Statistical analysis was used to compare the textbook visuals and students' sodium atom drawings. Chi-Square tests were applied to see if there was a relationship between the textbook visuals and students' drawings for the Sodium atom with respect to atom models, subatomic particles, nucleus, and orbitals. As shown in Table 5.41, the results indicated that there was a statistically significant difference between the students' drawings of Sodium atom and the visual representations of Sodium atom found in the textbooks (chi-square with five degree of freedom is 103.209, $p=0.000$).

Table 5.41. Chi-Square analysis between textbook visuals for sodium atom and students' mental models for sodium atom.

	Value	Df	Asymp. Sig. (2-sided)
Pearson Chi-Square	107.691 ^a	5	0.000
Likelihood Ratio	126.981	5	0.000
Linear-by-Linear Association	0.327	1	0.567
N of Valid Cases	180		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 12.83.

5.3.2. Consistency between students' representation of a Neon atom and textbooks' visuals of a Neon atom

Students' Neon drawings and textbooks' Neon visuals were compared. As shown in Table 5.42, in the 6th grade, only four students' drawings were consistent with the visuals given in the 6th grade textbooks and the other 26 students' drawings were inconsistent with the textbook visuals. In the 6th grade there were no visual representation of Neon, yet in the Table 5.20 it is clearly shown that 88 atom visuals out of 89 atom visuals are Dalton's atomic models in the 6th grade textbooks. Therefore, in the 6th grade if the students' drawings were Dalton's atomic models, they were coded as consistent with the textbook. Surprisingly, there were one atomic bomb picture in the 6th grade textbooks but half of the students drew an atomic bomb in their drawings for the "Test of Mental Models of Atom Test" (APPENDIX A). In the 7th grade, while 20 students' drawings were consistent with the visuals in textbooks, representations drawn by 10 students for the Neon atom were not similar to the ones given in the 7th grade textbook because they drew the different atom models than Dalton. In the 8th grade, there was a similar pattern for the consistency of

textbook visuals and students' drawing for Neon atom. Drawings of only 6 students were not consistent with the textbooks visuals which found in the 8th grade textbook. In the 9th grade, except one student, drawings of all students were consistent with the visual representations given in the 9th grade textbook. In the Table 5.39, it is seen that drawings of three students were consistent with the visual representations of atom given in the 10th grade textbook. in the 11th grade, none of the chapters included visuals of atom, so the drawings of 11th grade students were compared with the visuals in the 9th and 10th grade textbooks; and 20 drawings of students were found to be consistent with the visuals in the 9th and 10th grade textbooks. Totally, it was found that drawings of 80 students were considered as inconsistent, and drawings of 100 students were found to be consistent with the visuals in the textbooks. It is also shown as the bar graph in Figure 5.33.

Table 5.42. Consistency between textbook visuals of neon atom and students' mental models of neon atom.

		Grade						Total
		6	7	8	9	10	11	
	not consistent with textbook visual	28	10	6	1	27	13	85
	consistent with textbook visual	2	20	24	29	3	17	95
Total		30	30	30	30	30	30	180

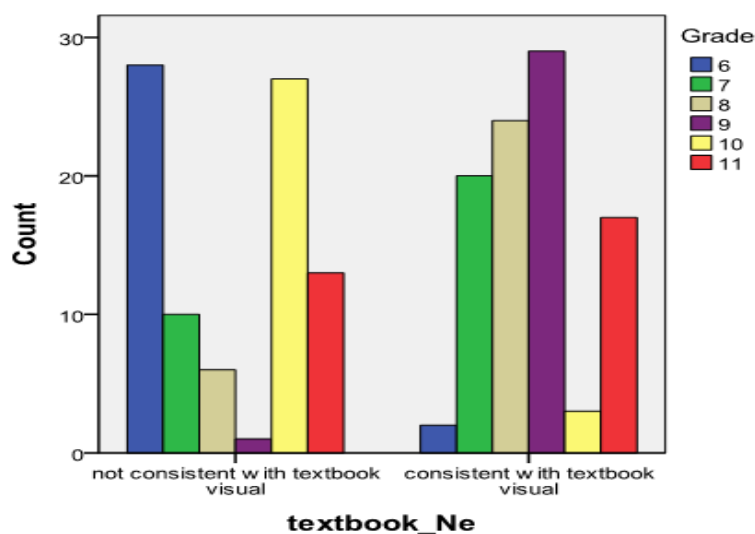


Figure 5.33. Consistency between textbook visuals of neon atom and student mental models of neon atom.

Statistical analysis was again used to compare the textbook Neon visuals with the students' Neon atom drawings. Chi-Square tests were applied to see if there was a relationship between the textbook visuals and students' drawings for the Neon atom. As shown in Table 5.43, the results indicated that there was a statistically significant difference between the drawings of students for the Neon atom and the visual representations of Neon atom in the textbooks (chi-square with five degree of freedom is 77.670, $p= 0.000$).

Table 5.43. Chi-Square analysis between textbook visuals of neon atom and students' mental models of neon atom

	Value	Df	Asymp. Sig. (2-sided)
Pearson Chi-Square	82.232 ^a	5	0.000
Likelihood Ratio	96.739	5	0.000
Linear-by-Linear Association	1.598	1	0.206
N of Valid Cases	180		
a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 14.7			

Statistical analysis of Chi-square was conducted to evaluate the consistency between textbook visuals and drawings of students, for each grade level.

5.3.3. Comparison of students' mental models of atomic structure with the visual representations of textbooks in the 6th grade

As shown in Table 5.44, while the representations of Dalton's atomic models were seen the most frequently in the 6th grade textbooks with the 99%, atomic bomb model representation was seen the most often as 50% of 6th grade students even though there was only 1 visual representation of atomic bomb in the 6th grade textbook. In addition, even though there were not any representations of Rutherford's atomic models in the 6th grade textbook, 7% of students drew the Rutherford's atomic model in their drawings. Finally, 29% of 6th grade students created their own model by integrating the different kinds of atom models. The bar graph of this comparison between 6th grade textbook and 6th grade students' mental model drawings are given in the Figure 5.34.

Table 5.44. Comparison of 6th grade students' mental models of sodium atom with the visual representation of sodium atom in 6th grade textbook.

		RQ1					
		NONE OF THE MODELS	DALTON	RUTHERFORD	BOHR	OTHER: ATOMIC BOMB	SYNTHETIC MODEL
Grade_VisualType	grade 6 textbook	0%	99%	0%	0%	1%	0%
	grade 6 student	7%	7%	7%	0%	50%	29%

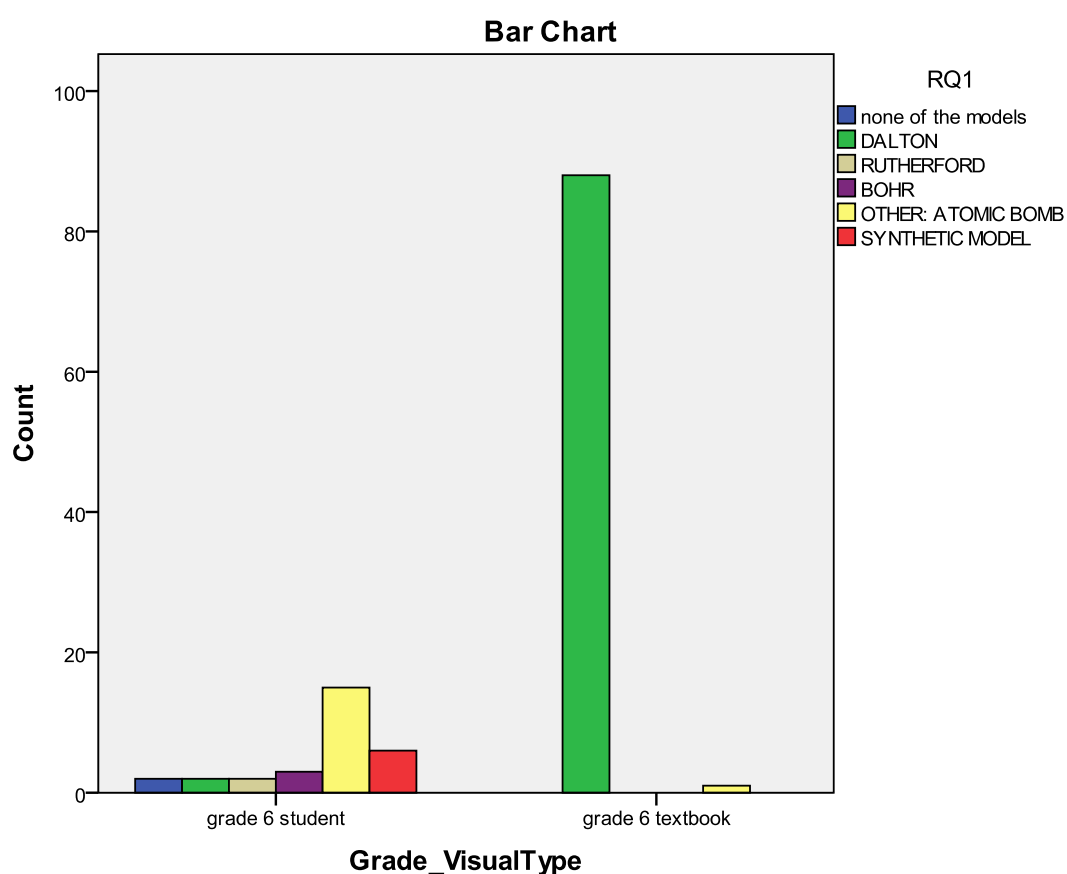


Figure 5.34. Comparison of 6th grade students' mental models of sodium atom with the visual representation of sodium atom in 6th grade textbook.

5.3.4. Comparison of students' mental models of atomic structure with the visual representations of textbooks in the 7th grade

When this study implemented to the 7th grade students, they haven't covered the atom chapter "The structure and Properties of Matter" in the 7th grade textbook so their mental models were compared with the visuals in the 6th grade textbook. As shown in

Table 5.45, 84% of the 7th grade students represented Dalton's atomic model in their drawings. The 99% of visuals in the 6th grade textbook were also Dalton's atomic model. Therefore, 7th grade students' mental models were found to be parallel with the visuals in the 6th grade textbook. In the 7th grade, 3% of students also draw the atomic bomb model which was represented in the 6th grade textbook. More surprisingly, 10% of 7th grade students drew their own model by integrating different models. Figure 5.35 represents the percentage distribution of 7th grade students' mental models of atomic representations and textbook representations of 6th grade which were seen for the 7th grade students.

Table 5.45. Comparison of 7th grade students' mental models of sodium atom with the visual representation of sodium atom in 6th grade textbook.

		DALTON	RUTHERFORD	OTHER: ATOMIC BOMB	SYNTHETIC MODEL
Grade_VisualType	grade 6 textbook	99%	0%	1%	0%
	Grade 7 student	84%	3%	3%	10%

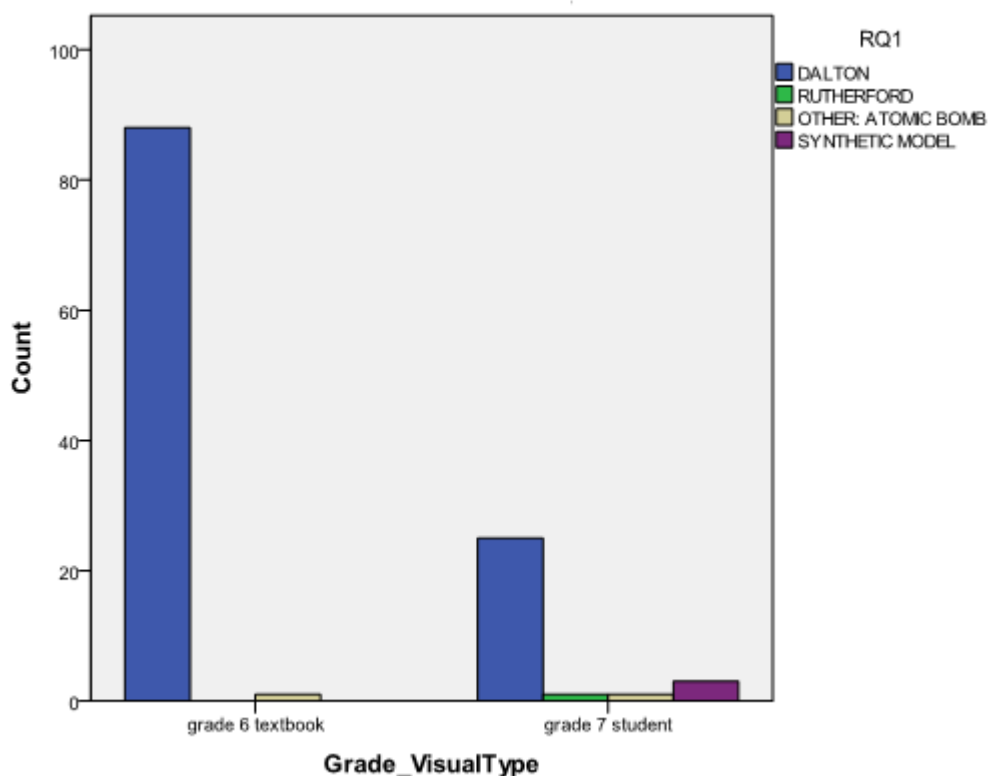


Figure 5.35. Comparison of 7th grade students' mental models of sodium atom with the visual representation of sodium atom in 6th grade textbook.

5.3.5. Comparison of students' mental models of atomic structure with the visual representations of textbooks in the 8th grade

Table 5.46 shows the comparison of the drawings of 8th grade students in the “Test of Mental Models of Atom” (Appendix B) with the 6th and 7th grade textbook visuals because the 8th grade students were only encountered with the 6th and 7th grade textbooks. First, “Test of Mental Models of Atom” was administered to 8th grades students before learning Chapter 3 “The structure and Properties of Matter” which includes the visual representations of atom. The 87% of the 8th grade students drew atom similar to Bohr’s atomic model which was the most frequently seen in the 7th grade textbook with 73% of visuals. Moreover, 14% of the students in the 8th grade created their own models which are the integration of different atom models and not similar to any other atom models. In addition, 3% of students from 8th grade also drew the representation of Dalton’s atomic model which was seen the most frequently in the 6th grade as 99% of visuals. Figure 5.36 represents the percentage distribution of 8th grade students’ mental model atomic representations and textbook representations for 6th and 7th grade.

Table 5.46. Comparison of 8th grade students’ mental models of sodium atom with the visual representation of sodium atom in 6th and 7th grade textbooks.

		DALTON	THOM- SON	RUTHER- FORD	BOHR	QUAN- TUM	OTHER: ATOMIC BOMB	SYNTHETIC MODEL
Grade_Visual Type	grade 6 textbook	99%	0%	0%	0%	0%	1%	0%
	grade 7 textbook	23%	2%	1%	73%	1%	0%	0%
	grade 8 student	3%	0%	0%	83%	0%	0%	14%

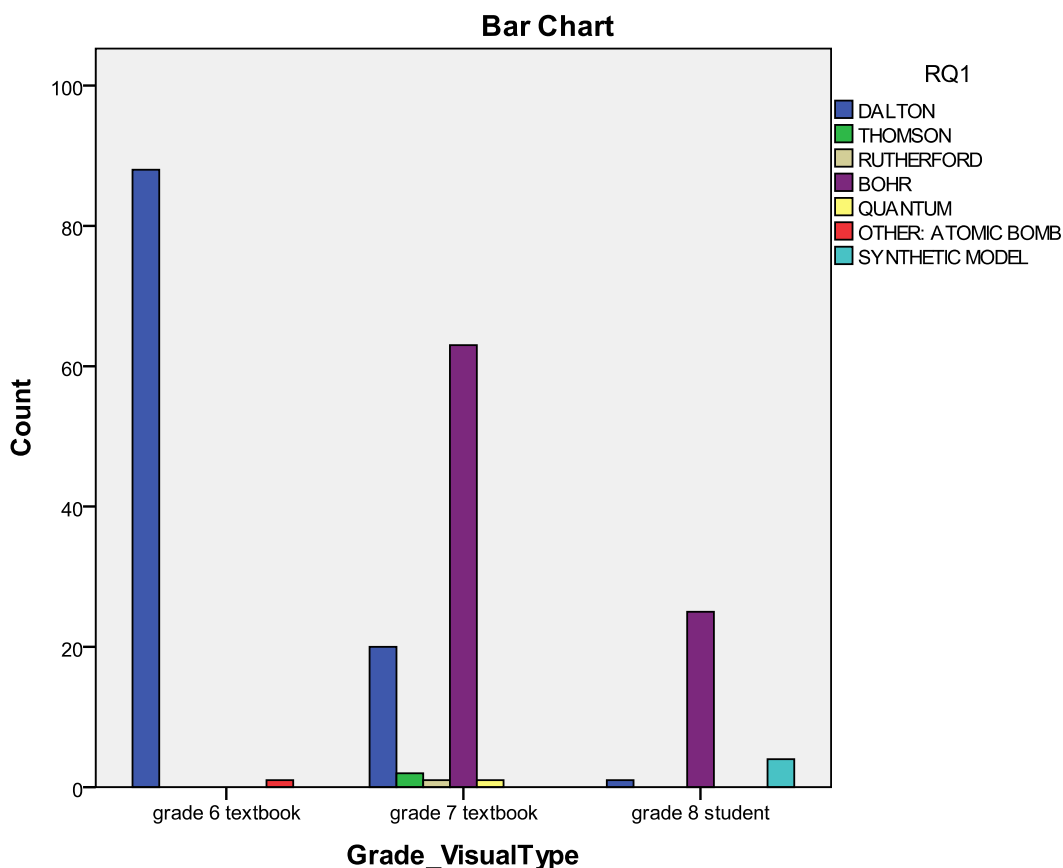


Figure 5.36. Comparison of 8th grade students' mental models of sodium atom with the visual representation of sodium atom in 6th and 7th grade textbooks.

5.3.6. Comparison of students' mental models of atomic structure with the visual representations of textbooks in the 9th grade

Table 5.47 shows the comparison of 9th grade students' mental models of atom shown by drawings and the visuals of atom which were found in the textbooks from the 6th grade to 9th grade. The 97% of the 9th grade students drew the representation of Bohr's atomic model in their atom drawings. Bohr's representation of atom also took large place in the 9th grade textbooks with 69 visuals which is the 38% of the 9th grade atom visuals. In addition, only 3% of the 9th grade student drew their own atomic model representations which were called synthetic model in this study. Moreover, even though the 83% of the 8th grade visual representations, 99% of 6th grade visual representations and 4% of the 9th grade visual representations in textbooks were found to be Dalton's atomic models, none of the 9th grade students drew the Dalton's atomic model in their atom drawings. Figure

5.37 also represents the percentage comparison of 9th grade mental model drawings of atom with the textbooks which the students had until 9th grade.

Table 5.47. Percentage comparison of 9th grade students' mental models of sodium atom with the visual representation of sodium atom in 9th grade textbook.

		RQ1								
		NONE OF THE MODELS	DALTON	THOMSON	RUTHERFORD	BOHR	QUANTUM	LEWIS	OTHER ATOMIC BOMB	SYNTHETIC MODEL
Grade_Visual Type	grade 6 textbook	0%	99%	0%	0%	0%	0%	0%	1%	0%
	grade 7 textbook	0%	23%	2%	1%	73%	1%	0%	0%	0%
	grade 8 textbook	4%	83%	0%	0%	13%	0%	0%	0%	0%
	grade 9 textbook	7%	4%	0%	0%	38%	0%	51%	0%	0%
	grade 9 student	0%	0%	0%	0%	97%	0%	0%	0%	3%

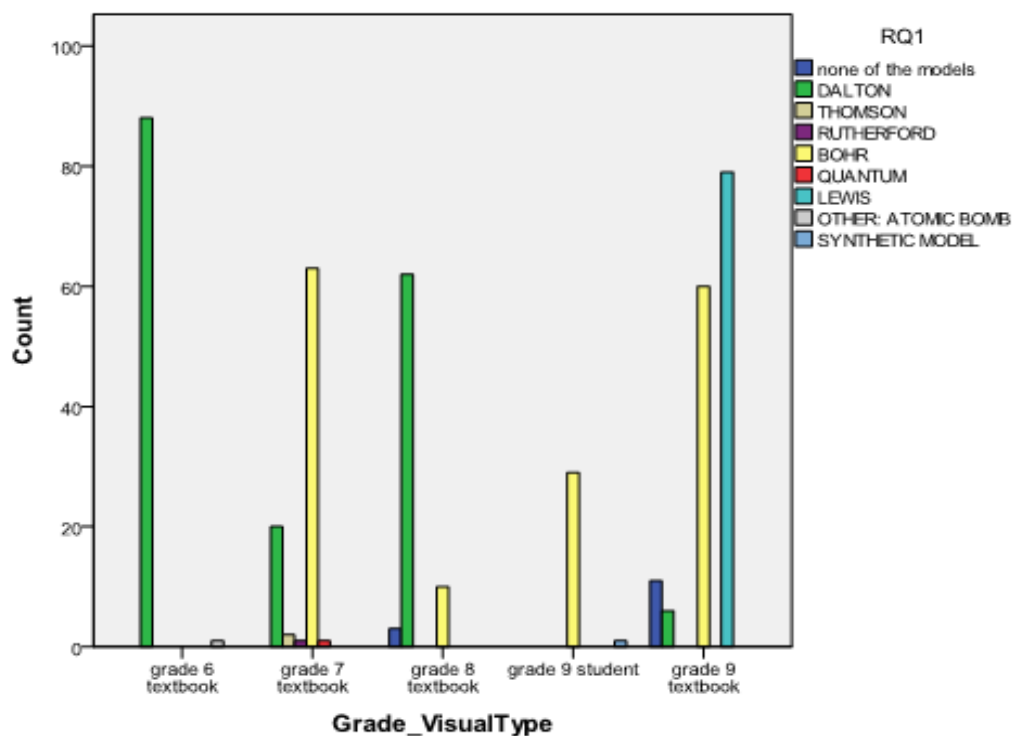


Figure 5.37. Comparison of 9th grade students' mental models of sodium atom with the visual representation of sodium atom in 9th grade textbook.

5.3.7. Comparison of students' mental models of atomic structure with the visual representations of textbooks in the 10th grade

It is clearly seen in the Table 5.48, while only 3% of the atom visuals are Bohr's atomic model in the 10th grade textbook, 77% of the 10th grade students drew the Bohr's atomic Model in their TMMA (APPENDIX A). Synthetic models were seen second highest percentage among the 10th grade students. The 10% of the 10th grade students preferred to represent their mental models by integrating different models. In addition, none of the students from 10th grade drew the Dalton's atomic model which has the highest percentage, 64%, in the 10th grade textbook. The Quantum atomic model visuals take place 18% of the 10th grade atom visuals in the textbook, but just only 3% of student drew Quantum atomic model in their mental model drawings.

Even though there was no representation of Rutherford's atomic model in the 10th grade textbooks, 7% of 10th grade students drew the visualization of Rutherford's atomic model in their drawings. The Rutherford's atomic models were seen only in the 7th grade textbooks just with 1 visual representation. Finally, 3% of 10th grade students drew the Thomson's atomic model which was the 2% of the atom visuals in the 10th grade textbooks. The percentage comparisons of 10th grade mental models of atom drawings with the visuals in the textbooks are given in the Figure 5.38.

5.3.8. Comparison of students' mental models with the visual representations of textbooks in the 11th grade

The chapters including the visuals about the atom or atom models were finally completed in the 10th grade. As shown in Table 5.49, it was found that 11th grade textbooks didn't include any visuals of atom. However, when the 11th grade students' mental models of atom were evaluated, 60% of the 11th grade students drew the representation of Bohr's atomic model because Bohr's atomic model was seen frequently in textbooks.

Table 5.48. Comparison of 10th grade students' mental models of sodium atom with the visual representation of sodium atom in 10th grade textbook.

		RQ1								
		NONE OF THE MODEL	DALTON	THOMSON	RUTHERFORD	BOHR	QUANTUM	LEWIS	OTHER ATOMIC BOMB	SYNTHETIC MODEL
Grade_Visual Type	grade 6 textbook	0%	99%	0%	0%	0%	0%	0%	1%	0%
	grade 7 textbook	0%	23%	2%	1%	73%	1%	0%	0%	0%
	grade 8 textbook	4%	83%	0%	0%	13%	0%	0%	0%	0%
	grade 9 textbook	7%	4%	0%	0%	38%	0%	51%	0%	0%
	grade 10 textbook	3%	64%	2%	0%	3%	18%	10%	0%	0%
	grade 10 student	0%	0%	3%	7%	77%	3%	0%	0%	10%

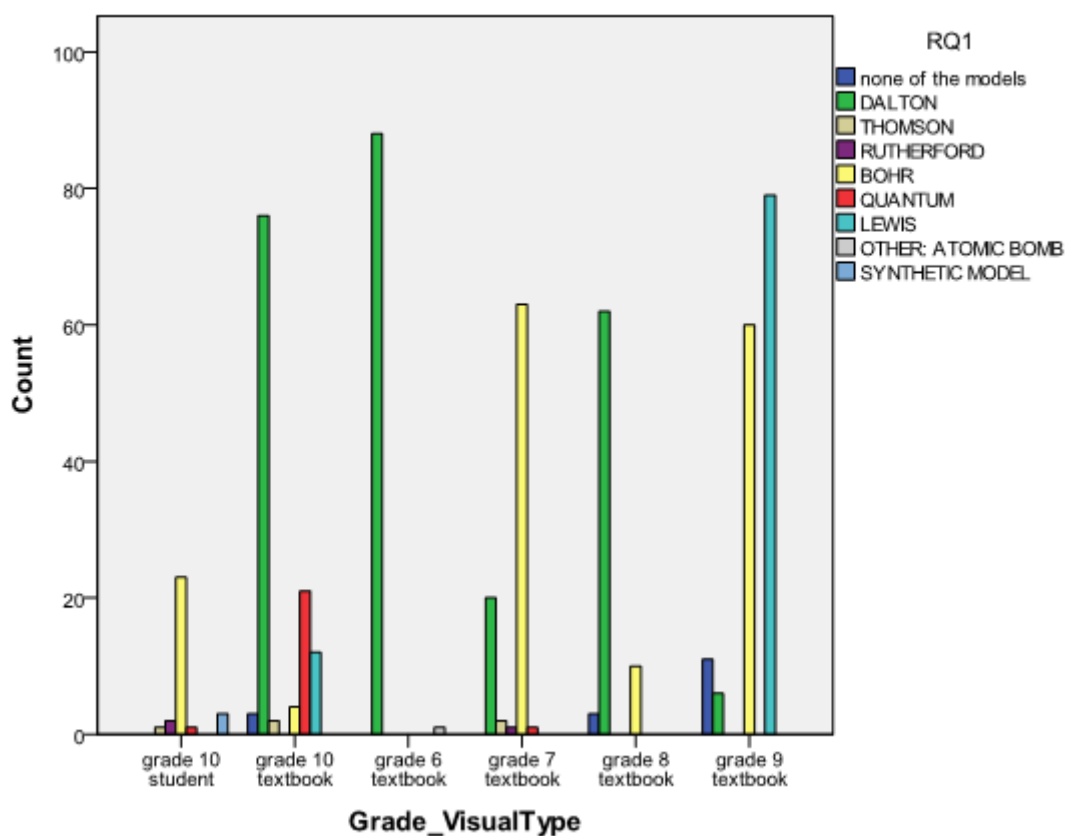


Figure 5.38. Comparison of 10th grade students' mental models of sodium atom with the visual representation of sodium atom in 10th grade textbook.

In the 9th grade textbook, %38 of atom visuals and in the 7th grade 78% of the atom visuals in textbooks are Bohr's atomic model. Surprisingly, 20% of the students from 11th grade represented the Rutherford's atomic model which was only represented in the 7th grade textbook once. In addition, 20% of students which is high percentage drew the different kind of atom model which are not categorized any of atom model taking place in the textbooks. In other words, 20% of the 11 grade students drew the synthetic model by integrating two or three different atom models in their minds. The percentage comparison of 10th grade students' mental models of atom drawings and the visual representations of atom found in the textbooks are also given in the Figure 5.39.

Table 5.49. Comparison of 11th grade students' mental models of sodium atom with the visual representation of sodium atom in previous grade' textbooks.

		RQ1								
		NONE OF THE MODEL	DALTON	THOMSON	RUTHERFORD	BOHR	QUANTUM	LEWIS	OTHER: ATOMIC BOMB	SYNTHETIC MODEL
Grade_Visual Type	grade 6 textbook	0%	99%	0%	0%	0%	0%	0%	1%	0%
	grade 7 textbook	0%	23%	2%	1%	73%	1%	0%	0%	0%
	grade 8 textbook	4%	83%	0%	0%	13%	0%	0%	0%	0%
	grade 9 textbook	7%	4%	0%	0%	38%	0%	51%	0%	0%
	grade 10 textbook	3%	64%	2%	0%	3%	18%	10%	0%	0%
	grade 11 student	0%	0%	0%	20%	60%	0%	0%	0%	20%

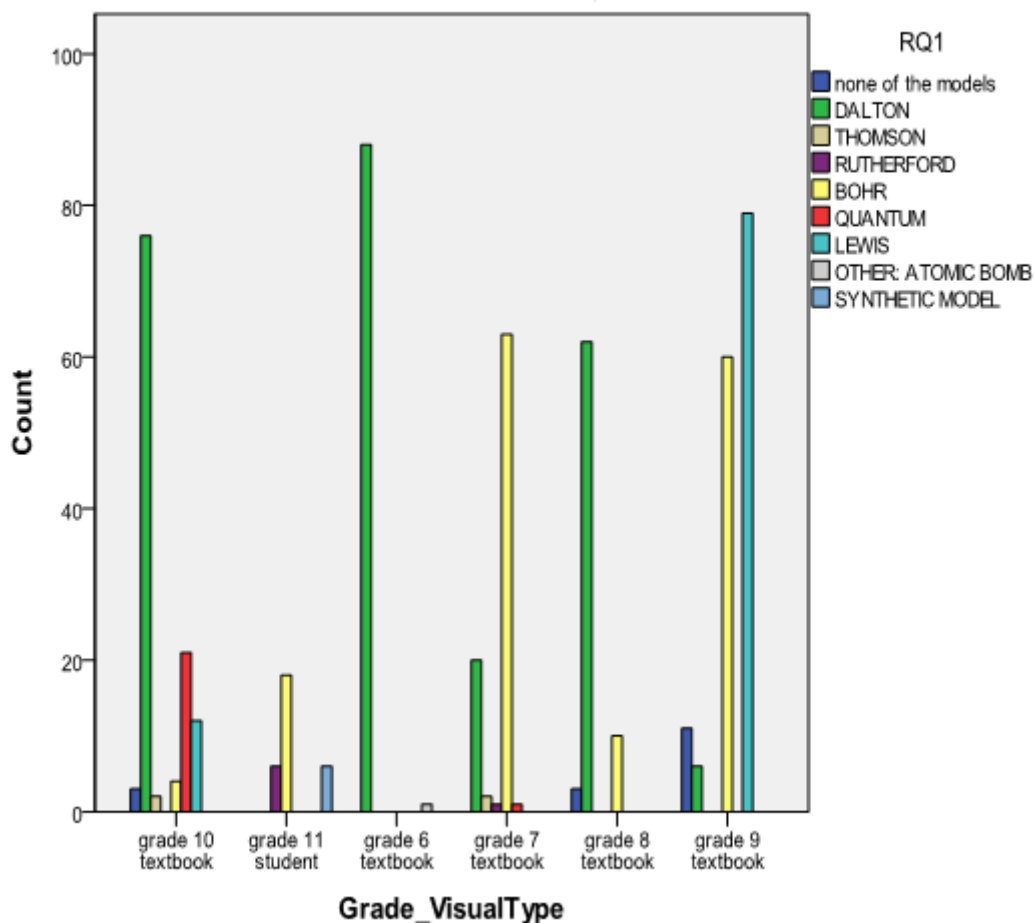


Figure 5.39. Comparison of 11th grade students' mental models of sodium atom with the visual representation of sodium atom in previous grade' textbooks.

in this section, results of the analysis with respect to the research questions about students' mental model drawings from 6th to 11th grade and atom visuals in the science and technology and chemistry textbook were reported. These results were discussed in the "Discussion and Conclusion" chapter in detail, with conclusions and comments for the further research.

6. DISCUSSION AND CONCLUSION

When the structural properties of matter are considered in a scientific frame, a good understanding of the atomic model becomes so important for students not to have alternative conceptions about the concept of atom. (Ben-Zvi, Eylon, and Silberstein, 1988). This is a very complicated issue since the nature of atom is within a nonobservable world. Then, the invisible atom concept becomes challenging and abstract for both elementary and secondary school students since it is different from what they are familiar to. (Taber, 2003). To identify what these abstract representations of students about atom concept, students' mental models were investigated in this study. It was also seen that students may have totally different or mixed mental models derived from the scientific ones. These alternative models were called synthetic models (Vosniadou, 2002). Therefore, to improve better teaching strategies and learning environments, it is important to know students' alternative conceptions and the type of those conceptions.

Researchers have argued that science textbooks are the major source of curriculum that determines how textbooks represent scientific methodology (Chipetta *et al.*, 2006; Gabel, 1983). Therefore, it is crucial to give importance how textbooks represent scientific methodology. This study aims to describe elementary and secondary school students' mental models and to compare students' mental models for the atom with the visual representations of atom found in elementary and secondary school textbooks. The comparison of the examples throughout the textbooks and students' drawings made it possible to determine and evaluate how they address atomic models.

The mental models of students about atom are shaped by the visuals in textbooks, the teachers' emphasized models, and the social environments such as the internet or television (Yıldız, 2006). In our study, it was seen that only solid sphere of the atom was given in the early years of elementary school textbooks. In addition, a clear atomic model was not given in the 6th grade textbooks. In that point, while there is a restriction to show atomic models in the early grades of elementary school textbooks, more freedom is given to teachers to show atomic models to students. Teachers can represent the basic model of atom to students for simple understanding. However, when a mental model is composed in

students' mind, it is not easy to change it in the higher grades. Driver, Guesne, and Tiberghien (1985) also stated that changing students' alternative conceptions based on their existing knowledge is very hard during their education life.

In the light of elementary school students' mental models, half of the 6th grade students drew the atomic bomb picture instead of the Dalton's atomic model which is the most frequently seen in the 6th grade textbooks. It shows that students' mental models about atom were not determined by only visual representations in the textbooks. The science teacher may give the example of the atomic bomb in the class because it is very hard to say that students are affected by just one atomic bomb picture in the 6th grade textbook. This result is consistent with the Nakiboglu's (2002) study. According to her study, the elementary school students drew the solar system model as their mental models instead of any scientific model. In addition, in the Yıldız's (2006) study, it is stated that elementary school students' mental models of atom are also related with pictures in the internet or television. In the present study, some elementary school students explained that they saw the atom in a movie or in a television program. Yıldız (2006) explained that these kinds of models which are seen in the internet or in the other media sources called mediatic models. This result also supports that even though Rutherford's atomic model was only seen in the 7th grade textbooks in the section of the historical improvement of atom models, 20% of the 11th grade students drew the Rutherford's atomic model in their drawings. Rutherford's atomic model is the most frequently seen in the internet material so it can be also called mediatic model for our study. In addition, Rutherford's atomic model is seen frequently in the 11th grade students' mental models because they are also attending different courses to pass the university entrance exam. They may encounter with the different visual materials more frequently than the students who are in the lower grades.

Elementary school and secondary school students have also different atomic models other than the scientific atomic models. Especially, it is surprising that the synthetic model which is the integration of different atom models were frequently seen in the 30% of the 6th grade students and 20% of the 11th grade students. In the elementary school students synthetic mental models were frequently seen as "Rutherford+Dalton" model whereas in the high school students drawings of atomic structure. It was seen as "Bohr+Rutherford" or "Bohr+Rutherford+Quantum" model. In addition, the small number of elementary school

students also drew the different models by mixing a biological concept such as cells or DNA rather than atomic models. These models were scored as “none of the models” which were seen only in the 6th grade students.

in our study, different than the study of Yıldız (2006), the historical changes of atomic models from Dalton’s atomic model to Quantum atomic model were given with visual representations and explanations in the elementary school science and technology textbook (grade 7). In the 7th grade, Quantum atomic model was explained by giving example of cat: “You have a cat in your home. You are not at home but you can predict the location of the cat approximately. It is similar to the atomic structure. We cannot see atom but we can predict the location of electrons in the atom. The probable location of the electrons is called as electron clouds.” The research also showed that establishing relationship with the historical improvement of atom models is an effective teaching strategy and prevents the alternative conceptions (Garnett, 1995; Griffiths, 1994; Herron, 1978). However, in our study none of the students in the elementary school mentioned about electron clouds or the Quantum atomic model even the historical improvement of atom models was given in the 7th grade textbook. In the Yıldız’s (2006) study, students also did not mention or draw the Quantum atomic model because the textbooks did not cover the Quantum atomic model. According to the results of our study even historical improvement of the atom models is included in the textbooks, students are still drawing the simpler or understandable models, the results also parallel with the related literature (Akyol, 2009; Ben-Zvi, Eylon and Silberstein, 1986; Yıldız, 2006). It can be recommended that Quantum atomic model can be explained before giving the historical changes of atomic models otherwise students adopt the basic or understandable model as their mental models.

Bohr’s atomic model was seen more frequently than the other models in secondary school students like the higher grades of elementary school students. It is hard to change the mental models when one model is accepted by students (Driver, Guesne and Tiberghien, 1985). Bohr’s atomic model was also represented as visuals in each grade of textbooks from the 7th grade. In addition, during the instruction, Bohr’s atomic model can be used more than other models because of its easy structure and easy drawings. However, the Quantum atomic model which is valid today is not preferred by teachers because of its

complicated structure. Therefore, even though the 7th grade textbooks mention about Quantum atomic model, it is not sufficient to construct a mental model in students' minds without teacher support.

in the students' mental models, all scientific atomic models and synthetic models were seen in different proportions but the Quantum atomic model, which is found more frequently than Rutherford's and Thomson's atomic models in the textbooks, is just represented by one student. In addition, it should not be ignored that the Quantum atomic model basically took place in the elementary school textbooks but in the 10th grade textbook the Quantum atomic model was included in the structure of the atom chapter with details. The Harrison and Treagust's (1996) study has similar results with our study. They found that Quantum atomic model was represented by the least number of students and the orbitals in the Quantum atomic model were not chosen by students. The causes of not representing the Quantum atomic model by students in our study can be stated as follows: Firstly, Quantum atomic model can be more detailed and complex than the other atom theories so students tend to draw more basic models than the Quantum atomic model. Secondly, imagination of the orbitals in Quantum atomic model can be harder than the other atom models because of the necessity of 3D thinking and because of the difficulty of representing 3 dimensional structures in 2 dimensional figures. Thirdly, in the textbooks, all atom models other than the Quantum atomic model have a certain shape but in the Quantum atomic model only the shapes of orbitals are given; there is no exact or definite shape of that model. Fourthly, the visuals representing s, p, and d orbitals were not represented in students' mental models as the atomic model because they were not shown in a specific atomic model, rather they were shown as an orbital. Students may not have visualized them altogether in a Sodium or Neon atomic model. In addition, there could be insufficient number (6%) of the visuals of orbitals given in the textbook about Quantum atomic model, so they may not have stayed in students' mind. The 19% of the orbitals were the solid circular orbitals and 33% of the students drew the solid circle representing the shape of the orbital. Finally, when the students learn the Bohr's atomic model in the 7th grade, it is hard to change it just by simply presenting the Quantum atomic model. Therefore, Quantum atomic model can be given in the early grades before they adopted any other model as their mental models.

Even though many teachers or the authors of textbooks do not have enough knowledge about modeling and the usage of models, their mental models have important impact on the students' mental models (Gulcicek, Bagcı and Mogol, 2003; Yıldız, 2006). Teachers prefer to choose easier models during their instructions rather than explaining all models with their insufficient properties. Therefore, students' modeling stays in the low level with only one model, and the textbooks are not sufficient to explain the different atom models by themselves. In our study, it can be seen that only one 10th grade student tried to draw Quantum atomic model even though they encountered with the Quantum atomic model in the 7th grade. However, it should not be ignored that Quantum atomic model was given only in the 7th and 10th grade but the Bohr's atomic model was given in each grade consistently and more than a half of the students drew the Bohr's atomic model with the similar result of the research in the literature (Akyol, 2009; Ben-Zvi, Eylon and Silberstein, 1986; Pideci, 2002, Yıldız, 2006). In addition, in our study Dalton's atomic model is the second common model throughout the students' mental model drawings showing a meaningful similarity with visuals in textbooks; since Dalton's atomic model was the second frequent atom model representation in the textbooks. According to these results, students' drawings were parallel with the visuals in textbooks used in our study.

The other conclusion from the students' mental model was that elementary school students have more synthetic models (Vosniadou, 2002) which were the integration of different atom models, than the secondary school students. It can be explained that elementary school students do not have a clear place about atom models in their minds; they do not realize the lack of previous models in the history of atom. In the 9th grade there is just one Synthetic model, all students were consistently drew Bohr's atomic model. However, after all atom concepts were completed in the textbooks the percentage of synthetic models again increased up to 20% of 11th grade students.

In addition, there was one important finding for the 9th grade students that none of the students showed the representation of Lewis structure in their drawings even though 51% of visuals in the 9th grade chemistry textbooks are Lewis structures. This could have occurred because students may not have thought of Lewis representation as a visual or drawing. There can be another reason that when the students' mental models were asked,

they think an atom model rather than the distribution of electrons like the Lewis dot structure. Lewis does not come up on students' minds as a visual.

When the representations of subatomic particles were analyzed, various results were seen. First, more than two third of the sample did not show the proton in their mental model drawings. This result was also parallel to the textbook visuals because the locations of the protons were not shown in the visual representations found in the 6th, 8th and 10th grade textbooks. In addition, students from 8th grade represented the proton with symbol of "p" and symbol of "+". Solid circle representations are also common in the 7th grade textbooks. In the 9th grade textbook the symbolic representation of proton was seen the more frequently than other representations; therefore the 9th grade students also showed the proton as a symbol in their representations. in the 10th grade, students' proton representations were not parallel with the visuals given in the same grade's textbook because in the 10th grade textbook, protons were more frequently represented with charge and symbol but students preferred to represent protons by numbers which was given similarly in the 9th grade textbooks. In the 11th grade, students do not cover the concept of atom in the curriculum, so none of the chapters included any visuals about the atom in their textbook and most of them represented the proton as a solid circle which was only seen in the 7th grade textbook. This result also shows that it is very hard to integrate new knowledge to the existing knowledge. Students' previous knowledge is hard to change (Driver, Guesne and Tiberghien, 1985).

Neutrons were represented only in the 7th grade textbooks visuals which were the 11% of the all textbook visuals. Even though the neutron representation took place only in the 7th grade, in each grade small number of students showed the neutron in their drawings.

There were 79 visuals in the textbooks represented the shape of the orbital by using an electron cloud representation, however what could be the reason that students do not show electron clouds by representing the shape of the orbital? Actually, it was really hard for students to realize the electron cloud from the textbook visuals, because the textbooks were the 2 dimensional and the clouds were three dimensional. in addition, the visuals were small in textbooks so students may not realize that the clouds, instead they see them as the certain circle orbitals.

The shape of the nucleus represented in the visuals of atom given in the students' drawings was parallel with the visuals given in the 7th, 8th and 9th grade textbooks. Similarly, about half of the students also did not draw the nucleus in their drawings and exactly half of the students drew the nucleus as a solid circle like represented in the textbooks. It also shows that students' drawings are parallel with the textbook visuals in the textbooks for the nucleus of atom.

Whether the motion of atoms was represented in the visuals of textbooks or in the students' drawings are discussed. In the textbooks, there were 54 visuals including motion with arrows or different symbols or sometimes with words, but only 2% of students (10th and 11th grade) showed the motion in their drawings. Even though 2% showed the motion in their atom drawings, it did not mean that only 2% of students thought that atoms were movable because students tried to show motion in two dimensions. More students 4% explained motion by including explanations to their drawings. Even more students can explain the motion in words but they could not show it in their mental models, it can also support that it is not easy to show motion in the two dimensional drawing pad. In addition, it should not be ignored that one third of the students especially from 6th and 7th grade students did not explain their drawings. Several research studies showed that students cannot explain chemical phenomena at the submicro level, instead students use symbols without understanding the meaning of the chemical concepts (Nakhleh, 1993; Nurrenbern and Pickering, 1987; Sawrey, 1990).

It was more challenging for the elementary school students to show motion in their drawing because they cannot imagine arrows or adding frame to create motion. Actually in the 6th grade there was no motion in any of the textbook visuals and only 1 visual in the 7th grade textbook included motion by adding different frames, it created motion by adding frames to the previous frame. The location of electrons was different in the each frame, so that the total frame images represented the motion. Under this situation, it was not meaningful to check 6th and 7th grade students' drawings with respect to motion because there were not enough visual representations in the textbooks to leave a permanent mark on students' minds about motion of atoms. However, it is important to include motion for atoms in the elementary school textbooks not to create alternative conceptions for students

in the higher grades because previous knowledge by creating alternative conceptions could be an obstacle to get the right concepts (Taber, 2003).

In addition, while one third of the other students' explanations were consistent with their drawings, explanations of the 4% of students were either incorrect or inconsistent with their drawings. In the explanations of 6th and 7th grade textbooks, visuals' daily life examples or daily life connections were included. For example, they make a visual of bullet with zooming to show the atom of lead or put battery and make a visual of battery with zooming to show the atom of zinc etc. in the Osborne and Cosgrove's (1983) study, it is stated that atom models are abstract concepts for students and they cannot establish connections with daily life events. Even though in our study the textbooks include the daily life examples, especially in the 6th and 7th grade, students' explanations or drawings did not include the daily life examples. One student both from 6th and 7th grade explained their drawings by mentioning daily life connections as saying "I saw the atom in a movie". The number of two students looked like very small but it should be taken into consideration because these students were 12 and 13 years old and textbooks cannot make strong impact on their minds without teacher support.

in addition, Özgür's (2007) study showed that 8th grade students mentioned about the noble gases and because of the noble gas structure they distributed electrons into the orbitals like 2-8-8. In the visual of textbooks, Bohr's atomic model was dominant so students explained the electron distribution like the Bohr's atomic model. Students in our study also gave importance to draw only 2 electrons in the first orbital. In addition, the students who already added extra information to their drawings mentioned about the noble gases. In the atom concept, the distribution of electrons with a structured rule is seen easy and when the students confront with a new knowledge they cannot make connections with the new knowledge and the existing knowledge (Ben-Zvi, Eylon, and Silberstein, 1988). Therefore, in our study the same results were seen that many students are still drawing Bohr's atomic model with the 2-8-8 electron distribution.

To summarize the results, Bohr's atomic model was the most common model in elementary school and secondary school students' drawings. The second common model was seen as the Dalton's atomic model among the drawings of elementary school students

and Synthetic model among the drawings of secondary school students. In addition, in the textbooks, the results were similar to the students' drawings, the highest percentage of the atom model was the Bohr's atomic model followed by the Dalton's atomic model. The synthetic model category which is the integration of different scientific models took place in the all grades students from 6th to 10th. Moreover, Quantum atomic model has the lowest percentage in the students' drawings but not least in the visuals of textbooks and in the early grade of elementary school students, pictures such as atomic bomb became more attractive for students than the Dalton's atomic model. Finally, most of the students both in elementary school and high school have the similar mental models because it is not easy to change existing model by simply presenting the new model.

6.1. Limitations of the study

In this study, the atom visuals in textbooks and students' atom drawings were compared according to prepared evaluation rubric (APPENDIX B). However, it is not possible to generalize the results of the study from 6th to 11th grade students other than the students of five schools in the study. The sample size of the study was small and sampling technique was not random selection so it was not appropriate to make generalizations for drawings. In addition, only Ministry of Education's Publication of textbooks were analyzed in the study. However, there were many public schools using publications than other the Ministry of Education.

In the statistical analysis part, it was not appropriate to compare the textbook visuals and students' drawings by grade because there were 30 students and at least more than 70 visuals in each grade. When two students drew according to different criteria, the statistical analysis in Chi-square wouldn't be meaningful because it is lack of statistical power with small sample. However, statistical analyses such as Chi-square are also necessary for the nominal data comparison.

Another problem was about the schedule of the implementation. This study was implemented in the mid of the first term of the academic year. However, in the 7th and 8th grade, chapters related with the atom had not been covered yet. Therefore, each textbook visual was compared with the previous grade students' drawings. Moreover, the students in

the sample did not cover the 8th grade atom chapter because they will cover it in the second half of the term. In addition, we could not evaluate the 9th grade students' drawings to compare with the visuals in the 8th grade textbooks because the 9th grade students also covered the 9th grade atom chapter before the implementation of the study. Therefore, there were missing data for evaluating the 8th grade textbook visuals. To get this data mental model test should have been applied to the 8th grade students after encountering the 8th grade atom visuals in the textbooks.

The classification of the atomic models was not easy and the inter-rater reliability was established after many discussions. For example, in one of the textbook visuals, the first scorer classified the visual as a Bohr's atomic model because of the definite orbitals and regular electron location; the second scorer classified the same visual as Rutherford's atomic model due to the electron orbitals region and the third one can categorized it as Quantum atomic model because of the electron clouds and probability of electron clouds location. This shows that how difficult to reach an agreement for the visuals as being different scorers especially with having the synthetic models of atom.

The visuals in the textbooks are not the only criteria which determine the students' mental models. The mental models of teachers, the social environment such as the internet, television, or attending a different education course are the other factors that may affect students' mental models. Therefore, the interview part could be taken into consideration to get better understanding of students' mental models about atom.

To summarize, the time of the implementation, lack of interviews and categorizing the mental models are the main limitations of this study.

6.2. Recommendations for Further Research and Implications

This study was conducted in order to compare students' mental models and the textbook visuals for atom models in each elementary school and high school grades. Although each result couldn't be analyzed statistically, descriptive analyses were supported in the study. In the further research, interviews should be done with students to explain their mental models effectively in the qualitative analysis. In addition, the 8th grade

textbook visuals couldn't be compared with the correct sample because 8th grade students didn't cover the atom concept in the first semester of the year. In addition, 9th grade students' drawings cannot be compared with the 8th grade textbook visuals because 9th grade students have already covered the atom chapter in the 9th grade textbook. Further research with a better implementation schedule may complete the missing part of the study.

In order to generalize results, a similar study may be carried out with more students from different schools including not only public schools but also private schools. In addition, different publications of textbooks could also be integrated into the study. Results may differ with a larger student sample size and different textbook publications.

There are also recommendations for the textbook authors and curriculum planners. Firstly, visuals of the Quantum atomic model should be given basically and clearly. For example, rather than showing s, p, d orbitals separate from the atom itself, there can be zooming into the atom to show the s, p, d orbitals. Therefore, it could be easy to connect orbitals with the atom simultaneously. Secondly, the Quantum atomic model can be given as a current valid model before the historical development of previous atom models. Thirdly, in the Quantum Theory of atom, motion of electrons is very important but students, seeing today's visuals in textbooks have difficulty understanding it. The motion should be shown with more effective ways. There was just one good example in the 7th grade textbook. There, the motion of electrons was shown by putting different snapshots one after the other to indicate the uncertainty of the location of electrons. That kind of visuals can be recommended to take place more frequently in the textbooks. The other recommendation is that the textbooks can also include CDs as supporting sources for students by considering textbooks' insufficiency. It can be more helpful for the elementary grade students because they draw the atomic bomb picture more frequently when asked to draw atom. In addition, for further research, students' mental models can be evaluated with computer-based 3-Dimensional programs rather than a paper based test. If there is an animation program such as Chemsense or K-sketch to draw their mental models instead of pen and paper, the students' drawings including motion can be more than 2%. Moreover, using 3-Dimensional programs (such as Chemsense or K-sketch which allow students to create their own animations involving dynamic processes or motion) can be helpful to understand students' mental models from their animations rather than their 2-Dimensional

drawings. It is challenging to see the mental models in the 2-dimensional paper based tests especially for a non-observable concept like atom which also includes motion. Finally, training about the Quantum atomic model visuals can be given to the science and chemistry teachers by the Ministry of Education.

The recommendations for the science or chemistry teachers are also the following: the atom models should be given with the explanations, and in the beginning of the atom concept teachers should not mention about the analogies that may affect students' thinking. It should be emphasized that the previous atom models are not valid today because of their deficiencies in the explaining of the correct atom concept. The limitations of the historical atom models should be given during instruction. Teacher should emphasize the Quantum atomic model in their drawings. In addition, teachers should show the 3D animations or simulations about the concept of atom in the instruction of atom concept.

For developing scientific knowledge, models and modeling become very important. Thus, students' modeling skills should be improved by the help of more effective visuals in textbooks and activities which are provided by teachers during instruction.

APPENDIX A: TEST OF THE MENTAL MODELS OF ATOM

Zihinsel Atom Testi

Merhaba, Ben Zeynep Polat, Boğaziçi Üniversitesi Orta Öğretim Fen ve Matematik Alanları Eğitimi Bölümü Yüksek Lisans öğrencisiyim. Yüksek lisans tez çalışmamda atom konusunda öğrencilerin zihinsel modellerini inceliyorum.

Bu test sizin zihninizde canlandırmış olduğunuz atom modellerini belirlemek amacıyla hazırlanmıştır. Testin ilk bölümü demografik özellikleri kapsayan 7 sorudan, ikinci kısmı da 4 tane açık uçlu sorudan oluşmaktadır. Vereceğiniz cevaplar bilimsel amaçlı yapılan atom konusundaki çalışmaya katkıda bulunacaktır. Katkılarınız için çok teşekkür ederim.

Okulunuz: _____

Sınıfınız: _____

Cinsiyetiniz: _____ Kız _____ Erkek

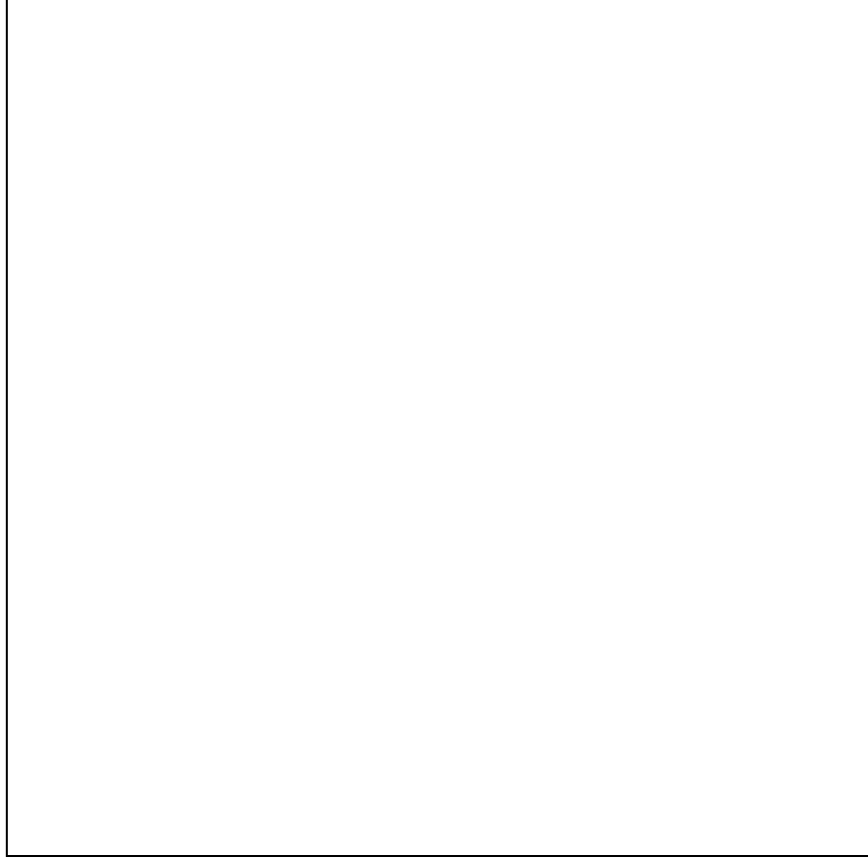
Yaşınız: _____

Mezun olduğunuz ilköğretim okulu: _____

Fen Bilgisi Notları? 6. Sınıf _____ 7. Sınıf _____ 8. Sınıf _____

Kimya Notları? 9. Sınıf _____ 10. Sınıf _____ 11. Sınıf _____

1. Zihninizdeki sodyum atom modelini çiziniz ve modelinizde gösterdiğiniz her ayrıntıya isim veriniz. ($_{11}^{23}\text{Na}$)



2. Sodyum atom modelinizi yazıyla açıklayınız ve çizimde gösteremediğiniz bir kısım ya da ayrıntı varsa yazıyla belirtiniz.

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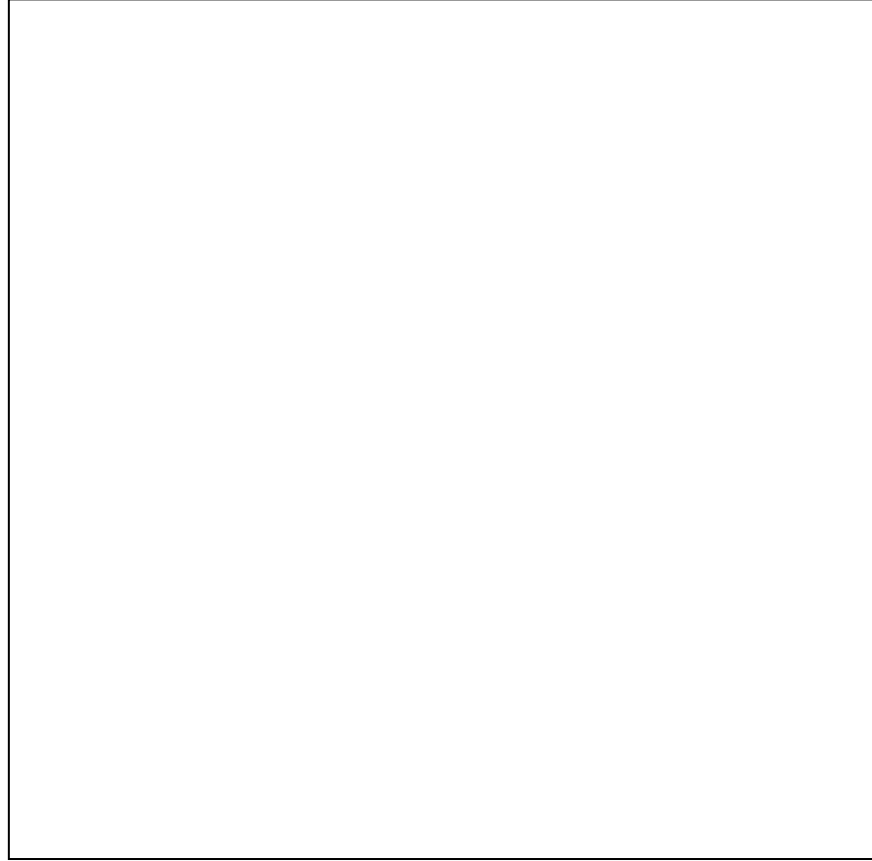
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3. Zihninizdeki neon atom modelini çiziniz ve modelinizde gösterdiğiniz her ayrıntıya isim veriniz. ($_{10}^{20}\text{Ne}$)



4. Neon atom modelinizi yazıyla açıklayınız ve çizimde gösteremediğiniz bir kısım ya da ayrıntı varsa yazıyla belirtiniz.

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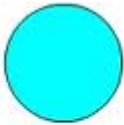
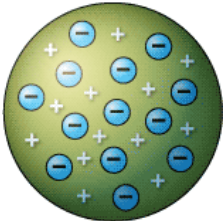
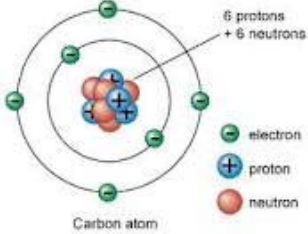
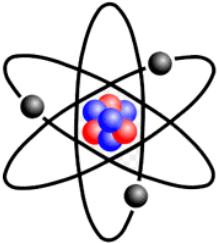
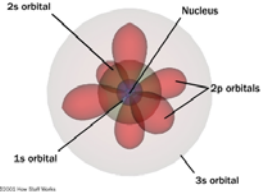

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APPENDIX B: EVALUATION RUBRIC FOR ATOMIC MODEL REPRESENTATIONS

1. Student's mental model or visual in textbook is similar to:

Dalton:	Thomson:	Bohr:
		
Dalton's Model "Hard sphere"		
<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Rutherford:	Quantum Model:	Lewis:
		
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

2.

	Charge				Location				Representation				
	+	-	0	Not shown	in the nucleus	in the orbital	Other	Not shown	Dot	Symbol	With charge	Words	Other
Proton	✓				✓					✓			
Neutron			✓		✓					✓			
Electron		✓				✓			✓				

3.

Ion Charge	Shown		Not Shown
	Different symbol or label	Ion charge	
	✓		

4.

Orbitals	Shape						Others	Not Shown
	Solid circles	Dash lines	Clouds	Half lines	Elliptical in different orientations	s, p orbital		
		✓						

5.

Nucleus	Charge			Shape		includings					Others	Not Shown	
	+	-	0	Circle	Solid circle	p	n	e	+	-			+and-
			✓		✓		✓	✓					

6.

Representation of motion	Shown			Not shown
	With symbols	With words	Other	

7.

Explanations with wordings	
Consistent with the drawing (nothing extra)	
Extra information (things not shown in drawing, neutral, octet, noble gas etc.)	✓ neutral
With symbols (electron configurations)	
Motion is included	
Inconsistent with drawings	

APPENDIX C: PERMISSION FROM MINISTRY OF NATIONAL EDUCATION OF TURKEY

T.C.
İSTANBUL VALİLİĞİ
İl Millî Eğitim Müdürlüğü

Sayı : B.08.4.MEM.0.34.24.01-020-/**140871**
Konu : Anket (Zeynep POLAT)

02.11./2011

VALİLİK MAKAMINA

- İlgi :** a) Boğaziçi Üniversitesi Ortaöğretim Fen ve Matematik Alanları Eğitimi Bölümünün 27/10/2011 tarihli ve 135 sayılı yazısı.
b) Millî Eğitim Bakanlığına Bağlı Okul ve Kurumlarda Yapılacak Araştırma ve Araştırma Desteğine Yönelik İzin ve Uygulama Yönergesi.
c) Millî Eğitim Bakanlığı Eğitim Araştırma Geliştirme Dairesi Başkanlığının 11/04/2007 tarih ve 1950 sayılı emri.
d) Millî Eğitim Komisyonunun 28/10/2011 tarihli tutanağı.

Boğaziçi Üniversitesi Ortaöğretim Fen ve Matematik Alanları Eğitimi Yüksek Lisans öğrencisi Zeynep POLAT'ın "**Öğrencilerin Atom Konusunda Zihinsel Modelleri ile Ders Kitaplarındaki Atom Görsellerinin Karşılaştırılması**" konulu tezine ilişkin İlimiz Şişli, Sarıyer, Beşiktaş ve Fatih ilçelerinde tez önerisinde belirtilen Ek-3 listesindeki okullarda test uygulanması talebi hakkındaki ilgi (a) yazı ve ekleri Müdürlüğümüzce incelenmiştir.

Yüksek Lisans öğrencisi Zeynep POLAT'ın söz konusu talebi; bilimsel amaç dışında kullanılmaması koşuluyla, okul idarelerinin denetim, gözetim ve sorumluluğunda ilgi (c) Bakanlık emri esasları dahilinde uygulanması, sonuçtan Müdürlüğümüze rapor halinde (CD formatında) bilgi verilmesi kaydıyla Müdürlüğümüzce uygun mütalaa edilmektedir.

Makamlarınızca da uygun görüldüğü takdirde Olurlarınıza arz ederim.


Dr. Muhammet YILMAZ
Millî Eğitim Müdürü

OLUR
02/11./2011

Mustafa GÜRBAN
Vali a.
Vali Yardımcısı

NOT: Verilecek cevapta tarih, numara ve dosya numarasının yazılması rica olunur.
STRATEJİ GELİŞTİRME BÖLÜMÜ E-Posta: sgb34@meb.gov.tr
ADRES: İl Millî Eğitim Müdürlüğü D Blok Bab-ı Ali Cad. No:13 Cağaloğlu
Telefon: Snt.212 455 04 00 Dahili: 243, Faks: 212 520 05 64 Şb.Md.: 212 511 16 65

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