COMPARISON OF THE EFFECTS OF MODEL – BASED AND COMPUTER – BASED INSTRUCTION ON 9TH GRADE STUDENTS' SPATIAL ABILITIES AND CONCEPTUAL UNDERSTANDING OF IONIC LATTICE

by

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This thesis is dedicated to my daughter, Deniz Naz

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ABSTRACT

COMPARISON OF THE EFFECTS OF MODEL – BASED AND COMPUTER – BASED INSTRUCTION ON 9TH GRADE STUDENTS' SPATIAL ABILITIES AND CONCEPTUAL UNDERSTANDING OF IONIC LATTICE

This study was designed for two main purposes. The first one is to develop and carry out two different instructional activities which were computer based modeling and physical modeling for two different treatment groups by switching the treatment order. The second one is to improve the spatial ability and conceptual understanding of ionic lattice structure of students during the 9^{th} grade chemistry lesson. This study was performed using crossover research design where the same group of students with the same teacher received a sequence of different treatments. In order to analyze the effect of computer based modeling with ChemSense and physical modeling with play doughs on the spatial ability and the conceptual understanding of ionic lattice structure, the quantitative data was collected from conveniently selected 43 ninth grade students. Five different instruments were administered to collect the data which were *the Purdue Spatial Visualization Test: Rotations, Conceptual Tests, Drawing from Text Tests, Writing from Picture Tests and ChemSense &Physical Models.* Three different inferential statistical methods were used for the analysis of data which were paired samples t-test, independent samples t-test and chi square. The results of the analysis indicated that mixing the two modeling tools improved statistically significant the spatial ability and the conceptual understanding of the ionic lattice form pretest to the posttest-2. The results of the study also indicated that regardless of the treatment order, the spatial ability and the conceptual understanding of the both treatment groups promoted statistically significant.

ÖZET

BİLGİSAYAR TABANLI MODELLEMENİN VE FİZİKSEL MODELLEMENİN 9. SINIF ÖĞRENCİLERİNİN UZAMSAL YETENEKLERİNE VE İYONİK BİLEŞİKLERİN KRİSTAL YAPILARINI KAVRAMA DÜZEYLERİNE ETKİLERİNİN KARŞILAŞTIRILMASI

Bu çalışma iki ana amaç doğrultusunda tasarlanmıştır. İlk olarak, bilgisayar tabanlı modelleme ve fiziksel modelleme kullanarak geliştirilen iki faklı öğretim uygulamasının iki farklı çalışma grubunda ve uygulama sırası değiştirilerek gerçekleştirilmesi amaçlanmıştır. İkinci olarak 9. sınıf öğrencilerinin uzamsal yeteneklerinin ve iyonik bileşiklerin kristal örgü yapılarının kavrama düzeylerinin geliştirilmesi amaçlanmıştır. Bu çalışmada çapraz araştırma deseni kullanılarak aynı öğretmen tarafından aynı sınıftaki öğrencilere farklı uygulamalar yapılmıştır. ChemSense programı kullanılarak geliştirilen bilgisayar tabanlı modellemenin ve oyun hamurları kullanılarak geliştirilen fiziksel modellemenin öğrencilerin uzamsal yeteneklerine ve iyonik bileşiklerin kristal yapılarını kavrama düzeylerine olan etkisini ölçmek için yargısal örnekle yöntemi kullanarak 43 tane 9. sınıf öğrencisinden nicel veriler toplanmıştır. Purdue Uzamsal Görselleştirme Testi: Döndürme, Kavramsal Testler, Metinden Çizim Testleri, Resimden Metin Testleri ve ChemSense & Fiziksel Modelleri olmak üzere beş farklı araç kullanarak veriler toplanmıştır. Eşleştirilmiş örneklem t-testi, bağımsız örneklem t-testi ve Ki kare testi olmak üzere üç farklı çıkarımsal istatistik yöntemi kullanılarak verilerin analizleri yapılmıştır. Bu analizlerin sonuçlarında iki modelleme aracının sırası değiştirilerek kullanılmasının öğrencilerin uzamsal yeteneklerinin ve iyonik bileşiklerin kristal yapılarını kavrama düzeylerini istatiksel olarak anlamlı bir şekilde ön-testten son test 2'ye kadar geliştirdiği gözlemlenmiştir. Bu çalışmanın sonucu ayrıca öğrencilerin uzamsal yeteneklerinin ve iyonik bileşiklerin kristal yapılarını kavrama düzeylerinin uygulama sırasında bağımsız bir şekilde istatiksel olarak anlamlı bir şekilde geliştiğini göstermiştir.

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LIST OF SYMBOLS

df	Degrees of freedom
f	Frequency
M	Mean
n	Number
t	t Value
X^2	Chi Square Value

LIST OF ACRONYMS / ABBREVIATIONS

CT1	Conceptual Understanding Test-1
CT2	Conceptual Understanding Test-2
CT3	Conceptual Understanding Test-3
DT1	Drawing from Text-1
DT2	Drawing from Text-2
DT3	Drawing from Text-3
Group CP	The Treatment Group which Firstly Received The Computer Based-Modeling and then The Physical Modeling.
Group PC	The Treatment group which Firstly Received The Physical Modeling and then The Computer-Based Modeling.
ROT	Purdue Spatial Visualization Test: Rotations
Sig.	Significance
Std. Deviation	Standard Deviation
WP1	Writing from Text-1
WP2	Writing from Text-2
WP3	Writing from Text-3

1. INTRODUCTION

Chemical structures are inherently three dimensional. Visualization and mental manipulation of molecules in three-dimensional space are important for understanding many chemical concepts such as the spatial orientation of orbitals, molecular geometries, crystal structures, *R* and *S* configurations of organic molecules, structure–function relationships (Pribly and Bodner, 1987; Coleman and Gotch, 1998). Therefore, true understanding of chemistry concepts requires a sufficient level of spatial ability (Barke and Engida, 2001).

However, understanding and representing the three dimensional space that surrounds the chemical entities and events has been a challenge for chemistry. (Harle and Towns, 2010) pointed out that one of the problems students face when taking a chemistry course that requires spatial skills is that instruction may not directly help them learn how to use domain-specific visuospatial skills to solve problems. Thus, in chemistry, the challenge for faculty is to help students become competent in the domain-specific spatial skills that are key to connecting particulate representations of molecules to conceptual and symbolic knowledge.

Similarly, National Research Council's (NRC) report, Learning to Think Spatially (2006) revealed that there is a persistent neglect of practice of using spatial ability in K-12 curriculum and currently there are no standards for how we should think or learn spatially and no standards for how spatial thinking can be taught and assessed. They declared that spatial thinking is a fundamental and necessary mode of thought applicable across the life span in everyday life, in work situations and in science, we must foster a generation of students who are spatially literate and we must facilitate the transfer of generalisable spatial thinking skills across domains of knowledge in the K-12 curriculum, thus enhancing learning across the curriculum. Moreover, they recommended that instruction in spatial thinking should play an equivalent role to that of the writing across the curriculum approach.

Turkish secondary level chemistry curriculum was renewed as a result of a reform action started in 2004. The new chemistry curriculum was initiated to be implemented since 2008-2009 academic year. The main objective of this reform was declared to adjust the chemistry curriculum according to principles of constructivism. However, current chemistry curriculum developers devoted relatively little attention on teaching of spatial abilities as a core subject. Moreover, the analysis of high school chemistry curriculum documents indicated that they do not include even a single word about the spatial ability.

In addition, spatial ability has been acknowledged as the essential skill to success in several occupations, such as piloting, mechanics, engineering drawing and surgery (Hegarty and Waller, 2005). These evidences summarized above revealed that spatial ability has not been thought formally and training the spatial ability is urgently required in school settings in order to enhance the success of students in chemistry education.

This lasting neglect of this ability lowers the overall success of students in science lessons as well as chemistry (Webb and Lubinski, 2007). This can be best observed by means of the international assessment exams. One of these exams is PISA (The Program for International Student Assessment) which is an international assessment that measures the performance of 15-year-olds in reading literacy, mathematics literacy, and science literacy every 3 years and coordinated by the Organization for Economic Cooperation and Development (OECD), an intergovernmental organization of 34 member countries. In all, 60 countries and 5 other education systems participated as partners in PISA 2009. The results of PISA (2009) reported in (OECD, 2010) and revealed that the average score of Turkish students were 454 points where OECD average was 501 points. Although, this average suggested that Turkish students showed a remarkable improvement of performance as compared to former PISA (2006) assessment with respect to scientific literacy, science literacy performances of Turkish students were still below the average of 65 participating countries like the previous assessments. These results showed that the overall science performances of Turkish students were in 43th place among 65 participating countries, and 32th place among the 34th among the other OECD member countries on scientific literacy where OECD average was 501 points and Turkey just passed two OECD countries which were Chile having the score of 447 points and Mexico who scored 416 points. Moreover, in order to rank the students' score, PISA used six literacy proficiency levels, ranging from 1 (indicates the lowest level) to

6 (indicates the highest level). Turkish students on average scored at level 2 on the science literacy scale. Level 2 was defined as the level at which students have adequate scientific knowledge to provide possible explanations in familiar contexts or draw conclusions based on simple investigations. They were capable of direct reasoning and making literal interpretations of the results of scientific inquiry or technological problem solving. In addition, PISA (2009) revealed that among fifteen-years-olds, only 1.1% of 4996 participating Turkish students scored at level 5 and more dramatically no student was reported at level 6.

This study was aimed to fill this gap by offering two types of instructional sequences. The instructional sequences consisted of two modeling methods which were physical modeling through play doughs and computer-based modeling through ChemSense software. Namely, the current study investigated the effects of different forms of modeling on 9^{th} grade students' spatial ability and conceptual understanding of ionic lattice.

2. LITERATURE REVIEW

2.1. What is the Modeling?

A model is defined as a representation of a phenomenon, an object, or an idea (Gilbert and Boulter, 2000). The report of (Department for Education and Skills, 2004) recognized the importance of modeling for science education and identified the main reasons for using models in educational purposes. They stated that teachers use models to help students make sense of their observations, findings and abstract ideas through the visualization of:

- objects that are too big, for example, solar system, an ecosystem;
- objects that are too small or not seen easily, for example, cell, heart;
- processes that cannot easily be seen directly, for example, digestions, erosion;
- abstract ideas, for example, particulate nature of matter, energy transfer.

There are many different types of modeling and the words used to categorize them can vary from researcher to researcher (Örnek, 2008; Greca and Moreira, 2000; Gilbert and Boulter, 1998; Norman, 1983).

Norman (1983) defined two types of modeling which were mental models and conceptual models. Mental models were expressed as the internal representations developed by individuals representing the individual and the things he or she is interacting with and conceptual models were considered as tools created for the teaching of physical systems.

Gilbert and Boulter (1998) defined four types of models which were *mental model* that we each of us visualize in our mind; *expressed model*, when we try to explain or present in another form our mental model; *consensus model*, an expressed model which has gained acceptance within the scientific community; *historical model*, a consensus model which has been superseded at the ‘cutting edge’ of science e.g. the ‘plum pudding’ model of an atom is an historical model superseded by ‘orbiting electrons’ model.

Greca and Moreira (2000) expressed the difference between mental model and the conceptual model where the former is internal representations created by individuals in their minds, while the latter is external representations created through consensus from various experts.

In this current study, two types of modeling methods were employed which were the computer based modeling with ChemSense and the physical modeling with play doughs. (Örnek, 2008) defined that the physical models are the models of real situations and can be carried, touched, or held whereas the computer models are the computer programs which attempts to simulate the behavior of a particular system.

2.2. What is the Spatial Ability?

Although the researchers from different domains agree the importance of the spatial ability for human cognitive functioning, there is no systematic definition of the concept of the spatial ability. Moreover, researchers even do not agree the birth date of this concept. For example, Coleman and Gotch, (1998) argued that spatial ability as a separate factor in intelligence was first proposed in the 1920s by Spearman. On the contrary, Mohler (2006) debated that Thorndike's publication in 1921 serves as the first identification of the spatial ability as a major factor in human intellect and the starting point for published spatial ability research. As it was elaborated in Mohler (2006), in this publication, he drew an important distinction among three broad classes of intellectual functioning, as opposed to Spearman's "singular view" of intelligence. He argued that standard intelligence tests measured only "abstract intelligence." While Thorndike included abstract intelligence in his own threefold model, he highlighted that "mechanical" and "social" intelligence was equally important. Through his work, he defined "mechanical intelligence" as the ability to visualize relationships among objects and understand how the physical world worked and "social intelligence" as the ability "to act wisely in human relations.

After about the century from the initial definition of Thorndike, today researchers approve that spatial ability is the inevitable part of the human cognitive functioning. But, there still exist another persistent problem about terminology to indicate this construct. As the study of Bakker (2008) indicated when defining spatial ability, most researchers do not consider it as a unitary trait. Rather, they think of it as consisting of different abilities or categories (Linn and Petersen, 1985; Carroll, 1993). As Miller and Bertoline (1991) mentioned researchers and theorists in the areas of cognitive psychology, art, science, math, and engineering education have used varying combinations of the words "visual" and "spatial" with "cognition", "ability", "skill", "orientation", "perception", "reasoning", "relations", "rotations", and "imagery", among others, in their attempts to more precisely classify and label this set of mental abilities. The terminology used by one researcher often subtle differences from the terminology of another. For example; spatial ability researchers proposed quite different constructs to refer the spatial ability such as dynamic spatial ability (Pellegrino and Hunt, 1991), spatial reasoning (Clements and Battista, 1992), spatial perception (Del Grande, 1987), spatial structuring (Battista, 1999), spatial sense (Wheatley, 1990). Namely, these spatial ability related concepts are interrelated and there are no clear distinctions made in these relationships. More recently, The Committee on Support for Thinking Spatially (2006) focused on the same deficiency that declared that there is as yet no clear consensus about spatial thinking. Thus, there are many related concepts in use: we speak about spatial ability, spatial reasoning, spatial cognition, spatial concepts, spatial intelligence, environmental cognition, cognitive mapping, and mental models. Moreover, it was also added that the most familiar of these terms is spatial ability.

Another long-lasting problem that the spatial ability faces is how to categorize this construct. D'Oliveira (2004) discussed this problem and showed that there are contradictions in the spatial domain literature, which makes the topic difficult to understand. She summarized those contradictions as follows:

- While there are same descriptions under different names, there are identical names for different components of spatial ability.
- Number of underlying components/factors of spatial ability varies by researchers - ranging from two to ten.
- Factor names vary across authors and even within a work of the same author.

- Confusion exists among the researchers regarding the names and contents of a variety of spatial ability tests.

Sorby (1999) discussed the difference between “spatial abilities” and “spatial skills’’ and described that the former refers to innate abilities to visualize that a person has before any formal training has occurred and the latter to learned abilities acquired through training. She also suggested that these two terms are often used interchangeably. Similarly, Baldwin (2005) indicated that there is considerable overlap in the definitions of spatial orientation and spatial visualization (Lohman, 1979), leading others (Pellegrino and Kail, 1982; Pellegrino and Hunt, 1991; Coleman and Gotch, 1998) and us to consider only two main categories of spatial ability: spatial relations and spatial orientation.

Piaget and Inhelder (1967) defined two types of spatial ability when a child interacts with his/her environment. First one was the *perceptual spatial ability*, the ability to perceive the spatial relationships between objects and second one was the *conceptual spatial ability*, the ability to build and manipulate a mental model of the environment. More recently, Gardner (1983) introduced the theory of multiple intelligences in *Frames of Mind*. He suggested that each individual possesses at least seven such relatively independent mental abilities or intelligences as opposed to the traditional view of intelligence as a unitary trait. One of these intelligences was the spatial intelligence that defined as an ability to perceive and represent the visual-spatial world accurately and to form and manipulate mental images.

The most commonly accepted definition of spatial ability was provided by Lohman (1979) stated that “spatial ability may be defined as the ability to generate, retain, and manipulate abstract visual images. He elaborated that spatial ability was composed of three primary factors (visualization, relations, and orientation) and several minor factors. He defined these factors as;

- Spatial relations : mental rotations and the ability to solve spatial problems quickly
- Spatial orientation : the ability to relocate the viewer and discriminate between left and right (relative to the problem)
- Spatial visualization: the ability to solve complex spatial problems that facilitate the use of multiple spatial and peripheral factors.

In a meta-analysis of the literature, (Linn and Peterson, 1985) evaluated the cognitive rationale of tasks requiring spatial abilities and identified three main categories: spatial visualization, spatial perception, and mental rotation.

- Spatial Perception: the ability to determine spatial relationships with respect to the orientation of one's own body, in spite of distracting information.
- Spatial Visualization: the ability to manipulate complex spatial information when several stages are needed to produce the correct solution.
- Mental Rotation: the ability to rotate, in imagination, quickly and accurately two- or three-dimensional figures.

In the study of same researcher after nine years (in Lohman, 1988), spatial ability is divided into ten categories which were general visualization, spatial orientation, flexibility of closure, closure speed, serial imagination, speeded rotation, spatial scanning, perceptual speed, visual memory, and kinesthetic. In addition, it was added in Lohman (1988) that among all of ten categories, even though there is no general agreement on the categories, general visualization, spatial orientation and spatial relations are the most well known of spatial categories. The final definition of spatial ability was given in 1993 was given by Lohman as the ability to generate, retain, retrieve, and transform well-structured visual images.

Carroll (1993) analyzed more than 140 datasets and detected five major clusters: *Visualization* (Vz), *Spatial Relations* (SR), *Closure Speed* (CS), *Flexibility of Closure* (CF), and *Perceptual Speed* (P). The factors detected by Carroll (1993) are shown in Figure 2.1.

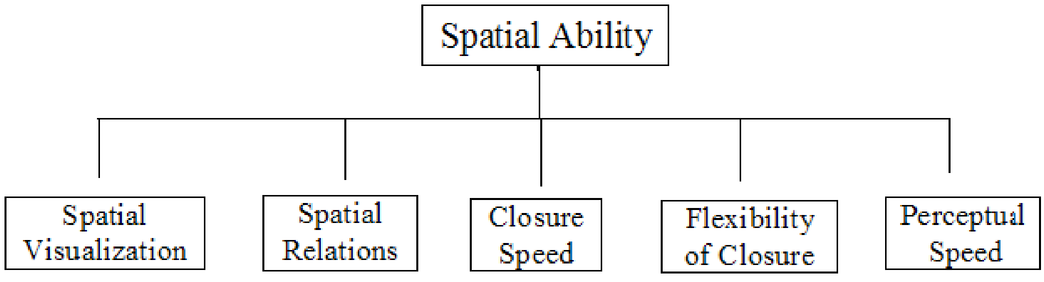


Figure 2.1. Major Factors of Spatial Ability Based on Carroll's (1993) Analysis.

Maier (1998) proposed five spatial factors and refers to these as the five elements of spatial intelligence. Each of these is briefly described below:

- Spatial Perception: “Spatial perception tests require the location of the horizontal or the vertical in spite of distracting information”.
- Visualization: “Comprises the ability to visualize a configuration in which there is movement or displacement among (internal) parts of the configuration”.
- Mental Rotation: “The ability to rapidly and accurately rotate a 2D or 3D-figure”.
- Space Relations: “The ability to comprehend the spatial configuration of objects or parts of an object and their relation to each other”.
- Spatial Orientation: “Spatial orientation is the ability to orient oneself physically or mentally in space. Therefore, the person’s own spatial position is necessarily an essential part of the task”.

Gilbert (2005) used the term metavisual capability to indicate the mental operations involving the ability to acquire, monitor, integrate and extend from representations. He referred to the classification of Barnea (2000) proposed that metavisual capability consists of the fluent deployment of three complimentary skills which were;

- Spatial Visualization: The ability to understand three-dimensional objects from two-dimensional representations of them (and vice-versa).
- Spatial Orientation: The ability to imagine what a three-dimensional representation will look like from a different perspective (this is ‘rotation’).
- Spatial Relations: The ability to visualize the effects of the operations of reflection and inversion.

(Sutton and Williams, 2008) indicated the importance of spatial ability as an inevitable skill for the designers to do the mental manipulation of designs or to appreciate the relationship of components of these forms. They defined the spatial ability as the performance on tasks that require mental rotation of objects, the ability to understand how objects appear at different angles, and how objects relate to each other in space.

This current study was organized according to the study of (Martín-Dorta and Contero, 2008) was aimed to measure the same subcategories of the spatial ability. In this study they stated that there are number of different approaches to define the spatial ability, classified two categories of the spatial ability and gave the following definitions for these categories;

- Spatial relations: the ability to imagine rotations of 2D and 3D objects as a whole body (this includes mental rotation and spatial perception).
- Spatial Visualization: the ability to imagine rotations of objects or their parts in 3D spatial by folding and unfolding.

2.3. The Need for Spatial Education

Chemistry students have been challenged to comprehend the particles or events of the subatomic world. The complete understanding of invisible world of chemistry demands students who are able to envision, manipulate and represent the spatially oriented structures and events of chemistry concepts. Thus, as (Harle and Towns, 2010) stated, “chemistry has a spatial language that students must master.”

The importance of learning the spatial ability for chemistry has been approved in many studies. In the meta-analyses (Newcombe and Shipley, 2010) discussed the importance of spatial ability for different disciplines. Although this study approved the importance of spatial skills for chemistry, the authors criticized the general view that is learning spatial skills mainly affect the thinking in STEM disciplines. They stated that learning spatial knowledge demands many difficult cognitive tasks about the intrinsic and extrinsic characteristics of an object such as shapes, locations, paths, relations among entities and relations between entities and frames of reference. Finally, they concluded that these cognitive challenges impact the way of thinking in many different disciplines, not in STEM disciplines. Similarly, (Wu and Shah, 2004) indicated that learning chemistry involves students’ spatial abilities that support students to perform certain cognitive operations spatially such as recognizing the graphic conventions, manipulating spatial information provided by a molecular structure, mentally tracking the constraints based on concepts, the representation of the shape and internal structure of chemical compounds, the ability to transform that representation by imagining the object's structure being rotated.

However, as the recent study of (Wai and Lubinski, 2009) pointed out that one of the concepts that suffering from persistent neglect is the spatial ability and there is little emphasis in the educational system on the development of spatial abilities perhaps because such abilities are taken for granted or believed to be innate. It has relatively little implementation for selection, curriculum and instruction in educational settings, even in STEM domains, where it appears to be highly relevant. Moreover, the authors claimed that "the educational needs of spatially talented youths are more unmet than those of mathematically or verbally talented youths, because the typical middle and high school curriculum has many more opportunities for developing mathematical and verbal ability than spatial ability."

In the last decade , the most comprehensive study about the importance of spatial thinking was presented on the book called Learning to Think Spatially (2006) published by the committee in National Research Council. They defined spatial thinking as "…a constructive amalgam of three elements: concepts of space, tools of representation, and processes of reasoning." At the beginning of the book, the authors pointed out that although the physical world is (at least) three dimensional, the image captured on the retina and represented topographically in visual areas of the cortex is two dimensional. Thus, the three-dimensional world is a mental construct built from numerous cues to depth as well as experience navigating the world. Then in the remaining chapters they opened a discussion about to what extent the American K-12 educational system responding to needs by producing students who are at least familiar with spatial thinking? The authors claimed that currently there is no significant systematic treatment of spatial thinking as part of standards-based instruction in the United States. After detailed analysis of the science standards, it was also verified that there are neither content standards nor valid and reliable assessments for spatial thinking. Namely, there is spatial thinking and spatial reasoning content, but neither phrase appears in the text, nor are the concepts addressed explicitly and systematically. Spatial thinking is only an implicit but nevertheless essential part of the process of doing science. It is central to science, but it is not explicitly presented as part of the responsibility of science educators in fostering scientific literacy in K-12 students. At the end of the book, it was declared that spatial thinking is a missing link across the curriculum, K-12 students are not being taught systematically to think spatially because as a society and we do not yet recognize the pervasiveness of spatial thinking and appreciate its power and value. That is to say, it was not just undersupported, but underappreciated, undervalued and therefore underinstructed.

The reason for this persistent neglect has consistent and common historical roots. Mayer (1996) dealt with this problem and concluded that students' opportunities for expression mainly involve verbal and textual forms. He indicated that when the goal of instruction is to help students be able to explain a scientific system in words (retention) and to use this explanation to solve problems (transfer), a common instructional practice is to provide a lengthy verbal explanation, such as a textbook passage or a classroom lecture. Indeed, instructors may believe that providing a lengthy verbal explanation fulfills their responsibility to provide information to the learner. In addition, Mathewson (1999) stated that educators commonly neglect teaching visual-spatial thinking. An examination of most paper-based materials reveals that they do little to foster developmental growth of spatial abilities. Almost all assume that student will be able to make the mental leap, piecing together the spatial puzzle. Teachers often assume students understand the visual images present in science textbooks. Bannatyne (2003) estimated that 80% of jobs primarily depend on spatial ability, not on verbal ability and surgeons, pilots, architects, engineers, mechanics, builders, farmers, tradesmen, and computer programmers all rely on spatial intelligence. However, Black (2005) expressed that spatial ability has been neglected in traditional education. He elaborated that students with weaknesses in verbal abilities are encouraged and given a great deal of practice, usually no specific help is given to students with weaknesses in spatial ability. Such students may eventually abandon the study of spatially-related disciplines, such as mathematics and science, when those topics become more difficult in middle and high school. More recently, Lubinski (2010) used the nickname *a sleeping giant* for the spatial ability and claimed that education and training in the US are severely comprised by ceiling effects for one (mathematical reasoning) while the other (spatial ability) is totally neglected.

2.4. The Impact of Chemical Modeling on the Spatial Education

The teaching and learning of chemistry requires three levels of representations, namely, macroscopic, microscopic and symbolic (Johnstone, 1991). Macroscopic representations describe the visible features, microscopic representations are the invisible nature of the chemical entities and finally representations of the symbolic mode include the formulas and equations (Johnstone, 1991). However , these three modes of representing chemistry has been identified as one of the most challenging problems to learning chemistry, because students often experience difficulties in integrating the different representation modes and switching between different representations (Dori and Hameiri, 2003; Gabel, 1999; Johnstone, 1999).

In order to overcome this difficulty, different types of chemical models have been proposed widely in chemical research and education as a tool to explain, describe, and predict chemical concepts, processes, and phenomena (Barak and Dori, 2000). (Coll and Taylor, 2002) stated that chemistry as a discipline is dominated by the use of models and modeling. Gilbert (2000) expressed that constructing models of abstract chemical phenomena enhances student's conceptual understanding and diminishes misconceptions.

Although, the literature showed various forms of modeling to enhance the science achievement of the students, research indicated teachers do not employ modeling activities properly. The study of (Barnea and Dori, 2000) highlighted this problem and described that teachers frequently use just one type of model, limiting students' experience with models and causing their model perceptions to be partially or completely inadequate. In order to verify this situation, (Dori and Barak, 2001) conducted a survey among 20 science teachers and 31 chemistry teachers regarding the use of models. They investigated the types of models and the topics in which the various models were incorporated in chemistry or science courses. The most prevalent model was found to be ball-and-stick, and the two most popular topics in which models were used were simple molecules and organic compounds. Most teachers indicated that they use models in cooperative learning (32%) and demonstrations (51%). Only a minority (17%) indicated the use of models in individualized active learning. The study of (Dori and Barak, 2001) revealed that incorporating a combination of virtual and physical models in chemistry teaching/learning as a means to foster meaningful learning and spatial understanding of molecular structure.

Recent advancements in the computer technology triggered and accelerated the use of computer based modeling practices in chemistry lessons. In order to overcome student difficulties in connecting the different representation modes for understanding chemical concepts and facilitate the students' ability to use the multiple representations properly and meaningfully, researchers recently have developed a variety of computer based tools such as 4M: CHEM (Kozma and Russel, 1997), ChemViz (Beckwith and Nelson, 1998), CMM (Barnea and Dori, 1999), eChem (Wu and Soloway, 2001), Vischem (Tasker and Dalton, 2002), ChemSense (Schank and Kozma, 2002), ChemDiscovery (Agapova and Jones, 2002), ChemLogo (Stieff and Wilensky, 2002), and Connected Chemistry (Stieff and Wilensky, 2003).

These tools can provide different forms of multiple representation modes, such as molecular animations and structures. These representations facilitate the students' use of explicit links between different representation modes. Moreover, as (Stanford, 2004) underlined that traditionally teachers could not see students' conceptions until the exams. She expressed that by means of these representational tools, teachers monitor the details of each students' conceptions during the lectures. (Schank and Kozma, 2002) showed that using ChemSense in chemistry lessons promotes representational ability and chemical understanding of submicro mechanisms. (Wu and Soloway, 2001) found that eChem improved the development of translation abilities.

Through this current study, ChemSense software was used to create the computer based models. This software is the product of National Science Foundation funded research project. The ChemSense software enables to the students to create their own representations of chemical phenomena generating drawings, animations or text. The main reason for selecting ChemSense for this study was it is free software. Also, the interface of the software was not complicated and specialized tools within this interface allow the users to operate easily.

2.5. How to Improve the Spatial Ability

As the spatial ability is a broad and complex concept, it encompasses many research areas. (Sorby and Baartmans, 1996), and Sorby (1999) proposed that a diverse range of spatial activities may be the key to effective spatial ability and other factors, such as playing with toys or working memory capacity, may be involved suggested that activities that require eye-to-hand coordination are particularly useful in developing these skills such as: (i) playing with construction toys (e.g., Legos) as a young child, (ii) participating in classes such as shop, drafting, or mechanics as a middle school or secondary student, (iii) playing 3-dimensional computer games, (iv) participating in certain types of sports (e.g., basketball), and (v) having well-developed mathematical skills. Therefore, researchers from different disciplines conducted many studies to show the relation of the spatial ability to other subjects.

Miller (1990) showed that instruction with 3D solid models and computer models allowed students to further advance their spatial abilities as compared to traditional engineering graphics instruction. (Kali and Orion, 1997) looked for a relationship between introductory geology courses and spatial ability development. They found a positive relationship between studying earth science and spatial skill development, observing an improvement after one year. (Travis and Lennon, 1997) used the MAPLE software environment in undergraduate Calculus course where students performed three-dimensional representations of mathematical concepts. They found that students who used the software scored higher on a test of spatial skills than students in regular calculus course. Computer-based 3D visualizations can provide learners with adequate spatial experiences for developing their spatial ability (Kwon, 2003). (Glick and Porter, 2011) emphasized that many of the concepts that are taught in core level construction management courses require students to conceptualize various relationships based on pictorial or written representations and therefore that the topic of spatial relations is important in construction management education. In order to improve students' spatial visualization ability, the authors developed an interactive 3-D homework module and examined the integration this module for construction education. The outcome of this study showed that adoption of 3-D models leaded to improvements the homework grades. (Mantin-Dorta and Contero, 2011) attempted to measure to what extent the opportunities for mobility and the new user interfaces that handheld touch screen devices offer, in a non-formal learning context, with a view to develop spatial ability. This research has addressed two objectives. First one was to analyze the effects that training can have on spatial visualization using the educational content developed for this pilot study. Second one was to evaluate the experience of users in the use of handheld touch screen devices and their degree of satisfaction with the on-line course proposed. Sixty eight volunteer first year engineering students participated in the study whose mean age was 20 (range 17-28). The participants have no previous experience with handheld touch screen devices. This study used two groups where the experimental group consists of 38 students who have volunteered to do the training program, and the control group, made up of 30 students who receive no training during the week that this study lasts. After the treatment period, each participant has completed the Mental Rotation Test (MRT) (Albaret and Aubert, 1996). After the statistical analysis the authors concluded that the main effect of treatment group (experimental group vs control group) was significant, $F(1,63)= 16.745$, $p < 0.001$, showing better performances for participants receiving training compared to the control group. Moreover, results show that, despite the initial differences between men and women, with specific training men and women achieve a similar mean gain in the MRT test.

Moreover, some current research topics also proved that the domain of the spatial ability is expanding and beginning to cover more research areas than it was estimated. (Schuster and Evans, 2008) sought the degree to which spatial ability, specifically spatial visualization, mediates the relationship between video game experience and route planning for unmanned ground vehicles (UGV) and unmanned aerial vehicle (UAV) operators. The study of (Hegarty and Montello, 2009) included the students from dentistry education and examined how spatial abilities and skills enhance success in dental education programs and whether dental education enhances an individual's spatial competence. (Puts and Cardenas, 2010) examined the relation between the spatial ability and testosterone hormone. (Hoffman and List, 2011) argued that persistent spatial differences between the males and females stem from the different nutrition choices and they designed a study to show the role of nurture in the gender gap in spatial abilities.

Although the importance of the spatial ability is widely proven, there is no common agreement how to teach it. (Harle and Towns, 2010) argued that the question of whether or not practice (repeated testing) or specific training (learning or having experience with strategies that are not assessed on the task) can improve spatial ability has been at the center of an on-going debate. Although some researchers (Gee, 2007; Green and Bevalier, 2003; Spence and Jeng, 2010; Subramayham and Greenfield, 1996) question training effects, many more researchers advocate the use of training to improve spatial ability (Tillotson, 1984; Sorby and Baartmans, 2000; Martin-Dorta and Contero, 2008).

In favor of the spatial training, Tillotson (1984) stated that most researchers have agreed that spatial ability is a trainable attribute. In their results from a six-year longitudinal assessment of a course to help engineering students overcome deficiencies in 3-D spatial visualization, (Sorby and Baartmans, 2000) showed that the single most significant predictor of success in the first year graphics course at Michigan Technological University (MTU) was the Purdue Spatial Visualization Test: Rotations (PSVT:R). (Potter and van der Merwe, 2001) conducted action research and demonstrated that spatial ability influences academic performance in engineering, and can be increased through instruction focused on using perception and mental imagery in three-dimensional representation. They used the instructional model which was based on Piagetian principles, and confirms Piaget's theories with respect to the trainability of spatial ability in adulthood. Their findings suggested that the importance of early identification of students with difficulty, as well as the potential value of an intervention aimed at training the processes involved in visualization through three-dimensional modeling and representation of objects. While spatial ability appears to be trainable through the methods we have developed, their research also indicated that level of spatial ability at time of intake to university is an important influence on academic performance, suggesting the value of instruction in visualization and three-dimensional representation at school level.

Alias (2002) suggested that activities should include experiences ranging from manipulation of concrete models to computer visualization. Mohler (2007) mentioned that over 100 years of literature on the subject, it is no surprise that many studies have reported the positive effects of direct and indirect instruction on spatial ability. Basham (2007) informed that since spatial ability is multifaceted, attempts to improve it may affect one aspect while not others. In one study, students improved orthographic projection skills after computer animated graphics, but did not improve rotational skills. It appears that providing diverse spatial activities may be key to enhancing overall spatial visualization ability. (Martin-Dorta and Contero , 2008) concluded that the development of spatial abilities can be achieved effectively through specific training and outlined that traditionally, any engineering curriculum at European universities has included engineering design graphics subjects in which, during at least one academic year, students received basic training in systems of representation, sketching, technical drawing, and CAD. However, in this context, development of spatial abilities has not been an explicit learning objective, and the development of spatial abilities has been considered an indirect learning outcome. More recently, (Harle and Towns, 2010) suggested that students should receive direct instruction in transformation between chemical formulas (symbolic representations), and 2-D and 3-D representations of molecules. Depiction of conceptual knowledge such as chemical formulas as 2-D structures with appropriately embedded 3-D cues should be integrated into lectures, recitations, and laboratories across the semester.

In the contrary, many researchers have evidenced that in spite of the general agreement that spatial ability can be taught in formal educational settings, spatial skills may be particularly well learned through informal learning experiences (Greenfield and Lohr, 1994; Okagaki and Frensch, 1994; Sims and Mayer, 2002). One particularly good example is the consequences of playing spatially-challenging video games on spatial attention and reasoning. The evidence is quite strong that playing video games increases visual-spatial attention, that this effect is causal in nature, and that it transfers to other tasks (Gee, 2007; Green and Bevalier, 2003; Spence and Jeng, 2010; Subramayham and Greenfield, 1996). For example, Green and Bevalier, 2003 found that playing *World of Warcraft* was associated with better visual-spatial attention, enumeration, and several other spatial skills. Moreover, an experimental study of non-video game players showed that learning to play video games confers these advantages, and thus there is a causal relation between video game playing and spatial thinking. Informal spatial education need not be limited to videogame playing (Benjamin and Wilkerson, 2010). For example, informal building activities in museums can provide an opportunity for parents and children to practice the communication and learning of spatial information. Newcombe

(2010) indicated that preschool children whose parents use a greater number of spatial words (like outside, inside, under, over, around and corner) show better growth in spatial thinking than children whose parents do not use such language.

Another problem associated with the teaching spatial abilities is the lack of consensus on how to design the instructional activities. Although, researchers in recent years have conducted many investigations using different instructional methods to find the possible ways to improve spatial ability, only a limited number of studies have demonstrated with clear consensus showing the superiority of a certain approach. Baldwin (2002) considered the same problem asking the following question "*are there instructional strategies that will develop students' conceptual understanding of science and their spatial ability?"* It was argued in the same article that although the positive impact of the spatial ability on the achievement of the science courses has been reported, there still exists lack of agreement about what types activities and how much time are required to promote the spatial ability. The NRC report (2006) emphasized the same problem and suggested that spatial thinking is multifaced in its operation that comprises broad sets of interconnected competencies that can be taught and learned and: just as there is no single recipe for how to think verbally or mathematically, there is no single way to think spatially. Similarly, (Ferguson and Anderson, 2008) pointed out that there has been no clear consensus on what combination or duration of instructional methods are most effective for improving spatial ability. Finally, Newcombe (2010) expressed the same problem. She suggested that there certainly are situations in which instruction is appropriate, effective, and efficient to foster the development of the spatial skills. However, she expressed that there is a lack of a coordinated approach on how to promote the spatial development in the educational settings.

2.6. Spatial Ability Research in Chemistry

Research on the role of spatial ability in teaching and learning chemistry has been accelerated during the last three decades. Especially, the successive studies of Bodner

(Bodner and McMillan, 1986; Pribly and Bodner, 1987; Carter and Bodner, 1987) during the second half of 1980s can be accepted as the spark of this development.

Bodner and McMillan (1986) suggested that chemistry courses are ideal places to help students learn how to solve problems and high spatial ability in organic chemistry lessons enhance the problem solving skills in areas where the problem does not actually involve visualization. For the verification of this claim, they examined the correlation between university students' scores on spatial ability tests and problem solving performance in general or organic chemistry. They administered a battery of four tests to collect the data in which the spatial ability of the participants was measured through the Purdue Visualization of Rotations Test (Guay, 1977). They found statistically significant correlation between the students' performance on the spatial tests and their performance on highly spatial concepts in chemistry such as the structures of metallic and ionic solids. Moreover, their results revealed that there were statistically significant correlations between spatial ability and achievement, not only on spatial concepts such as the manipulation of solids, but also on multiple choice stoichiometry problems. Thus, this study proposed that the spatial ability of students can be improved by means of experiencing the spatial tasks and that this can enhance the students' ability to solve a wide range of scientific problems by improving their ability to identify and restructure relevant information.

(Pribly and Bodner, 1987) designed an ongoing study to investigate the extent to which spatial ability affects performances of university students across a spectrum of organic courses. They used two tests to measure spatial ability: the 20-item version of the Purdue Visualization of Rotations test (Bodner and Guay, 1997) and the 20-item Find-A-Shape-Puzzle (Linn and Gans, 1981; Linn and Kyllonen, 1981). This study suggested that there was a small but positive relationship between spatial ability and achievement in organic chemistry. Students with high spatial scores did significantly better on questions which required problem solving skills, such as completing a reaction or outlining a multi-step synthesis, and questions which required students to mentally manipulate two-dimensional representations of a molecule. However, spatial ability was not significant for questions which could be answered by rote memory or by the application of simple algorithms.

(Carter and Bodner, 1987) investigated the relationship between spatial ability and performance in introductory chemistry courses, two spatial tests were given to 1648 students in a course for science and engineering majors and 850 students in a course for students from nursing and agriculture and performance on these spatial tests were correlated with students' scores on chemistry exams and subscores created by grouping similar exam questions. Two measures of spatial ability were used in this study: the 20-item version of the Purdue Visualization of Rotations test (Bodner and Guay, 1997), and the 20-item Find- A-Shape-Puzzle (Linn and Kyllonen, 1981; Linn, Pulos and Gans, 1981). The results of this study were consistent with (Pribly and Bodner, 1987) and it was suggested that general chemistry students with high spatial ability significantly outperformed students with low spatial ability on molecular geometry and crystal structure exam questions.

(Coleman and Gotch, 1998) published the results of the longitudinal study which examined chemistry students in three different courses and focused on changes in mental proficiencies of those students during a 12-year period, between 1979 and 1994. Initially, students were just given the cognitive development tests from fall to spring 1982. They administered the 72-items multiple choice test called An Inventory of Piaget's Developmental Task (IPDT) to students in three freshman chemistry courses to measure the changes in the cognitive development. The tests were administered in the first half of each semester before topics of molecular geometry and hybridization were introduced. Between the years 1992 and 1994, they expanded the study to include the analysis of the spatial ability. Lastly, using a subset of our test population, they studied how the use of concrete and computer models to affect cognitive performance in the spatial area. A group of students in worked with models in 1992 and 1994. During the modeling sections in 1992, students used the ball-and-stick models and performed a lab based on measuring bond lengths and bond angles using ball and stick models. Students in 1994 used computer models using stick-frame and space-filling models of VSEPR structures of H_2O, NH_3, CH_4, and CCl_4 and the same molecules used in the ball-and-stick laboratory experiment. The results of this study showed that students' spatial abilities can be refined through educational interventions. This study also suggested that learning the subjects of chemistry is closely linked to strong spatial ability skills. The researchers suggested that using models in a lab, a hands-on activity, or computer models should be a means to stimulate spatial skills. Finally, the researchers indicated that time duration of the modeling practices are important factor and one or two 1-2 hour sessions practices with models are not adequate to improve the spatial ability.

The importance of using student generated physical models for the improvement of the spatial ability in chemistry lessons has long been mentioned by many researchers (Barke, 1993; Kahveci, 2009; Barke and Engida, 2001; Bakker, 2008; Uyulgan and Kartal 2010).

Barke (1993) questioned whether the illustrations of space models actually recognized as being spatial by the learners? He argued that although student generated models are beneficial tools to promote the understanding of the essential chemistry concepts such as close packing of spheres, crystal lattices or molecular models of other elements and compounds, the common practice for the teachers is to show models as illustrations in school books or in transparencies. Moreover, teachers expect the students to recognize the illustrated space models' as three-dimensional structures or to determine the coordination numbers as 12 and 6 from given models. The researcher designed a study that included the students from seven, eight and ninth grades where their average ages were 13, 14 and 15 respectively. Then, he developed a test called ‘Space Test’ that contained the illustrations of polyhedrons and spatial cubes. The test contained 56 items arranged as multiple choice questions that have to be answered within 45 min. The test was taken before and after all lessons involving the introduction of chemical symbols. During this period of about four months the experimental group worked with structural models such as packing of spheres, crystal lattices, and 3D-stereo-pictures. They built structural models of substances before and after chemical reactions, and derived chemical symbols from these models (formulae of substances, equations of chemical reactions).In control groups formulas were introduced by means of comparison of masses or the mole concept. These groups did not use structural models in their lessons. The results of the study showed that the experimental group using structural models achieved significantly (5 % level) better results in spatial ability than all control groups. The researcher expressed that the improvement of all groups can be explained through knowing and repeating the space test and the *big improvement* of the experimental group is due to and increase in spatial ability. The researcher concluded that spatial ability has not developed sufficiently compared to general intelligence until grade eight and students cannot be expected to recognize two dimensional drawings or illustrations of spatial structures as being three-dimensional at the age of 14. In grades eight and nine, spatial ability has improved so far, compared with general intelligence, that this ability can be presupposed in the majority of students. Due to the fact that many students at-the-age of 14 or 15 are in Piaget's stage of "concrete operations of thinking", real spatial models of the structure of solids such as close packing of spheres and crystal lattices should be employed first. Later on the teacher can begin using two-dimensional illustrations of structural models. Now the students are able to recognize spatial relations that they have seen with real models.

Another research by (Kahveci, 2009) showed that the concept of crystal lattice is challenging even for older students. She conducted a cross-sectional survey to prospective chemistry teachers in the university from first to fifth years to outline prospective chemistry teachers’ profile, understand their teaching beliefs and attitudes toward teaching as a profession and investigate the prospective teachers’ understanding of fundamental chemistry concepts, including the concepts of element, compound, the particulate nature of matter and chemical bonding. One hundred and forty chemistry teacher candidates responded voluntarily to the surveys. The results of the study revealed that fourth year students, totally 19 students, were the least successful with the idea that sodium chloride (table salt) did not exist in molecular form but as a lattice consisting of sodium and chloride ions (25.7% of students answering correctly). The researcher connected this deficiency former science curriculum. She stated that former science curriculum did not include the separate units about the particulate nature of matter as a chemistry concept. She added that, in Turkey, science curricula for middle school have been renewed since 2005 and it is not surprising that the pre-service teachers still rely on insufficient chemistry knowledge traditionally taught with an implicit mention of the particle model of matter at most.

(Barke and Engida, 2001) organized an ongoing study to compare the spatial abilities of students at grades 7-12 of secondary schools (ages 13-18 years), from two different countries which were Germany and Ethiopia. The researchers suggested that although true understanding of structures in chemistry requires a sufficient level of spatial ability and the stick-and-ball model of molecular structures widely used in organic chemistry lessons to discuss isomers or to derive structural formulas, it is not common practice to use ball-and-stick model, sphere packings or crystal lattices as structural models of inorganic solids. The researcher expressed that because of this deficiency, students know formulas like NaCl, $CaCl_2$ or Al_2O_3, but they have no mental pictures of the structures of these substances. They hardly even know about any crystal structure. They further have no idea about the building blocks of these crystal structures, because unit cells are usually not part of high-school curricula in Germany. In this descriptive study, both researchers collected data just using Barke's Spatial Ability Test. It was applied to randomly selected classes from both counties. Totally 1505 students participated in the study where 763 students were from Ethiopia and 742 from Germany. The analysis of the test scores revealed that as far as secondary schools are concerned, childhood experiences and cultural factors play probably little part in explaining differences in spatial abilities and the school curricula was indicated to be the most influential factor in determining the differences in spatial ability of secondary school students. Moreover, it was suggested that students should start to use the structural models as early as possible and it was claimed that students in grade 8 can be expected to find the coordination number, to extract the elementary cube out of the closest cubic packing, to work with the unit cell. Finally, the researchers suggested that the structures of molecules should be visualized with the aid of the well-known ball-and-stick models or other molecular models. Working with structural models will not only help students to develop their spatial ability earlier than usual, it would also lead to a better understanding of chemistry, especially to understanding the meaning of formulas and equations. If students are asked to build structural models by themselves, they will develop both abilities: good chemical understanding and spatial ability.

Bakker (2009) investigated the effects of Tridio on 5th-graders' (11-year-olds') spatial ability. Tridio is the learning material that developed with the aim of enhancing primary school children's spatial ability in the Netherlands and consisting of cubes with white, black, and green sides, mosaic pieces in the same colors and a board to place the cubes on. Of the cubes, opposite sides have the same color, while adjacent sides have different colors. Accompanying this material, several exercise sets have been developed. Accompanying exercises involving isometric and orthogonal views has been developed with the aim of enhancing children's spatial ability. Some exercises require the student to construct a cube building displayed in a picture. In others, an orthogonal top view and two side views of a cube building are provided, and the student is asked to make a cube building that fits all three views. Another core activity with Tridio is to lay out the isometric view of a cube building using the mosaic pieces. Around 40% of primary schools in the Netherlands have purchased the Tridio material as estimated by Herel (2008), in part because of its assumed benefits for advancing children's spatial skills. In this study, a matched-pairs pretest-posttest design (25 pairs) was used. Experimental group children received training with Tridio totally 2.5 hours were split up into five sessions of 30 minutes each to keep the students' motivation high and improve the effectiveness of the training (Baenninger and Newcombe, 1989). Spatial relations were measured using the Card Rotations test and the Flags test; the Paper Folding test and the Mental Rotations test were used as tests of VZ. Furthermore, a content-specific test of Tridio performance was administered. Partial correlations between the content-specific and the spatial ability test scores, controlling for school performance, indicated that Tridio adds to the general school curriculum in focusing on spatial ability, but that not all types of Tridio exercises contribute to this. Transfer effects of the Tridio training on spatial ability were, however, not found. With a higher power, effects on SR may be found, but probably not on VZ. The authors suggested that the found lack of effect on VZ may be due to the young age of the participants, or to the fact that many children did not get to the more complex Tridio exercises. Content-specific effects were present, indicating that children possibly learned something other than spatial ability.

(Uyulgan and Kartal, 2010) implemented a study with the second year university students during the inorganic chemistry laboratory sections. The students were expected to construct the crystal lattice structure of given salts using the play doughs and the tooth sticks. During the implementation part, students' ability to indicate the number of cations and anions, coordination numbers of them and their effect on the structure and vacancy types in the structure were evaluated. It was found that the most difficult part to construct the lattice structure was the coordination number and the researcher reported that there were 36 participants in the study and no one was able to calculate the exact coordination number for the given lattice. In addition to, they stated that students did not take into account the number of cations and anions in the unit cell.

Some researchers have revealed that computer based models are as effective as physical model to promote the spatial ability of the chemistry students. (Wu and Soloway, 2001) argued that many students experience the difficulties about the mental transformation between two-dimensional (2-D) and three-dimensional (3-D) representations and are not able to form 3-D mental images by viewing 2-D chemical structures and to mentally rotate 3-D images. In their study, they investigated how students developed an understanding of chemical representations with the aid of a computer-based visualizing tool, eChem that allowed them to build molecular models and view multiple representations simultaneously. During the study, students had learning activities that incorporated the main actions of eChem for studying hydrocarbons and alkanes (eChem I), names of alkanes (eChem II), and representations of chemistry (eChem III) for two entire weeks. The first eChem activity was tied to a lecture on covalent bonds and introduced structures and properties of organic compounds. Students constructed models of alkanes, viewed various representations simultaneously, and developed an understanding of the relationship between boiling points of alkanes and their number of carbon atoms. The second activity introduced the IUPAC (International Union of Pure and Applied Chemistry) nomenclature of organic compounds, the naming rules currently used in chemistry. Students created models on eChem and followed the rules to name their models. For example, they made an eChem model with a total of six carbon atoms and one substituent group and then named and drew it on paper. The third activity was designed for students to visualize various two-dimensional (2-D) and three-dimensional (3-D) chemical representations. The 2-D representations included structural formulas, condensed structural formulas, very condensed structural formulas, and chemical formulas. The 3-D models constructed in this activity were ball-and-stick, space-filling, and wire-frame models. Students constructed models on eChem and with ball-and-stick model kits and compared differences and similarities between these two types of models. At the end of the study a positive learning effect, shown by the significant difference between the scores of pre- and posttests, may be partially attributed to using a visualization tool in science classrooms. A computer-based visualization tool like eChem in particular improved students' ability to make transformations between 2-D and 3-D models, and this ability might help them to develop an understanding of isomers and polarity.

Some researchers used the physical models and computer models together to compare their effects on the spatial ability in other disciplines. Sorby (2001) designed and implemented a trimester course to improve spatial skills for engineering students; students that worked with handheld objects and interactive computerized models four hours a week for ten weeks improved their scores on tests of spatial ability. The study of (Ferguson and Anderson, 2008) sought to determine the effects of mechanical dissection manipulatives on improving the spatial visualization ability of freshmen students in two Technology Systems course sections where one group received lectures and exercises on engineering drawing principles and practices while *the other* group received hand-held mechanical dissection manipulatives for use in lectures and exercises on engineering drawing principles and practices. The Purdue Spatial Visualization Test: Rotations was used as the pre-post measure of SV ability. The study yielded that there was a statistically significant difference in the pre-post scores for Group EM, but no significant difference for Group E. Similarly, Yıldız (2009) investigated the effects of using 3-D virtual environments and concrete manipulatives on spatial visualization and mental rotation abilities in chemistry. For this purpose, a 3-D virtual unit block simulation was designed. A pre-test post-test experimental research design that was quasi-experimental type was followed in the study. The study was implemented at a public school and a private school. The 3-D virtual environment was used in the experimental groups. Unit blocks were used as concrete manipulatives in the control groups. Spatial Visualization and Mental Rotation Tests were applied before and after the implementations. There was a minimum of 21 days between pre-tests and posttests. In the public school; Spatial Visualization and Mental Rotation Test scores increased both in experimental and control groups. In terms of Spatial Visualization Test scores, there was a statistically significant difference in favor of the experimental group; however, there was no significant difference between the groups in terms of Mental Rotation scores. In the private school; Spatial Visualization and Mental Rotation Test scores increased in the experimental group; however, there was no change in scores for the control group.

In the correlational study of Sorby (2006) the relationship between spatial skills and success in advanced chemistry courses were examined. Namely, 3-D spatial skills, as measured by the Purdue Spatial Visualization Test: Rotations (PSVT:R), were compared to student performance in two different chemistry courses—University Chemistry II and

Organic Chemistry II. It was noted that the most spatially demanding task in the study of general chemistry is thermodynamics and the most challenging component of the organic chemistry would be chirality and mirror images. This study revealed the significant correlations between spatial skill levels and performance on two of three exams in University Chemistry II were observed. However, there were no significant correlations between spatial skill levels and performance in Organic Chemistry II were found, in contrast with previous studies on the subject.

Sorby (2006) implemented a study with 450 students from middle and high school students to investigate the effect of multimedia computer software which was originally designed for university students. The studies indicated that the workbook and software materials developed by (Sorby and Wysocki, 2003) for college students in engineering were effective when used with middle school students. Two key components were added in the schools study: active teacher involvement, and the use of peer mentoring.

2.7. How Spatial Ability Measured?

Many tests have been developed to measure spatial skills. Some of the primary tests used in educational research to assess the spatial skills include the Mental Cutting Test (MCT), The Mental Rotation Test (MRT), The Perspective Taking/Spatial Orientation Test (SOT), and The Purdue Spatial Visualization Test: Rotations (ROT).

The Mental Cutting Test (1939) was first developed for a university entrance exam in the USA and consists of 25 items. For each problem on the exam, students are shown a criterion figure which is to be cut with an assumed plane. They must choose the correct resulting cross-section from among five alternatives.

The Mental Rotation Test (Vandenberg and Kuse, 1978) is developed to assess a person's skill in visualizing rotated. It includes consists 20 items. Each problem contains a criterion figure with two correct alternatives and two incorrect alternatives. Students are asked to identify which two of the alternatives are rotated images of the criterion figure.

The Perspective Taking/Spatial Orientation Test (Hegarty and Kozhevnikov, 1999) presents participants with a picture of an array of objects. Each item consists of a circle with a line drawn from the center to the top of the circle. The center is marked with the object they are to imagine themselves standing at, the top is marked with the name of the object they are to imagine themselves facing, and the participant is asked to indicate the angle to the third object by drawing another line from the center of the circle. Participants were given four minutes to complete the 10 items on the test.

The Purdue Spatial Visualization Test: Rotations (ROT) was developed by (Guay, 1977). It includes 30 multiple-choice items. With this test, students are shown a criterion object and a view of the same object after undergoing a rotation in space. They are then shown a second object and asked to indicate what their view of that object would be if the second object were rotated by the same amount in space. This study employed ROT to assess the participants' spatial ability in which it has a adequate validity and reliability on assessing spatial ability as it was mentioned in methodology section.

To sum up, the review of the literature section, the literature indicated that various studies using the different types of modeling practices have been carried out to enhance the students' ability to think spatially. However, there are no studies that have explored the comparative effects of constructing the physical and computer based models on the influence of the spatial ability of high school students. Therefore, there is a need for the current educational settings that combine activities which foster an understanding of this concept. This study was intended to fill this gap for the concept of the spatial ability and the conceptual understanding of the ionic lattice.

3. SIGNIFICANCE OF THE STUDY

Chemical entities are mainly dominated spatially relevant features and students in chemistry lessons have to mentally translate among the representations of 2D and 3D spaces to interpret events that take place in space. As Bannatyne (2003) emphasized the intellectual ability that primarily used to function and operate in 2 or 3 dimensional spaces is the spatial ability. Although the significance of spatial ability in chemistry education has been evidenced substantially, three is still a lack of agreement on how to teach spatial ability and how to integrate spatial activities across the school curriculum. The report of National Research Council (NRC, 2006) emphasized this problem and reported that spatial ability was not just undersupported, but underappreciated, undervalued and therefore underinstructed. The report also recommended infusing and integrating diverse spatial thinking activities throughout K-12 curriculum. Similarly, chemistry education in Turkey has suffered from neglecting the training of the spatial ability formally in school curriculum. The renewed chemistry curriculum have been begun to implement since 2007, the new chemistry curriculum documents did not include any explicit connections to develop the students' spatial ability.

This current study included the crossover research design combining the computer based modeling and physical modeling and examined to what extent integration of two modeling activities impact students' spatial ability and conceptual understanding of the lattice structure. More specifically, this study design included two instructional sequences by switching the treatment orders and compared the effectiveness of this design conditions on the conceptual understanding of the ionic lattice and the spatial ability. These two basic features of the study will be a guide for the future studies by showing the predominant role of integration of two models based instructional tools on the spatial ability and the conceptual understanding of the ionic lattice structure. Moreover, the shifting nature of treatments will be a guide for chemistry educators as a new pedagogical approach to enhance the student's achievement of the spatial ability and conceptual understanding of the ionic lattice.

4. STATEMENT OF THE PROBLEM

People need sufficient amount of spatial abilities to communicate easily. Spatial abilities allows people to use concepts of shape, features, and relationships in both concrete and abstract ways, to make and use things in the world, to navigate, and to communicate (Cohen and Hegarty, 2003; Newcombe and Huttenlocher, 2000)

Much of the literature shows that interventions can improve spatial ability (Bodner and McMillen, 1986; Pribyl and Bodner, 1987; Barke, 1993; Sorby, 2009; Terlecki and Newcombe, 2008). Spatial ability can be improved in secondary school students (Barke, 1993, Coleman, 1998; Sorby, 2006). Several studies indicate that spatial ability can be improved if training with appropriate materials are provided (Cohen, 2003; Potter and van der Merwe, 2001).

However, as Lohman (1993) define the spatial ability as the ability to generate, retain, retrieve, and transform well-structured visual images and argued that spatial abilities have long been relegated to a secondary status in accounts of human intelligence and the typical middle and high school curriculum has many more opportunities for developing mathematical and verbal ability than spatial ability. As (NRC, 2006) suggested there is urgent need in how to utilize spatial ability for curriculum design and in how to refine educational interventions and procedures on the basis of individual differences in spatial ability. (Mantin-Dorta and Contero, 2011) stated that over the last half century, spatial abilities have been given increasing recognition and, despite the fact that not so much attention has been paid to them as to verbal and numeric abilities.

Basham (2007) indicated that there is little emphasis in the educational system on the development of spatial abilities, perhaps because such abilities are taken for granted or believed to be innate. Moreover, as (Ferguson and Anderson, 2008) indicated that there has been no clear consensus on what combination or duration of instructional methods is most beneficial for improving spatial visualization ability.

The main motivation to implement this study to ninth graders was that latest version of Turkish chemistry curriculum documents that do not consider the topic of spatial ability as a core concept as the previous versions of the curriculum. Moreover, none of the current national chemistry curriculum documents for secondary schools include specific set of objectives about the topic of spatial ability which is inevitable component for success in chemistry. Although, the renewed ninth grade chemistry curriculum includes the topic, crystal lattice structures of the salts, which is closely related with the spatial ability, the objectives of this topic implicitly includes the connections with the spatial ability. It just suggests using modeling activities to teach the structures of salts without focusing the spatial ability. The researcher recognized the importance of enabling the students to learn the spatial ability and decided that it must be taught as possible as at early grades to foster the understanding of chemistry concepts meaningfully. Then, the researcher selected ninth grades to administer the study and designed instructional sequences to promote spatial abilities of the students building crystal lattice structures through the two kinds of instructional activities: physical and computer – based modeling.

The present study has two main purposes. The first one is to develop and carry out two different instructional activities which were computer based modeling and physical modeling for two different treatment groups by switching the treatment order. The second one is to improve the spatial ability and conceptual understanding of students during the 9th grade chemistry lesson.

4.1. Research Questions

The present study examined the effects of types of instructions on the spatial ability and conceptual understanding of ionic lattice using following research questions. There were 13 research questions in the study and they were grouped under the five categories.

4.1.1. Investigating the Effect of Computer-Based Modeling

Research Question 1: Is there any significant effect of creating computer-based models of ionic lattice using the program ChemSense on promoting 9th grade students' conceptual understanding of ionic lattice?

Research Question 2: Is there any significant effect of creating computer-based models of ionic lattice using the program ChemSense on promoting 9th grade students' spatial ability?

4.1.2. Investigating the Effect of Physical Modeling

Research Question 3: Is there any significant effect of constructing physical models of ionic lattice on promoting 9th grade students' conceptual understanding of ionic lattice?

Research Question 4: Is there any significant effect of constructing physical models of ionic lattice on promoting 9th grade students' spatial ability?

4.1.3. Comparing the Effects of Two Types of Instructions

Research Question 5: Is there a significant difference between the two treatment groups where one group used computer-based modeling and the other one used physical modeling on promotion of conceptual understanding of ionic lattice of 9th grade students?

Research Question 6: Is there a significant difference between the two treatment groups where one of them used the computer based modeling and the other one used the physical modeling with regard to the promotion of spatial ability of 9th grade students?

4.1.4. Investigating the Effect of Having Two Types of Instructions

Research Question 7: Is there any significant effect of constructing a model of ionic lattice first with computer-based modeling using ChemSense and then with physical models on promoting 9th grade students' conceptual understanding of ionic lattice.

Research Question 8: Is there any significant effect of constructing a model of ionic lattice first with computer-based modeling using ChemSense and then with physical models on promoting 9th grade students' spatial ability?

Research Question 9: Is there any significant effect of constructing a model of ionic lattice first with physical models and then with computer-based modeling using ChemSense on promoting 9th grade students' conceptual understanding of ionic lattice?

Research Question 10: Is there any significant effect of constructing a model of ionic lattice first with physical models and then with computer-based modeling using ChemSense on promoting 9th grade students' spatial ability?

4.1.5. Comparing the Effects of Order of Types of Instructions

Research Question 11: Is there a significant difference between the promotion of conceptual understanding of ionic lattice of 9th grade students in two different treatment groups who use modeling methods in reverse orders?

Research Question 12: Is there a significant difference between the promotion of spatial ability of 9th grade students in two different treatment groups who use modeling methods in reverse orders?

4.1.6. Analysis of Students Generated Materials

Research Question 13: To what extent switching the order of two different instructional methods, namely computer–based modeling and physical modeling, promote the ability of students to use more spatially related terms during drawing, modeling and writing activities?

4.2. Variables and Operational Definitions

4.2.1. Variables

The dependent variables of this study were students' spatial ability and conceptual understanding of ionic lattice and the independent variables were the types of instruction for the ninth grade ionic bonding topic.

4.2.2. Operational Definitions

Spatial ability: It was agreed in this study that spatial ability is the combination of the subskills. This study was conducted the treatments and measurements according to the definition of Martín-Dorta, Saorín, and Contero (2008) where they defined two subskills for the spatial ability which were;

- Spatial Relations: the ability to imagine rotations of 2D and 3D objects as a whole body.
- Spatial Visualization: the ability to imagine rotations of objects or their parts in 3D spatial by folding and unfolding.

Conceptual Understanding of Ionic Lattice: It refers to students' understanding level of the lattice structure of the ionic salts based on scores of conceptual tests.

Types of Instructional Tools: It refers to two types of instructional tools that received in switching order which were computer-based modeling and instruction with physical modeling.

5. METHODOLOGY

5.1. Sample

The school that was chosen for this study is private high school which is situated in Sakarya, in Turkey. It is a foundational school that situated 5 km from the city center of Sakarya and founded immediately after the Marmara earthquake of 1999. The school has six hundred students who are granted by scholarships in their education from the primary school until the end of university years. The researcher has been teaching chemistry for eleven years at the same school. The researcher conducted this research in the classes he has been teaching chemistry.

The research was carried out in two sections of ninth grade , 9-A and 9-B during their chemistry lessons. Two hours of chemistry per week was allocated as a compulsory course. The medium of instruction was Turkish. The sample of the study consisted of 43 students. The average age of the students was 15. Table.1 illustrates the demographic profile of the sample.

Table 5.1. Demographic Characteristics of the Sample.

Treatment Group	Sample Size	Gender	Frequency	Percent
Group CP	21	Male	8	38
		Female	13	62
Group PC	22	Male	9	41
		Female	13	59

The sampling procedure that was employed in this study was the convenient sampling method. There were three reasons that governed this selection. The researcher was an only chemistry teacher in the school, there were only two ninth grade classes in the school and the subject of interest in this research included in the ninth grade chemistry curriculum. Based on the researcher’s knowledge and experience of the population and addressing the purpose of the research, the researcher purposively decided to select these classes. The assignment of the classes into the control and experimental groups was done randomly in order to eliminate bias.

5.2. Design and Procedure

This study involved random assignment of intact groups to treatments, not random assignment of individuals. A crossover research design was used (Ratkowsky and Alldredge, 1993) where the same group of students with the same teacher received a sequence of different treatments.

The study included two groups and the design of this study was presented in Table 5.1. These randomly assigned groups were given two different treatments to compare the effects of interventions. One of the groups, Group CP firstly studied with computer-based models using ChemSense software and then with physical models using play dough. Other group, Group PC studied in reverse order, first physical and then computer-based modeling.

The overall data collection was carried out in three sections. These sections were lasted in the following order: pre-treatment, treatment-1 and treatment-2. Through these treatments multiple sources of data were collected. Students did not receive any instruction about the crystal lattice of the ionic salts before and between the treatments.

In the pre-treatment section, four different tests were administered as a pretest to both treatment groups. At the beginning of the study, the participants were informed about the procedure of the study. Firstly, Purdue Spatial-Visualization Test/Visualization of Rotations (ROT) was administered to measure the students' existing level of spatial ability. The duration of the test was 10 minutes as suggested by the developers. Secondly Conceptual Test-1 (CT1) was administered to measure the students' existing level for the prerequisites of the structures of ionic lattices. Third test was drawing from Text (DT1). Before the treatment, all participants were given the text that describes the formation of NaCl ionic lattice structure. Then, a drawing task was administered to measure how students will interpret and draw the spatial information about ionic lattice structure. Fourth test was Writing from Picture (WP1). Before the treatment, all participants were given the picture that depicts the ionic lattice of LiCl. Then, a writing task was administered to measure how students interpreted and explained the spatial relations in the picture.

Before the first treatment, students in both groups were taught how to use ChemSense program. This activity was carried out during the regular class hours by computer teachers and lasted for one class hour (40 minutes).

Following the ChemSense study, participants took the first treatments. Group CP carried out computer-based modeling and Group PC carried out physical modeling treatment. At the end of the modeling activities, the researcher kept the student developed models to use them for the quantitative analysis. Physical models were kept in the form of digital photos and ChemSense models were sent to the researcher’s mail account. After the first treatments, four different tests were administered as first posttests. Firstly, Spatial-Visualization Test/Visualization of Rotations (ROT) was administered to measure to what extent the first treatments promoted the students’ spatial ability. Conceptual Test-2 (CT2) was administered to measure to what extent the conceptual understanding of students about the structure of the ionic lattice structure promoted after the first treatment. Drawing from Text (DT2) was administered to investigate to what extent representational competence of students about the spatial relations depicted in texts promoted after the first treatments. Participants took the spatial test about CsCl lattice formation and produced their own drawings using pencils for DT2. Writing from Picture (WP2) test was administered to investigate to what extent the interpretation ability of students about the spatial relations depicted in pictures promoted after the first treatments. Participants took the Picture of MgO lattice structure and wrote down their interpretations for WP2.

During the second treatments Group CP carried out physical modeling and Group PC was received computer-based modeling treatment, in other words the order of the first treatment was switched. At the end of the section, the researcher took the photos of the physical models and obtained the ChemSense models via e-mail for the analysis section. After the second treatment, four different tests were administered as second posttests considering the same purposes and application order as in the first posttests. The improvement with respect to spatial ability was measured through Purdue Spatial-Visualization Test/Visualization of Rotations (ROT), the change in students’ conceptual understanding was measured through Conceptual Test-3 (CT3). The spatial text that depicts the crystal lattice structure of AgCl salt was given for Drawing from Text-3 (DT3). The picture of MgS salt lattice structure was given for Writing from Picture-3 (WP3). No instruction was given during and between the treatments.

Table 5.2. Design of The Study.

TREATMENTS	MEASUREMENTS
Pre – Treatment	ROT Conceptual Test – 1 (CT1) Drawing from Text – 1 (DT1) Writing from Picture – 1 (WP1)
ChemSense Introduction	ChemSense (Introduction & Practice)
Treatment – 1	Group – 1 ChemSense Modeling
	Group – 2 Physical Modeling
Post Test – 1	ROT Conceptual Test – 2 (CT2) Drawing from Text – 2 (DT2) Writing from Picture – 2 (WP2)
Treatment – 2	Group – 1 Physical Modeling
	Group – 2 ChemSense Modeling
Post Test – 2	ROT Conceptual Test – 3 (CT3) Drawing from Text – 3 (DT3) Writing from Picture – 3 (WP3)

5.3. Instruments

5.3.1 Purdue Spatial-Visualization Test : Rotations (ROT)

The Purdue Spatial Visualization Test: Rotations (ROT) (See Appendix A) was developed by Guay (1977). It is a paper pencil test and consists of 20 multiple-choice items. The ROT was designed to measure the participants' ability to visualize the rotation of three-dimensional objects. The ROT was used in this study to measure the participants' spatial visualization ability. It will be based on the mental rotation task in which students must decide as quickly as possible whether one object when rotated in three dimensional space would look the same as another.

With this test, students are shown a criterion object and a view of the same object after undergoing a rotation in space. Then, they are given five choices, one of which matches the rotation of the original object example. Finally, they are asked to indicate what their view of that object would be if the second object were rotated by the same amount in space. 8th question of the ROT given as a sample question shown below in Figure 5.1.

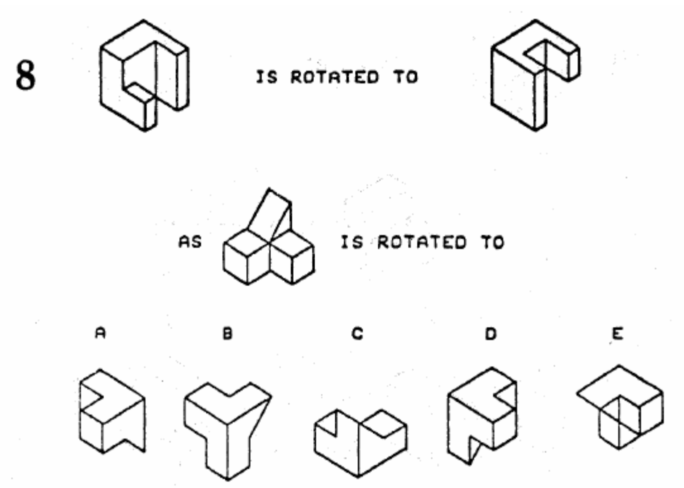


Figure 5.1. A sample Question from The Purdue Spatial Visualization Test: Rotations (ROT)

The instrument was administered to all participants in 10 minutes and scored using the key provided by the publisher.

Reliability for original ROT on studies of chemistry students (Bodner and Guay, 1997), report the Kuder-Richardson 20 (K-20) internal consistency test values of .80, .78, and .80 with samples of 758, 850, 1273 respectively. They also reported Split Half reliabilities of .83, .80, .84, .85, .82, and .78 with samples of 757, 850, 127, 1273, 1648, and 158 respectively. During this current study, the researcher firstly translated the original ROT to the Turkish and calculated the Split Half Reliability. The highest Cronbach alpha value was found to be 0.57 which is less than .80 and indicated the poor internal consistency.

The construct validity for the original ROT is supported by a study of five measures of spatial ability (Bodner and Guay, 1997). The highest correlation was between the ROT and the Shepard-Metzler test ($r=0.61$, $p<0.001$). The lowest correlation was between ROT and the Minnesota Paper Form Board (MPFB) test ($r=0.25$, $p<0.01$).

5.3.2 Conceptual Tests

Three different conceptual tests were used in this study to assess and monitor participants' chemical understanding of structures of ionic lattices. These tests were developed by the researcher. First conceptual test was used as a pretest. Second and third conceptual tests were used as postest1 and posttest2 respectively. All conceptual tests were prepared on the item by item basis identically. The content validity of the items in CT1, CT2, and CT3 were performed qualitatively by two academicians and one chemistry teacher.

<u>5.3.2.1. Conceptual Test–1 (CT1).</u> CT1 consisted of six items (See Appendix B). It is developed by the researcher to measure students' prior knowledge on the prerequisite topics for the crystal lattice structures and students' preconceptions about the structure of the crystal structures. The first two items of the test was prepared to measure students'

prerequisite knowledge about the crystal structures. The prerequisite concepts included in the first two questions in CT1 were valance electrons, charges on ions and Lewis structure. These prerequisites were determined according to the concept lists stated in ninth grade chemistry curriculum prepared by the Ministry of National Education. Next four open-ended questions of the test was prepared to measure students' pre-instructional conceptions of the structure of ionic lattices. The administration of test lasted 10 minutes. The participants did not study the concept of the ionic lattice prior to this study. They started to learn this concept through this study.

For the inter-scorer reliability 25% of the student paper, 11 papers, for CT1 were randomly selected. The researcher and a chemistry teacher scored students answer according to answer key using scoring tables developed by researcher. Then the interrater reliability analysis using Cohen's Kappa statistic was performed to determine consistency among raters. The interrater reliability for the raters was found to be Kappa = 0.955 which indicated the almost perfect agreement.

<u>5.3.2.2. Conceptual Test–2 (CT2).</u> Conceptual Test-2 (CT2) was prepared as a posttest1 by the researcher to measure the effect of first treatments (See Appendix C). It consisted of six items. The administration of test lasted 10 minutes. The sequence of items in test was prepared in parallel with CT1.

The first two items of the test was prepared to measure to what extent the treatment enhanced the students' initial knowledge about the prerequisite concepts; valance electrons, charges on ions and Lewis structure. Next four open – ended question of the test was prepared to measure to what extent the treatments enhanced students' understanding of the structure of ionic lattices.

11 CT2 papers of 43 students, which are 25% of the all students' papers, were selected randomly to measure the interrater reliability. The researcher and a chemistry teacher conducted the reliability study using the answer key developed by the researcher. Then, the interrater reliability analysis was carried out using Cohen's Kappa which was calculated as Kappa = 0.899. This meant that there is almost perfect agreement between the raters.

<u>5.3.2.3. Conceptual Test – 3 (CT3).</u> Conceptual Test-3 (CT3) was prepared as a posttest2 by the researcher to measure the effect of second treatments (See Appendix D). It

consisted of six items. The administration of test lasted 10 minutes. The sequence of items in test was prepared in parallel with CT1.

The first two items of the test was prepared to measure to what extent the treatment enhanced the students’ initial knowledge about the prerequisite concepts; valance electrons, charges on ions and Lewis structure. Next four open-ended question of the test was prepared to measure to what extent the treatment enhanced students’ understanding of the structure of ionic lattices.

Interrated reliability analysis was fulfilled using 11 different CT3 papers of randomly selected students among totally 43 students. This step was performed by the researcher and a chemistry teacher using the answer key which was developed by the researcher. The analysis was carried out through Cohen’s Kappa statistic. The analysis revealed that there was almost perfect agreement between the raters where Kappa = 0.919.

5.3.3 Drawing from Text Tests

Immediately after the conceptual tests, participants had to perform the drawing tasks. Participants had to draw all the relevant information they could interpret from the spatial texts on a blank paper in any order. Three different drawing tests were used in this study to assess and monitor participants’ representational elaboration of structures of ionic lattices. These tests were developed by the researcher. First drawing test was used as a pretest. Second and third drawing tests were used as postest1 and posttest2 respectively. All drawing tests were prepared identically. Each drawing session lasted 10 minutes. The content validity of the items in DT1, DT2 and DT3 were done qualitatively. Two academicians and one chemistry teacher examined DT1, DT2 and DT3 for the content validity.

<u>5.3.3.1 Drawing from Text Test–1 (DT1).</u> Drawing from text test-1 (DT1) was developed by the researcher to assess the initial preconceptions of students about the structure of the ionic lattices (See Appendix E). It consisted of three open-ended items that aimed to probe macro, micro and symbolic level representational competences of students

respectively. First and second items required students to use drawings to show their understanding of what an ionic lattice of LiCl salt looks like at the macroscopic and microscopic level respectively. Third item required students to use iconic representations to show the formation of the LiCl salt ionic lattice.

The researcher and a chemistry teacher scored the papers of DT1 using the answer key to calculate the interrater reliability analysis. 11 papers of 43 students were selected randomly to carry out the analysis. The interrater reliability analysis was performed using Cohen's Kappa statistic. Kappa = 0.893 was found after the analysis. This proposed that there was high consistency between the raters and showed the almost perfect agreement.

<u>5.3.3.2 Drawing from Text Test–2 (DT2).</u> Drawing from text test-2 (DT2) was developed as a posttest1 by the researcher to assess the effect of first treatment on students' understanding of the structure of the ionic lattices (See Appendix F). It consisted of three open – ended items that aimed to probe macro, micro and symbolic level representational competence of students respectively. First and second items required students to use drawings to show their understanding of what an ionic lattice of MgO salt looks like at the macroscopic and microscopic level respectively. Third item required students to use iconic representations to show the formation of the MgO ionic lattice.

In order to conduct the interrater reliability, 25% of DT2 papers were selected randomly which were 11 papers. This analysis was performed by the researcher and a chemistry teacher. They used the answer key which was developed by the researcher. After scoring DT2 papers, the data was analyzed using Cohen's Kappa statistic to examine the consistency among raters. This analysis indicated that there was the almost perfect agreement among the raters where Kappa = 0.914.

<u>5.3.3.3 Drawing from Text Test–3 (DT3).</u> Drawing from text test-3 (DT3) was developed as a posttest2 by the researcher to assess the effect of second treatment on students' understanding of the structure of the ionic lattices (See Appendix G). It consisted of three open – ended items that aimed to probe macro, micro and symbolic level representational competence of students respectively. First and second items required students to use drawings to show their understanding of what an ionic lattice of MgS salt looks like at the macroscopic and microscopic level respectively. Third item required students to use iconic representations to show the formation of the MgS ionic lattice.

Interrater reliability analysis was conducted by the researcher and a chemistry teacher. Firstly, 11 papers among 43 DT3 paper were selected randomly which was 25% of DT3 papers. Then, these 11 DT3 papers were scored using the answer key developed by the researcher. After this step, the data gained after scoring was analyzed using Cohen's Kappa to find the consistency among the raters. This analysis revealed that there was the almost perfect agreement between the raters where Kappa = 0.928.

5.3.4 Writing from Picture Tests

Three different writing tests were used in this study to assess and monitor how the participants interpret the representational sources of spatial information. Prior to every administration each participant was given a pictorial representation of lattice structure of an ionic salt. Then, students were asked to write down what they interpret from the pictures. Tests were developed by the researcher. First writing test was used as a pretest. Second and third writing tests were used as postest1 and postest2 respectively. All writing tests were prepared item by item basis identically. The content validity of the items in WT1, WT2 and WT3 were evaluated qualitatively by two academicians and one chemistry teacher.

<u>5.3.4.1. Writing from Picture Test–1 (WT1).</u> Writing from picture test-1 (WT1) was developed by the researcher as a pretest to assess the initial preconceptions of students about the structure of the ionic lattices (See Appendix H). Students were given a pictorial illustration of ionic lattice structure of LiCl salt. They were expected to provide only verbal descriptions to write down what they understand from the picture.

The interrater reliability analysis of WT1 was performed by the researcher and a chemistry teacher. They scored randomly selected 11 papers of 43 WT1 papers using the answer key developed by the researcher. In order to determine the consistency between the raters, Cohen's Kappa value was calculated and it was found as Kappa = 0.841. This result indicated that there was almost perfect agreement between the rates with respect to WT1 scores.

5.3.4.2. Writing from Picture Test–2 (WT2). Writing from picture test-2 (WT2) was developed by the researcher as a posttest to assess to what extent students' understanding about the structure of the ionic lattices was changed after the first treatments (See Appendix I). Students were given a pictorial illustration of ionic lattice structure of MgO salt. They were expected to provide only verbal descriptions to write down what they understand from the picture.

For the interrater reliability 25% of the student papers, which was equal to 11 papers for WT2 were randomly selected. The researcher and a chemistry teacher scored students answer according to answer key using scoring tables developed by researcher. Then the interrater reliability analysis using Cohen's Kappa statistic was performed to determine consistency among raters. The interrater reliability for the raters was found as Kappa = 0.929 which indicated the almost perfect agreement.

5.3.4.3. Writing from Picture Test – 3 (WT3). Writing from picture test-3 (WT3) was developed by the researcher as a posttest to assess to what extent students' understanding about the structure of the ionic lattices was changed after the second treatments (See Appendix J). Students were given a pictorial illustration of ionic lattice structure of MgS salt. They were expected to provide only verbal descriptions to write down what they understand from the picture.

The interrater reliability study of WT3 was carried out by the researcher and a chemistry teacher. Firstly, 11 papers of 43 WT3 papers were selected randomly to perform the analysis. Then, these papers were evaluated using the answer key developed by the researcher. As a last step, Cohen's Kappa analysis was used to analyze the data obtained after the scoring. The result of the analysis showed that Kappa = 0.923. This meant that there was high consistency between the raters and indicated the almost perfect agreement.

5.3.5 ChemSense and Physical Models

During the modeling treatments, each student developed two different modeling to represent the crystal lattice structure and composition NaCl salt. The researcher developed a scoring rubric to measure to what extent the student-generated physical and ChemSense models reveal the spatial features of the lattice crystals. The content validity of the items in this scoring rubric was performed qualitatively by two academicians and one chemistry teacher.

The interrater reliability analysis was carried out using 25% of the student generated models, namely 11 physical models and 11 ChemSense models were randomly selected among 43 models of ChemSense and physical models. The researcher and a chemistry teacher scored students' models according to answer key developed by researcher. Then the interrater reliability analysis was performed using Cohen's Kappa statistic to determine consistency among raters. The interrater reliability for the raters was found to be Kappa = 0.854 which indicated the almost perfect agreement.

5.4. Treatments and Instructional Materials

This section includes the detailed description of the treatments and the instructional materials. The researcher developed the instructional sequences to achieve the multiple pedagogical goals which are to investigate the comparative effects of two different modeling activities, which were computer–based and solid modeling and to promote the spatial abilities and conceptual understandings of the participants.

The duration of the study was three-weeks, namely totally eight lesson hours. Two treatment groups, Group CP and Group PC conveniently determined and randomly assigned to the two treatment groups. Modeling activities took place in two different learning environments. ChemSense modeling activities held in the computer lab and physical modeling activities held in the chemistry lab. Both groups are assigned to construct the same unit cells at the same order but switching the modeling methods. Students in both groups worked individually during the treatments.

During the modeling activities, students were expected to realize the relationship between the structure and composition of ionic salts and the researcher simply observed the participants' performances and reasoning without commenting on their accuracy. Modeling activities provided the participants with an opportunity to describe the role of electrons in creating lattice structure identify the relative sizes of ions, describe the number of cations and anions in the lattice structure and the arrangement of cations and anions in ordered crystal lattice structures.

During the instructional activities, both treatment groups carried out the same task using the identical handouts (See Appendix K and Appendix L). The only difference between the handouts was that students had to follow the different modeling approaches to complete the same task. Students in one group used the play doughs and the other group used the ChemSense software to represent the three dimensional lattice structures of the salt lattice or vice versa. Handouts included two sections. First section included the procedure of the study and the spatial text passage taken from ninth grade chemistry textbook published by the Ministry of Education of Turkish which describes the formation of crystal structures textbook individually. The second section included three follow-up questions about the activity.

Physical modeling sections lasted two lesson hours, namely 80 minutes. Students worked individually. This section consisted of hands-on molecule modeling activities. Students generated three dimensional crystal lattice models of NaCl salt. Physical models were developed using easily accessible and safe materials which were play doughs and tooth sticks. The ions in the lattice were made using play doughs because of their relatively durable forms and different colors to display different ions. Bonds were made of toothpicks which are cheap and easier to stick in. Play doughs were provided by the researcher. At the beginning of the treatment, the researcher placed all boxes of the play doughs on the teacher desk and students were allowed to choose their own color and sufficient amount to represent the ions in the lattice. During the activity, students shaped the play doughs into the shape of different forms to represent the ions and their sizes and attached the toothpicks to represent the chemical bonds and display the arrangements of ions in the crystal lattices. During and after the treatment, the researcher just observed the students’ reasoning without commenting and took the instant photos and videos of the students’ work to use in the analysis part.

Computer modeling sections lasted two lesson hours. Students used the computer generated visualizing tool ChemSense to draw three dimensional lattice structure of NaCl salt. ChemSense software was installed in every computer before the treatments by the researcher. The use of ChemSense software was freely warranted by the developer. The

ChemSense software is an open source product of the National Science Foundation funded research project. The goal of developing the ChemSense software is to help students overcome their difficulties in understanding chemical concepts by providing students access to rich representational tools that can fill a gap in their ability to experience or imagine the world of invisible molecular entities (http://www.chemsense.sri.com). During the ChemSense activities, the participants used the toolbars and the drawing area to build their own models of ionic lattice structures. To select the ions of interest, they firstly clicked the icon of the ball molecules in the toolbar. After clicking, a colored periodic table, named as choose an element or ion, appeared in a small window. Students then selected the element and moved it the drawing area. To select the bonds, they followed the same steps using the icon of single line in the toolbar menu. Then, students created their own ChemSense models as the following screen capture presents one of the participants' NaCl model in Figure 5.2. During and after the treatment, the researcher observed the students' reasoning without commenting and took the instant photos and videos of the students' work to analyze. At the end of the treatment, students saved their ChemSense models on the desktop and also mailed the researcher through e-mail.

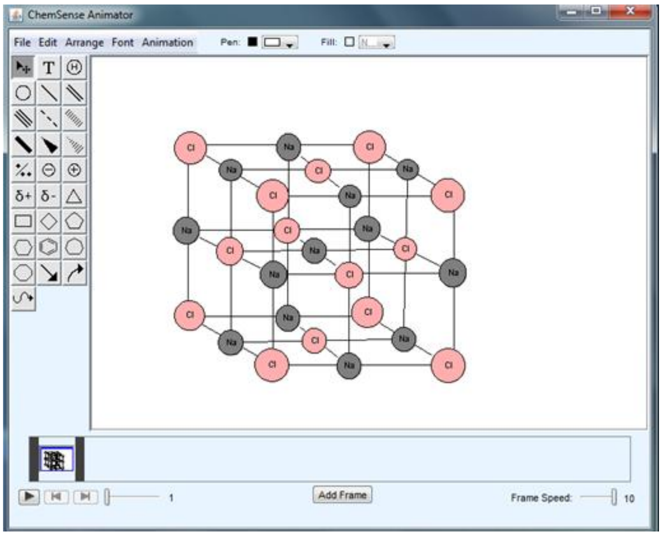


Figure 5.2. An Example of NaCl Crystal Lattice Model Developed in ChemSense.

6. DATA ANALYSIS AND RESULTS

To determine the effect of the independent variables (instruction with computer based modeling and instruction with physical modeling) on the dependent variables (conceptual understanding of the ionic lattice and spatial ability), the data were gathered from 43 students which were conveniently selected from two classes of the same school, one of them had 21 students and the other one had 22 students. This study included 13 research questions. These questions were grouped under the investigating the effect of computer-based modeling, investigating the effect of physical modeling, comparing the effects of two types of instructions, Investigating the effect of having two types of instructions, comparing the effects of order of types of instructions, and analysis of student generated materials. As the data were in the ratio level; t-test was used for the first 12 research questions, to infer the conclusions. Table 6.1 summarizes which statistical method was performed for each research question and which groups were compared.

Table 6.1. Statistical Analysis Procedures for Research Questions 1-12.

Research Question	Dependent Variable	Compared Treatments	Statistical Analysis
RQ1	Conceptual understanding	CT1 – CT2 scores of Group CP	Paired sample t - test
RQ2	Spatial Ability	ROT1 – ROT2 scores of Group CP	Paired sample t - test
RQ3	Conceptual understanding	CT1 – CT2 scores of Group PC	Paired sample t - test
RQ4	Spatial Ability	ROT1 – ROT2 scores of Group PC	Paired sample t - test
RQ5	Conceptual understanding	CT1 and CT2 scores of Group CP&PC	Independent samples t - test
RQ6	Spatial Ability	ROT1 and ROT2 scores of Group CP&PC	Independent samples t - test
RQ7	Conceptual understanding	CT1 – CT3 scores of Group CP	Paired sample t - test
RQ8	Spatial Ability	ROT1 – ROT3 scores of Group CP	Paired sample t - test
RQ9	Conceptual understanding	CT1 – CT3 scores of Group PC	Paired sample t – test
RQ10	Spatial Ability	ROT1 – ROT3 scores of Group PC	Paired sample t - test
RQ11	Conceptual understanding	CT1 and CT3 scores of Group CP&PC	Independent samples t - test
RQ12	Spatial Ability	ROT1 and ROT3 scores of Group CP&PC	Independent samples t - test

6.1. Investigating the Effect of Computer-Based Modeling

Research Question 1: Is there any significant effect of creating computer-based models of ionic lattice using the program ChemSense on promoting 9th grade students' conceptual understanding of ionic lattice?

For the analysis of research questions where the dependent variable was *conceptual understanding* of ionic lattice, the analyses were performed quantitatively using descriptive and inferential statistical methods. Students received three different conceptual tests, each lasted for 10 minutes. First conceptual test (CT1) was given in the beginning of the study as a pretest, second conceptual test (CT2) was given after the first treatments as posttest1 and third conceptual test (CT3) was given after the second treatments as posttest2. All conceptual tests included six identical questions about Lewis diagram, valance electrons, ionic radius, electrostatic forces, and lattice structure of salts. The validity and reliability of these conceptual tests were completed prior to the study. All the students received conceptual tests at the same order. Responses of the students were evaluated using the answer keys where the total score of each conceptual test was 41.

The effectiveness of conducting computer based modeling through ChemSense on conceptual understanding of ionic structure of Group CP was evaluated in the analysis of research question 1. For the descriptive part of the analysis, students' scores on conceptual tests were computed, and then descriptive statistics were carried out in order to compare the mean score of students in each group. The mean of scores of CT1 and CT2 were calculated for Group CP and it is found to be $M=13.52$ and $M=15.00$. Table 6.2 shows the mean and standard deviation of scores of students from CT1 and CT2. These results indicated that the mean scores of Group CP increased at the end of study compared to CT1.

Table 6.2. Descriptive Statistics of CT1 & CT2 Scores of Group CP.

Test	Mean	Std. Deviation	N
CT1	13.5238	6.20982	21
CT2	15.0000	6.44205	21

As it is displayed in Table 6.2, there was an increase in the CT scores of students in the CP group. Then, paired samples t-test was carried out to compare the mean CT scores of students in order to determine whether this increase is statistically significant or not. The results of the analyses were presented on Table 6.3.

Table 6.3. Paired Samples t – Test Results of CT1 & CT2 Scores of Group CP.

Compared Tests	t	df	Sig. (2- tailed)	Mean	Std. Deviation	Std. Error Mean
CT1 & CT2	0.922	20	0.368	1.47619	7.33907	1.60152

As it is shown in Table 6.3, analyzing the scores of CT1 and CT2, no statistically significant difference ($p>0.05$) was found. The result of the analysis for Group CP revealed that there was no statistically significant effect of constructing computer-based models by using ChemSense on the improvement of conceptual understanding of the ionic lattice of students, $t(20) = 0.922$, $p= 0.368$.

Research Question 2: Is there any significant effect of creating computer-based models of ionic lattice using the program ChemSense on promoting 9th grade students' spatial ability?

For the analysis of the second research question where the dependent variable was *spatial ability*, the paired samples t-test analysis was carried out using the Purdue Spatial Visualization Test: Rotations (ROT) scores. Before the study, ROT was translated to Turkish by the researcher. This 20 multiple-choice items and 10 minutes lasting test was administered three times to both treatment groups in the same order before the study (ROT1), after the first treatments (ROT2) and after the second treatments (ROT3). The responses of students were evaluated using the answer key supplied by the developer of the test. Each correct answer was given one point and there was no penalty for incorrect answers. After obtaining the students' scores, the descriptive and inferential statistics were used to make inferences from data.

Analysis of research question 2 was carried out to reveal the effect of creating computer-based models of ionic lattice using the program ChemSense for Group CP on spatial ability of 9th grade students. First, descriptive statistics were carried out to compare students' mean scores of ROT1 and ROT2 tests for Group CP. The mean of scores in ROT1 and ROT2 were calculated for students in Group CP, and they were found to be M=9.91 and M=11.14. Table 6.4 shows the mean and standard deviation of scores of students in ROT1 and ROT2. These results indicated that the mean scores of Group CP increased at the end of first treatment compared to ones in the beginning of the study.

Table 6.4. Descriptive Statistics of ROT1 & ROT2 Scores for Group CP.

Test	Mean	Std. Deviation	N
ROT1	9.9048	2.7185	21
ROT2	11.1429	3.3658	21

As it is displayed in Table 6.4, there was an increase at the end of the study in the ROT scores of students in the Group CP. Then, paired samples t-test was carried out for the mean scores of students within the same group to determine whether this increase is statistically significant or not.

In order to perform paired samples t-test within Group CP, total scores of students obtained from ROT1 and ROT2 were compared. The results of the analyses were presented in Table 6.5.

Table 6.5. Paired Samples t – Test Results of ROT1 & ROT2 Scores for Group CP.

Compared Tests	t	df	Sig. (2- tailed)	Mean	Std. Deviation	Std. Error Mean
ROT1 & ROT2	2.244	20	0.036	1.23810	2.52794	0.55164

As it is shown in Table 6.5, a statistically significant difference ($p<0.05$) was found between the scores of ROT1 and ROT2 before and after constructing computer-based models of ionic lattice using ChemSense. The result of the analysis for Group CP revealed that there was a statistically significant effect of constructing computer-based models using ChemSense on the improvement of spatial ability of students, $t(20) = 2.244$, $p= 0.036$.

6.2. Investigating the Effect of Physical Modeling

Research Question 3: Is there any significant effect of constructing physical models of ionic lattice on promoting 9th grade students' conceptual understanding of ionic lattice?

First, as it was described in research question 1, students' scores on CT1 and CT2 were calculated, then descriptive statistics were carried out in order to compare students' mean scores in these tests. The aim of this analysis was to evaluate the effect of treatment on conceptual understanding of ionic lattice for the Group PC who first received physical modeling treatment using Play Doughs and then computer-based modeling treatment using ChemSense. The mean of scores of conceptual test-1 (CT1) and conceptual test-2 (CT2) were calculated for Group PC and they were found to be M=11.91 and M=14.77. Table 6.6 shows mean and standard deviation of scores of students during CT1 and CT2. These results indicated that the mean scores of Group PC were increased at the end of study as it compared with CT1.

Table 6.6. Descriptive Statistics of CT1 and CT2 Scores of Group PC.

	Mean	Std. Deviation	N
CT1	11.9091	4.60754	22
CT2	14.7727	5.95164	22

As it is displayed in Table 6.6, there was an increase at the end of the study in terms of CT scores of students in Group PC where students used the physical modeling. Then, paired samples t-test was carried out for the mean scores of students in order to determine whether this increase is statistically significant or not.

In order to perform the paired samples t-test, all the scores obtained from CT1 and CT2 were tabulated and analyzed. The results of the analyses were presented on Table 6.7.

Table 6.7. Paired Samples t – Test Results of CT1 Scores for Group PC.

Compared Tests	t	df	Sig. (2- tailed)	Mean	Std. Deviation	Std. Error Mean
CT1 & CT2	2.212	21	0.038	2.86364	6.07333	1.29484

As it is presented in Table 6.7, a statistically significant difference ($p<0.05$) was found, analyzing the scores of CT1 and CT2. The result of the analysis for Group PC revealed that there was a statistically significant effect of constructing physical models using Play Dough on improvement of conceptual understanding of ionic lattice of 9th grade students, $t(21) = 2.212$, $p= 0.038$.

Research Question 4: Is there any significant effect of constructing physical models of ionic lattice on promoting 9th grade students' spatial ability?

As described in the analysis of research question 2 first, students' mean scores of ROT1 and ROT2 were calculated, then descriptive statistics were carried out in order to compare their mean scores of ROT1 and ROT2 for the students in Group PC. The students in Group PC first received the physical treatment using Play Doughs and then the computer based modeling treatment using ChemSense. The aim of this analysis was to evaluate the effect of first treatment, constructing physical models, on the spatial ability of 9th grade students. The mean of scores in ROT1 and ROT2 were calculated for Group PC and they were found to be M=10.96, and M=11.82. Table 6.8 shows mean and standard deviation of scores during the ROT1 and ROT2. These results indicated that students in Group PC reached higher score average in ROT2 than ROT1.

Table 6.8. Descriptive Statistics of ROT Scores of Group PC.

Test	Mean	Std. Deviation	N
ROT1	10.9550	3.2729	22
ROT2	11.8182	3.6598	22

As it is revealed in Table 6.8, there was an increase at the end of the study in of the ROT scores of the students after the treatment of building physical models using Play Doughs. Then, paired samples t-test was carried out to compare the mean scores of students within the same group in order to determine whether this increase is statistically significant or not as it is presented in Table 6.9.

Table 6.9. Paired Samples t-Test Results of ROT Scores for PC.

Compared Tests	t	df	Sig. (2- tailed)	Mean	Std. Deviation	Std. Error Mean
ROT1 &ROT2	1.749	21	0.095	0.86364	2.31549	0.49366

As it is shown in Table 6.9, statistically no significant difference ($p>0.05$) was found between the scores of ROT1 and ROT2 of students in Group PC. The results of the analysis for Group PC revealed that constructing physical models did not have a significant effect on improving spatial ability of 9th grade students, $t(21) = 1.749$, $p= 0.095$.

6.3. Comparing the Effects of Two Types of Instructions

Research Question 5: Is there a significant difference between the two treatment groups where one group used computer-based modeling and the other one used physical modeling on promotion of conceptual understanding of ionic lattice of 9th grade students?

First, as described in research question 1, students' scores on conceptual understanding tests, CT1, and CT2, were calculated, and then descriptive statistics were carried out in order to compare students' mean scores in these tests. The aim of this analysis was to compare the effectiveness of the first treatments in each group on the conceptual understanding of ionic lattice structure by comparing test scores of CT1 (Conceptual Test-1 administered at the beginning of study as pretest) and CT2 (Conceptual Test-2 administered after the first treatments as posttest1). Group CP received the computer based modeling using ChemSense and Group PC received the physical modeling treatment using Play Doughs. The mean of scores of conceptual test-1 (CT1) for Group CP and Group PC were calculated and they were found to be M=13.52, and M=11.91. Table 6.10 shows mean and standard deviation of scores of students from Group CP and Group PC after CT1. These results indicated that the mean score of CT1 of Group CP was higher than that of Group PC.

Table 6.10. Descriptive Statistics of CT1 Scores for groups CP & PC.

Test	Groups	Mean	Std. Deviation	N
CT1	Group CP	13.5238	6.20982	21
	Group PC	11.9091	4.60754	22

Then, independent samples t-test was carried out the mean scores of CT1 from Group CP and Group PC in order to determine whether this difference is statistically significant or not. Table 6.11 shows the comparison of the mean scores of Group CP and Group PC with respect to CT1 test scores.

Table 6.11. Independent Samples t – Test Results of CT1 Scores for Groups CP & PC.

Compared Tests	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
CT1	0.917	0.344	0.971	41	0.337	1.61472	1.66217

The analysis of data showed that there was no statistically significant difference ($p>0.05$) between the Group CP and Group PC in terms of CT1 scores where t (41) = 0.344, p=0.337. So, the groups were said to be similar in terms of their conceptual understanding of ionic lattice.

In the second part of this analysis, the mean of scores of conceptual test - 2 (CT2) for Group CP and Group PC were calculated and they were found to be M=15.00 and M=14.91. Table 6.12 shows mean and standard deviation of scores of students from Group CP and Group PC after CT2. These results indicated that the mean scores of both groups increased from CT1 to CT2. Also, this table revealed that, as it appeared during CT1, the mean score of Group CP was higher than Group PC, yet the groups were not significantly different from one another.

Table 6.12. Descriptive Statistics of CT2 Scores for Groups CP & PC.

	Groups	Mean	Std. Deviation	N
CT2	Group CP	15.000	6.44205	21
	Group PC	14.7727	5.95164	22

Then, independent samples t-test were carried out the mean scores of CT2 from Group CP and Group PC in order to determine whether this difference was statistically significant or not. Table 6.13 shows the comparison of the mean scores of Group CP and Group PC with respect to CT2 test scores.

Table 6.13. Independent Samples t – Test Results of CT2 Scores for Groups CP & PC.

Compared Tests	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
CT2	0.300	0.587	0.120	41	0.905	0.22727	1.89019

Table 6.13 indicates the comparison of the mean scores of Group CP and Group PC with respect to CT2 test scores. The analysis of data showed that there was no statistically significant difference ($p>0.05$) between Group CP and Group PC in terms of CT2 scores where $t(41)= 0.587$, $p= 0.905$. These results revealed that the first treatments led to no significant learning difference in terms of conceptual understanding of lattice structure of ionic salts between the two treatment groups.

*Research Question 6***:** Is there a significant difference between the two treatment groups where one of them used the computer based modeling and the other one used the physical modeling with regard to the promotion of spatial ability of 9th grade students?

In order to compare the calculated mean score values of spatial ability tests of the students from Group CP and Group PC, as it was mentioned in the research question 2, firstly descriptive statistics were employed. Group CP received the computer based modeling using ChemSense and Group PC received the physical modeling treatment using Play Doughs. The aim of this analysis was to compare the effectiveness of the first treatments in each group on the spatial ability by comparing test scores of ROT1 administered at the beginning of study as pretest) and ROT2 (administered after the first treatments as posttest1). The mean of scores of ROT1 for Group CP and Group PC were calculated and they were found to be M=9.91, and M=10.96. Table 6.14 shows mean and standard deviation of scores of students from Group CP and Group PC after ROT1. These results indicated that the mean score of ROT1 of Group PC was higher than Group CP.

Table 6.14. Descriptive Statistics of ROT1 Scores for Groups CP & PC.

	Groups	Mean	Std. Deviation	N
ROT1	Group CP	9.9048	2.7185	21
	Group PC	10.9550	3.2729	22

Then, independent samples t-test was carried out for the mean scores of ROT1 for Group CP and Group PC in order to determine whether this difference was statistically significant or not. Table 6.15 shows the comparison of the mean ROT1 scores of students in Group CP and Group PC.

Table 6.15. Independent Samples t-Test Results of ROT1 Scores for Groups CP & PC.

Compared Test	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
ROT1	1.186	0.283	1.141	41	0.260	1.04978	0.91990

The analysis of data showed that there was no statistically significant difference ($p>0.05$) between the Group CP and Group PC in terms of ROT1 scores where $t(41) = 0.283$, $p=0.260$. Therefore, the groups were said to be similar in terms of their spatial abilities before the treatments they received.

In the second part of this analysis, the mean ROT2 scores of students in Group CP and Group PC were calculated and they were found to be M=11.14, and M=11.82. Table 6.16 shows mean and standard deviation of scores of students from Group CP and Group PC after ROT2. These results indicated that the mean scores of both groups increased from CT1 to CT2. Also, this table revealed that, the mean ROT2 scores of Group CP was higher than that of Group PC.

Table 6.16. Descriptive Statistics of ROT2 Scores for Groups CP & PC.

	Groups	Mean	Std. Deviation	N
ROT2	Group CP	11.1429	3.3658	21
	Group PC	11.8182	3.6598	22

After computing the mean values for ROT2 tests, independent samples t -test was carried out for the mean scores of ROT2 for Group CP and Group PC to determine whether this difference was statistically significant or not. Table 6.17 indicates the comparison of the mean scores of Group CP and Group PC with respect to ROT2 test scores.

Table 6.17. Independent Samples t – Test Results of ROT2 Scores for Groups CP & PC.

Compared Test	F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
ROT2	0.026	0.872	0.629	41	0.533	0.67532	1.07371

The analysis of data showed that there was no statistically significant difference ($p>0.05$) between Group CP and Group PC in terms of ROT2 scores where $t(41) = 0.872$, $p= 0.533$. This result reveals that the first treatments did not lead to statistically significant differences in terms of the spatial ability between the two treatment groups.

6.4. Investigating the Effect of Having Two Types of Instructions

Research Question 7: Is there any significant effect of constructing a model of ionic lattice first with computer-based modeling using ChemSense and then with physical models on promoting 9th grade students' conceptual understanding of ionic lattice?

First, as it was described in research question 1, students' scores on conceptual understanding tests were calculated, then descriptive statistics were carried out to compare students' mean scores of in these tests. Group CP first received the computer based modeling using ChemSense, and then received the physical modeling treatment using Play Doughs. The aim of this analysis was to evaluate the combined effect of two treatments, constructing computer-based and physical models, on conceptual understanding of the lattice structure by comparing test scores of CT1 (Conceptual Test-1 administered at the beginning of study as pretest) and CT3 (Conceptual Test-3 administered after two treatments as posttest2). The mean of scores of conceptual test-1 (CT1) and conceptual test-3 (CT3) were calculated for Group CP and it is found to be M=13.52, and M=18.19 respectively. Table 6.18 shows mean and standard deviation of scores of students during CT1 and CT3. These results indicated that the mean scores of Group CP increased at the end of study compared to the scores before any treatment, namely CT1.

Table 6.18. Descriptive Statistics of CT1 & CT3 Scores of Group CP.

	Mean	Std. Deviation	N
CT1	13.5238	6.20982	21
CT3	18.1905	7.08956	21

The analysis of Table 6.18 showed that there was an increase at the end of the study the of CT scores. Then, in order to conclude whether this increase was statistically significant or not, paired samples t-test was carried out to compare the mean scores of students before and after having two treatments. The results of the analyses were presented on Table 6.19.

Table 6.19. Paired Samples t-Test Results of CT1 & CT3 Scores for Group CP.

Compared Tests	t	df	Sig. (2- tailed)	Mean	Std. Deviation	Std. Error Mean
CT1 & CT3	2.872	20	0.009	4.66667	7.44536	1.62471

As it is presented in Table 6.19, statistically significant difference ($p<0.01$) was found as a result of the analysis of the scores of CT1 and CT3. The result of analysis for Group CP revealed that there was a statistically significant effect ($p<0.01$) of combined treatments; constructing computer models first using ChemSense and then physical models using Play Doughs on improvement of conceptual understanding of the ionic lattice of 9^{th} grade students, $t(20) = 2.872$, $p= 0.009$.

Research Question 8: Is there any significant effect of constructing a model of ionic lattice first with computer-based modeling using ChemSense and then with physical models on promoting 9th grade students' spatial ability?

This analysis of research question 8 was performed to compare the combined effects of two treatments for Group CP where firstly received the computer-based modeling using ChemSense and then received the physical modeling treatment using Play Doughs. This analysis conducted in three steps where initially students' scores on ROT tests were calculated, then descriptive statistics were carried out and finally paired samples t-test were performed. Test scores of ROT1 (administered at the beginning of study as pretest) and ROT3 (administered after two treatments as posttest2) were used to infer the effects of two treatments on the spatial ability of 9^{th} grade students.

The mean of scores of ROT1 and ROT3 were calculated for Group CP and they were found to be $M=9.91$, and $M=12.57$. Table 6.20 shows mean and standard deviation of scores of students in ROT1 and ROT3. These results indicated that the mean ROT scores of Group CP increased at the end of study (ROT3) compared to the scores in ROT1.

Table 6.20. Descriptive Statistics of ROT Scores of Group CP.

	Mean	Std. Deviation	N
ROT1	9.9048	2.7185	21
ROT3	12.5714	3.4434	21

Table 6.20 indicated that there was an increase at the end of the study in terms of ROT scores. In order to determine whether this increase was statistically significant or not, paired samples t-test was carried out to compare the mean scores of students before and after having two treatments. The results of the analyses were presented on Table 6.21.

Table 6.21. Paired Samples t – Test Results of ROT Scores for Group CP.

Compared Tests	t	df	Sig. (2- tailed)	Mean	Std. Deviation	Std. Error Mean
ROT1 & ROT3	4.044	20	0.001	2.66667	3.02214	0.65949

As it is presented in Table 6.21, analyzing the scores of ROT1 and ROT3, the scores were found to be statistically significant different ($p<0.01$) The result of analysis for Group CP showed that there is a statistically significant effect of combined treatments; constructing computer models using ChemSense first and then physical models using Play Doughs on the improvement of the spatial ability, $t(20) = 4.044$, $p= 0.001$.

Research Question 9: Is there any significant effect of constructing a model of ionic lattice first with physical models and then with computer-based modeling using ChemSense on promoting 9th grade students’ conceptual understanding of ionic lattice?

During the analysis of research question 9, it was aimed to compare the effects of two modeling treatments on conceptual understanding of the ionic lattice structure of

Group PC. Namely , students scores in CT1 (Conceptual Test-1 administered at the beginning of study as pretest) and CT3 (Conceptual Test-3 administered after two treatments as posttest2) were calculated and compared for Group where first received the physical modeling treatment using Play Doughs and then received the computer based modeling using ChemSense. The mean scores were found to be M=12.24, and M=16.81 for CT1 and CT3 respectively.

Table 6.22 shows mean and standard deviation of scores of students in CT1 and CT3. These results indicated that the mean scores of Group PC were increased at the end of study as it compared with CT1.

Table 6.22. Descriptive Statistics of CT1&CT3 Scores of Group PC.

	Mean	Std. Deviation	N
CT1	11.9091	4.60754	22
CT3	16.7273	5.70031	22

As it is displayed in Table 6.22, there was an increase at the end of the study in terms of CT3 scores. Then, paired samples t-test was carried out the mean scores of students in order to determine whether this increase was statistically significant or not. The results of the analyses were presented on Table 6.23.

Table 6.23. Paired Samples t – Test Results of CT1&CT3 Scores for Group PC.

Compared Tests	t	df	Sig. (2- tailed)	Mean	Std. Deviation	Std. Error Mean
CT1 & CT3	3.513	21	0.002	4.81818	6.43381	1.37169

The results in Table 6.23 evidenced that, there existed statistically significant different differences between the scores of CT1 and CT3 ($p<0.01$). This meant that in Group PC , constructing physical models using Play Doughs first and then computer based models using ChemSense led to the improvement of conceptual understanding of ionic lattice of 9th students, $t(21) = 3.513$, $p= 0.002$.

Research Question 10: Is there any significant effect of constructing a model of ionic lattice first with physical models and then with computer-based modeling using ChemSense on promoting 9th grade students' spatial ability?

Group PC first received the physical modeling treatment using Play Doughs and then received the computer-based modeling using ChemSense. The mean of scores of ROT1 and ROT3 were calculated for Group PC and they were found to be M=10.96, and M=12.46. Table 6.24 shows mean and standard deviation of scores of students during ROT1 and ROT3. These results indicated that the mean scores of Group PC were increased at the end of study ROT3 as it compared with ROT1.

In order to analyze the research question 10, students scores on ROT tests were employed to reveal the effect of constructing physical models first and then computer based models, on the spatial ability of 9^{th} grade students. Comparison was fulfilled using the test scores of ROT1 (administered at the beginning of study as pretest) and ROT3 (administered after two treatments as posttest2). The mean scores of ROT1 and ROT3 were given in the following Table.6.24.

Table 6.24. Descriptive Statistics of ROT Scores of Group PC.

	Mean	Std. Deviation	N
ROT1	10.9550	3.2729	22
ROT3	12.4545	3.3909	22

Results in Table 6.24 meant that there was an increase in the ROT3 scores compared to that of ROT1 scores. Then, paired samples t-test was carried out the mean scores of students in order to determine whether this increase was statistically significant or not. The results of the analyses were presented on Table 6.25.

Table 6.25. Paired Samples t – Test Results of ROT1&ROT3 Scores for Group PC.

Compared Tests	t	df	Sig. (2- tailed)	Mean	Std. Deviation	Std. Error Mean
ROT1&ROT3	2.462	21	0.023	1.50000	2.85774	0.60927

As it is presented in Table 6.25, statistically significant difference ($p<0.05$) was found in analyzing the scores of ROT1 and ROT3. The result of analysis for Group CP revealed that there was a statistically significant effect of combined treatments; constructing computer models using ChemSense first and then physical models using Play Doughs on the improvement of the spatial ability, $t(21) = 2.462$, $p= 0.023$.

6.5. Comparing the Effects of Order of Types of Instructions

Research Question 11: Is there a significant difference between the promotion of conceptual understanding of ionic lattice of 9th grade students in two different treatment groups who use modeling methods in reverse orders?

During the analysis of research question 11, the mutual scores of both treatment groups were compared in order to reveal the impact of switching the orders of treatments in each group on the conceptual understanding of lattice structure. That is to say, test scores of CT1 (administered at the beginning of study as pretest) first and then CT3 (administered after two treatments as posttest2) were compared to understand the combined effects of both treatment orders. As it was presented in Table 6.26, the mean score of CT1 for Group CP was M=13.52 and Group PC was M=11.91. These results indicated that the mean score of CT1 of Group CP was higher than that of Group PC.

Table 6.26. Descriptive Statistics of CT1 Scores for Groups CP & PC.

	Groups	Mean	Std. Deviation	N
CT1	Group CP	13.5238	6.20982	21
	Group PC	11.9091	4.60754	22

Then, independent samples t-test was performed to compare the mean scores of CT1 of Group CP and Group PC and to determine whether this difference was statistically significant or not. Table 6.27 shows the comparison of the mean scores of Group CP and Group PC with respect to CT1 test scores.

Table 6.27. Independent Samples t-Test Results of CT1 Scores.

Compared Tests	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
CT1	0.917	0.344	0.971	41	0.337	1.61472	1.66217

The analysis of data showed that there was no statistically significant difference ($p>0.05$) between the Group CP and Group PC in terms of CT1 scores where $t(41) = 0.344$, $p=0.337$.

After calculating CT1 mean scores, the mean scores of CT3 for both treatment groups were measured. They were found to be M=18.19 for Group CP and M=16.81 for Group PC as given in Table 6.28. As it was reported in Table 6.28, the mean scores of both groups increased from CT1 to CT3. Also, the results in the same table showed that the mean score of CT3 for Group CP is higher than that of Group PC.

Table 6.28. Descriptive Statistics of CT3 Scores for Groups CP & PC.

	Groups	Mean	Std. Deviation	N
CT3	Group CP	18.1905	7.08956	21
	Group PC	16.7273	5.70031	22

Following the descriptive analysis of CT3 scores , as it was presented in Table 6.29, independent samples t-test was carried out the mean scores of CT3 from Group CP and Group PC to determine whether this difference was statistically significant or not.

Table 6.29. Independent Samples t-Test Results of CT3 Scores.

Compared Tests	F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
CT3	4.122	0.049	0.748	41	0.459	1.46320	1.95730

The analysis of data showed that there was no statistically significant difference ($p>0.05$) between Group CP and Group PC in terms of CT3 scores where $t(41) = 0.049$, $p= 0.459$. These results reveal that switching the order of the treatments led to no significant learning difference in terms of the conceptual understanding of lattice structure of ionic salts between the two treatment groups.

*Research Question 12***:** Is there a significant difference between the promotion of spatial ability of 9th grade students in two different treatment groups who use modeling methods in reverse orders?

The analysis of research question 12 was intended to show the effects of the switching the treatment orders in each group on the spatial ability of students in Group PC. The mean scores of ROT1 (administered at the beginning of study as pretest) and ROT3 (administered after two treatments as posttest2) were analyzed quantitatively using the paired samples t-test. As it was appeared in Table 6.30, the mean scores ROT1 were M=9.91 for Group CP and M=10.96 for Group PC. Results in table 6.30 meant that the mean score of ROT1 for Group PC was found to be higher than that of Group CP.

Table 6.30. Descriptive Statistics of ROT1 Scores for Groups CP & PC.

Test	Groups	Mean	Std. Deviation	N
ROT1	Group CP	9.9048	2.7185	21
	Group PC	10.9550	3.2729	22

In order to determine whether the difference between the mean scores of ROT1 of Group CP and Group PC was statistically significant or not, independent samples t-test was carried out and results were presented in Table 6.31.

Table 6.31. Independent Samples t-Test Results of ROT1 Scores.

Compared Tests	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
ROT1	1.186	0.283	1.141	41	0.260	1.04978	0.91990

The analysis of data showed that there was no statistically significant difference ($p>0.05$) between the Group CP and Group PC in terms of ROT1 scores where $t(41) = 0.283$, $p= 0.260$.

As a second part of the analysis, students' scores in ROT3 were compared. Mean score of Group CP was M=12.57 and that of Group PC was M=12.46. These results were summarized in table 6.32. The analysis of Table 6.32 revealed that the mean scores of both groups increased from ROT1 to ROT3. Also, this table revealed that unlike the result of ROT1mean scores, the mean score of Group CP was higher than that of Group PC.

Table 6.32. Descriptive Statistics of ROT3 Scores.

Test	Groups	Mean	Std. Deviation	N
ROT3	Group CP	12.5714	3.4434	21
	Group PC	12.4545	3.3909	22

Then, independent samples t-test was carried out the mean scores of ROT3 from Group CP and Group PC in order to determine whether this difference was statistically significant or not. Table 6.33 displays the comparison of the mean scores of Group CP and Group PC with respect to ROT3 scores.

Table 6.33. Independent Samples t – Test Results of ROT3 Scores.

Compared Tests	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
ROT3	0.384	0.539	0.112	41	0.911	0.11688	1.04233

The analysis of data showed that there was no statistically significant difference ($p>0.05$) between Group CP and Group PC in terms of ROT3 scores where $t(41) = 0.539$, $p= 0.911$. This result reveals that switching the order of the treatments did not lead to a significant difference.

6.6. Analysis of student generated materials.

*Research Question 13***:** To what extent switching the order of two different instructional methods, namely computer-based modeling and physical modeling, promote the ability of students to use more spatially related terms during drawing , modeling and writing activities ?

Student generated materials were analyzed using the scoring rubric developed by the researcher. After the treatments to calculate the interrater reliability coefficient, 25% of the student generated models were randomly selected. Namely, 11 student-generated physical models and 11 ChemSense models were chosen. The researcher and a chemistry teacher evaluated the student generated models according to scoring rubric developed by researcher. Then the interrater reliability analysis using Cohen's Kappa statistic was performed to determine consistency among raters. The interrater reliability for the raters was found to be Kappa = 0.854 which indicated the almost perfect agreement.

The analysis of the last research question was carried out using data obtained from three different self generated materials of students from Group CP and Group PC. The self generated materials were drawings, student verbal explanations and physical and computer models generated by students. Unlike the first 12 research problems where the analyzed data were in the form of ratio scale, the data analyzed for the 13th research problem were in the form of nominal data. Therefore, the 13th research question was analyzed using non-parametric statistics, specifically, by chi square analysis which requires the data to be classified in to categories. Before the analysis of 13th question, in order to fulfill the two required assumptions of chi square analysis which are the data must be categorical and the expected count in each cell must be greater than or equal to 5. Then, all the student generated materials firstly categorized to list the general tendencies of the students and then frequency counts for the variables under consideration were prepared in contingency tables. As the sample size of this study is small, 43 participants, to increase the number of similar frequency counts in every cell, data were purposefully categorized into 2x2 contingency tables.

In order to complete the categorization, data obtained from drawings, verbal explanations and models of students were analyzed to identify the general preferences and to form categories for the comparison of groups as it was presented in Table 6.34. These categories were created by the researcher after analyzing all the students generated materials qualitatively. This analysis of student generated drawings and student generated writings revealed that the treatments mainly changed the use of 3D instead of 2D, the use of spatially related terms and the use of explanations about relative sizes of ions in the lattice structure. After these analysis, student generated drawings categorized into three groups where representation of shape of lattice, representation of orientation of ions in the lattice and representation of sizes of ions. Similarly, student generated explanations were categorized under the three categories which were describing the dimensions of the lattice, describing the location of ions relative to each other using spatial terms and describing the relative sizes of ions. As a last step of the categorization, the analysis of student generated physical and computer models revealed that two instructional sequences effected the use of 3D models instead of 2D models, the use of different connection types and the scientific accuracy of the student generated models. In addition, the interface of ChemSense software indicates the relative sizes of ions in the lattice automatically; the last categorization did not include the category about the relative size of ions. Then, student generated models were categorized under the three categories which were dimension of the lattice, connection of ions and accuracy of the models.

Table 6.34. Categorization of Data for Chi Square Analysis.

Data Collection Instrument	Number of Categories	Name of Categories
Drawing from Text (DT)	3	1. Representation of shape of lattice 2. Representation of orientation of ions in the lattice. 3. Representation of relative sizes of ions.
Writing from Picture (WP)	3	1. Describing the dimensions of the lattice. 2. Describing the location of ions relative to each other using the spatial terms. 3. Describing the relative sizes of ions.
Physical and Computer Models	3	1. Dimension of the lattice. 2. Connection of ions. 3. Accuracy of the models.

After the categorization, first, the analysis of student generated drawings was performed. In order to apply the chi square analysis for each category, the frequencies from DT1, DT2 and DT3 were computed and compared within the same group. This produced three comparison groups which were DT1-DT2, DT2-DT3 and DT1-DT3. This comparison yielded 3 different chi square analyses for Group CP and Group PC, totally 6 analyses. Then the mutual scores of Group CP and Group PC obtained during DT1, DT2 and DT3 were compared. That is to say, the frequencies for DT1, DT2 and DT3 for Group CP and Group PC were paired to compare. This analysis resulted in 3 different chi square analyses. Thus, each category of student generated drawings was analyzed using 9 different chi square analyses. As the student generated drawings consisted of 3 different categories, 27 chi square analyses were performed to analyze this category. This categorization was outlined in Table 6.35.

Table 6.35. Chi Square Categorization of Students Generated Drawings.

Data Collection Instrument	Name of Category	Compared Tests			Total Number of Analysis
		Group CP	Group PC	Group CP & Group PC	
Drawing from Text (DT)	Representation of shape of lattice	DT1 – DT2 DT2 – DT3 DT1 – DT3	DT1 – DT2 DT2 – DT3 DT1 – DT3	DT1 – DT1 DT2 – DT2 DT3 – DT3	9
	Representation of orientation of ions in the lattice.				9
	Representation of relative sizes of ions.				9

Similarly, students' verbal explanations during the treatments, WP1, WP2 and WP3, included three different categories for each treatment group. Therefore, they were analyzed in the same way as the student generated drawings were analyzed using 27 chi square analysis. It was given in Table 6.36.

Table 6.36. Chi Square Categorization of Students Generated Verbal Explanations.

Data Collection Instrument	Name of Category	Compared Tests			Total Number of Analysis
		Group CP	Group PC	Group CP & Group PC	
Writing from Picture (WP)	Describing the dimensions of the lattice.	WP1 – WP2 WP2 – WP3 WP1 – WP3	WP1 – WP2 WP2 – WP3 WP1 – WP3	WP1 – WP1 WP2 – WP2 WP3 – WP3	9
	Describing the location of ions relative to each other using the spatial terms.				9
	Describing the relative sizes of ions.				9

Finally, the analysis of student generated physical and computer models were carried out. This analysis did not include the mutual frequency comparisons between two treatment groups. Namely the treatments performed within the same groups were compared. For example; the frequencies of Group CP which conducted the computer based modeling first were compared with that of the same group after they created their own physical models. Thus, each category of the student generated models was analyzed separately for Group CP and Group PC. Finally, as the student generated models were categorized under 3 titles, these comparisons yielded 6 separate chi-square analysis to determine if any observed frequencies between the categories were significant or not. This categorization was shown in Table 6.37.

Table 6.37. Chi Square Categorization of Students Generated Models.

Data Collection Instrument	Name of Category	Compared Treatments	Total Number of Analysis
Physical and Computer Models	Dimension of the lattice.	Group CP (Computer Modeling) – Group CP (Physical Modeling)	2
	Connection of ions.		2
	Accuracy of the models.	Group PC (Physical Modeling) – Group PC (Computer Modeling)	2

After completing the categorization, the next step was to fulfill the second requirement of chi square analysis where there should be at least 5 expected count in each cell. In order to complete this requirement, first, the data obtained converted into the frequency counts and presented in the contingency tables to place the similar responses in the same category.

6.6.1. Analysis of Student Generated Drawings

Student generated drawings were generated in DT1, DT2 and DT3 by each treatment group. Both treatment groups received the same drawing task in which students were expected to draw the lattice structure of a selected salt on a blank paper using pencil after reading a text which explained the formation and inner structure of crystal lattice of a given salt verbally. This text was taken from the 9th grade chemistry textbook.

Student-generated drawings were analyzed with respect to the categories presented in Table 6.35. above. These categories were representation of shape of lattice, representation of orientation of ions in the lattice and representation of sizes of ions. The first category identified in the drawings was the *representation of shape of lattice* which was defined as the preference of students using 3D structures instead of 2D structure to draw the lattice structure. During this analysis, if a student used a 2D representation to draw the lattice structure, it was categorized as 1 and if the student used a 3D representation to draw the lattice structure, it was categorized as 2. The following photos presented in Figure 6.1. selected as an example to show the change in one of the participants drawing from Group CP with respect to shape of lattice during DT1,DT2 and DT3 respectively. As the Figure 6.1 revealed the student initially used the 2D representation and after the first and second treatments begun to use 3D representations.

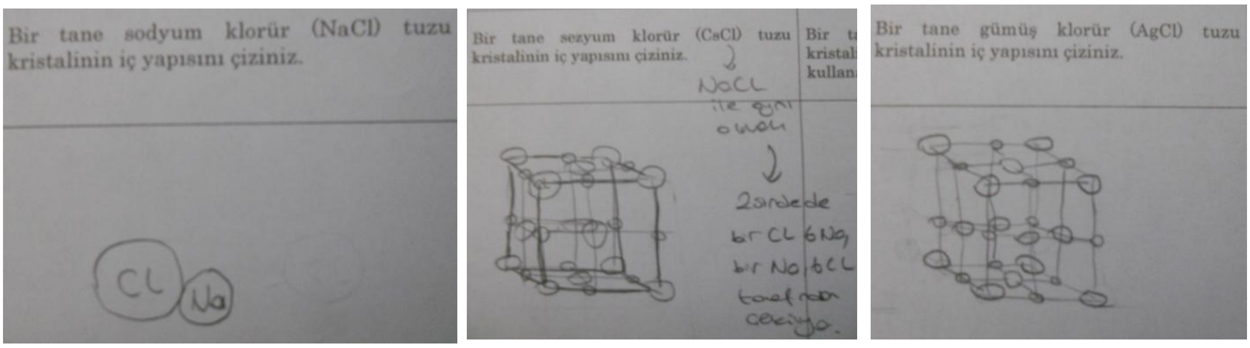


Figure 6.1. Examples of Student Generated Drawing for the Representation of Shape of Lattice.

After the categorization of the data, the frequencies obtained from the categorization were tabulated as it was shown in Table 6.38 and chi square analysis was performed.

Table 6.38. Tabulation of Frequencies with Respect to Representation of Shape of Lattice.

Group Name	Instrument's Name	Number of Observed Frequencies for Each Subcategory	
		Students use 2D representations	Students use 3D representations
Group CP	DT1	20	1
	DT2	10	11
	DT3	12	9
Group PC	DT1	20	2
	DT2	13	9
	DT3	12	10

After the analysis, it was found that the analysis between Group CP and Group PC with respect to comparison of DT1 scores did not satisfy the assumption of chi square where expected cell count was less than 5. Therefore, this analysis was not included in the evaluation part. The results of the analyses for within the same groups and between two treatment groups were presented in Tables 6.39 and 6.40 respectively.

Table 6.39. Chi Square Analysis for Representation of the Shape of the Lattice within the Same Group.

Compared Tests	Compared Groups	X^2	df	Asymp. Sig. (2 – sided)
DT1 & DT2	Group CP	11.667	1	0.001
	Group PC	5.939	1	0.015
DT2 & DT3	Group CP	0.382	1	0.537
	Group PC	0.093	1	0.761
DT1 & DT3	Group CP	8.400	1	0.004
	Group PC	7.333	1	0.007

The results in Table 6.39 presented statistically significant outcomes with respect to students' preferences in using 3D representations instead of 2D representations. The first row of table where the frequencies of DT1 & DT2 compared showed the effects of first treatments where Group CP studied with computer-based models and Group PC studied with physical models. It can be concluded from the first row that the chi square was significant for both treatment groups where (X^2 (1, n = 21) = 11.667, $p < 0.05$) for Group CP and (X^2 (1, n = 22) = 5.939, $p < 0.05$) for Group PC. This meant that number of students who preferred to use 3D representations instead of 2D representation improved statistically significantly in both treatment groups after the first treatments. The second row of Table 6.39 was used to compare the development after the first treatment and second treatment. Namely, to what extent the second treatments where Group CP studied with physical models and Group PC studied with computer based models improved the frequencies of the students who used 3D representations instead of 2D representations as it was compared to the results of first treatments. It can be drawn from the second row that the chi square was not significant for both treatment groups where (X^2 (1, n = 21) = 0.382, p = 0.537) for Group CP and (X^2 (1, n = 22) = 0.093, p = 0.761) for Group PC. These results revealed that second treatments did not provide statistically significant effects on promoting the use of 3D representations instead of 2D representations compared to first treatments. The third row of Table 6.39 indicates the overall changes of students from DT1 to DT3 with respect to representation of the shape of the lattice. It can be drawn from the third row that the chi square was significant for both treatment groups where (X^2 (1, n = 21) = 8.400, $p < 0.05$) for Group CP and (X^2 (1, n = 22) = 7.333, $p < 0.05$) for Group PC. This evidenced that the number of students who were able to use 3D representations instead of 2D representations promoted statistically significantly from the beginning to the end of the study.

Table 6.40. Chi Square Analysis for Representation of the Shape of the Lattice between Groups.

Compared Tests	Compared Groups	X^2	df	Asymp. Sig. (2-sided)
DT1	Group CP & Group PC	Not calculated		
DT2		0.568	1	0.451
DT3		0.029	1	0.864

Table 6.40 shows the mutual frequency comparisons of Group CP and Group PC with respect to representation of the shape of the lattice. First row of Table 6.40 indicates that chi square value to compare the results of DT1 between groups were not computed as it did not fulfill the requirement of chi square where there should be at least 5 expected frequencies for each cell. As it is shown in Table 6.40., the analysis of data showed that there was no statistically significant differences between the Group CP and Group PC with respect to the representation of the shape of the lattice between the scores of DT2 (X^2 (1, N=43) = 0.568, p=0.451) and DT3 (X^2 (1, N=43) = 0.029, p= 0.864). These results indicated that although some treatments led to the statistically significant improvements within the same group, there was no statistically significant

difference between the treatment groups with respect to the representations of the shape of the lattice. This meant that both groups were similar.

Second category of this analysis was the *representation of chemical bonds* in the lattice. This analysis was aimed to reveal students' tendency to indicate the bonds between the ions. If the student did not use any representation to indicate the chemical bonds in the lattice structure, it is categorized as 1 and if the students used ball-and-stick or space filling models, it is categorized as 2. The following photos presented in Figure 6.2 selected as an example to show the change in one of the participants drawing in Group PC with respect to representation of chemical bonds DT1, DT2 and DT3 respectively. Figure 6.2 showed that the student did not use any representation in DT1, after first treatment he used ball-and-stick model and finally after second treatment he used space filling model to indicate the bonds.

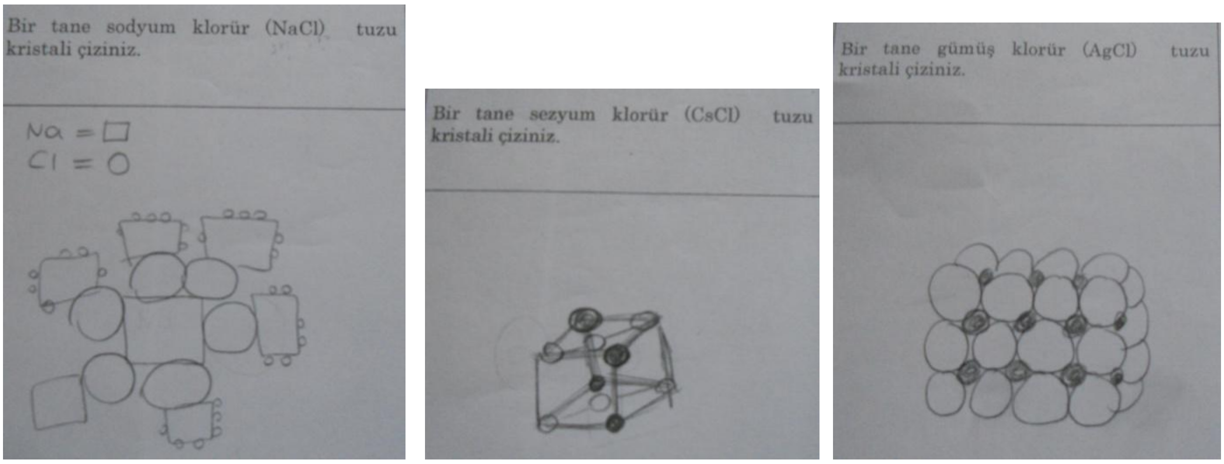


Figure 6.2. Examples of Student Generated Drawings for the Representation of Chemical Bonds

Before the chi square analysis, all the observed frequencies were tabulated as it appeared in Table 6.41 and then, chi square analysis was conducted.

Table 6.41. Tabulation of Frequencies with Respect to Representation of Orientation of Ions in the Lattice.

Group Name	Measurement Name	Number of Observed Frequencies for Each Subcategory	
		Students did not use any representation of chemical bonds	Students used ball – and – stick or space filling models.
Group CP	DT1	9	12
	DT2	5	16
	DT3	3	18
Group PC	DT1	14	8
	DT2	9	13
	DT3	9	13

After performing the chi square analysis, the examination of the contingency tables suggested that the analysis for Group CP for DT2 & DT3 did not fulfill the requirements of the chi square analysis where the expected frequency was less than 5. Therefore this analysis discarded from the study. The result of this analysis was presented in Table 6.42 and Table 6.43 respectively.

Table 6.42. Chi Square Analysis for Representation of Orientation of Ions in the Lattice within the Same Group.

Compared Tests	Groups	X^2	df	Asymp. Sig. (2-sided)
DT1 & DT2	Group CP	1.714	1	0.190
	Group PC	2.277	1	0.131
DT2 & DT3	Group CP	Not calculated		
	Group PC	0.000	1	1.000
DT1 & DT3	Group CP	4.200	1	0.040
	Group PC	2.277	1	0.131

The results in Table 6.42 presented that only the results of the analysis between DT1 & DT3 scores in Group CP yielded a statistically significantly different outcome, (X^2 (1, n=21) = 4.200, $p < 0.05$). This implied that number of students who could employ ball-and-stick and space filling models to indicate the bonds in the ionic lattice increased statistically significantly after two treatments just in group CP from the beginning of the study to the end. These results also indicated that other treatments did not result in statistically significant differences within the same groups with respect to representation of ions in the lattice.

Table 6.43. Chi Square Analysis for Representation of the Orientation of Ions in the Lattice between Groups.

Compared Tests	Compared Groups	X^2	df	Asymp. Sig. (2-sided)
DT1	Group CP & Group PC	1.865	1	0.172
DT2		1.431	1	0.232
DT3		3.785	1	0.052

As it can be seen in Table 6.43, the analysis of data showed that there was no statistically significant differences between Group CP and Group PC with respect to the representation of the orientations of ions in the lattice between the scores of DT1, DT2 and DT3, although the results of the analysis between DT3 scores approached to the statistically significant level ($p= 0.052$).

The last category of this analysis was *representation of relative sizes of ions* in the lattice. This analysis was related with the students' visualization abilities of relative dimensions in the lattice structure. If the student represented the size of cation equal or bigger than the size of anion in the lattice structure, it was categorized as 1 and if the students represented the size of cations smaller than the size of anion, it was categorized as 2. The following photos presented in Figure 6.3 selected as an example to show the change in one of the participants drawing in Group PC with respect to representation of relative sizes of ions DT1, DT2 and DT3 respectively. This student showed that anions are bigger than cations in every measurement.

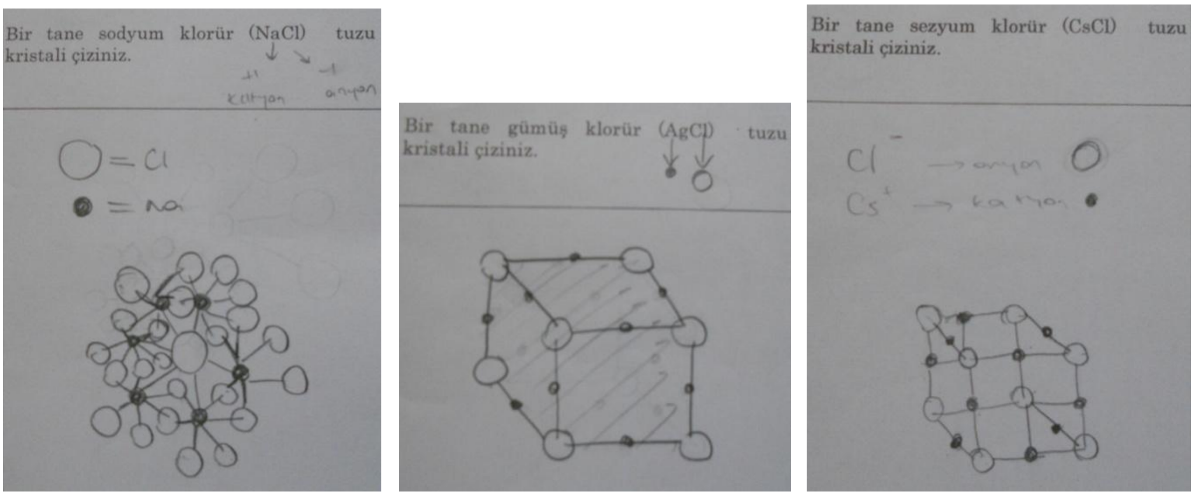


Figure 6.3. Examples of Student Generated Drawings for the Representation of Relative Sizes of Ions.

The tabulation of the data in frequencies in order to carry out the chi square analysis was displayed in Table 6.44 as follows.

Table 6.44. Tabulation of Frequencies with Respect to Representation of Sizes of Ions.

Group Name	Measurement Name	Number of Observed Frequencies for Each Subcategory	
		Student represented the size of cation equal or bigger than the size of anion in the lattice structure.	Students represented the size of cations smaller than the size of anion.
Group CP	DT1	17	4
	DT2	20	1
	DT3	20	1
Group PC	DT1	19	3
	DT2	20	2
	DT3	19	3

The results of analysis for this category revealed that none of the analyses met the basic requirements of the chi square analysis where there should be at least 5 expected frequency in each cell.

6.6.2. Analysis of Student Generated Verbal Explanations

During the data collection periods of WP1, WP2, and WP3 students were given three different 3D illustrations. These illustrations included the lattice structure of selected salts and did not contain any verbal explanations and students were expected to write down what they understood from the drawing. Figure 6.2 presented one of the students' verbal explanations. There were three categories in this analysis which were describing the dimensions of the lattice, describing the location of ions relative to each other using the spatial terms and describing the relative sizes of ions.

The first category of analysis of the student generated drawings was the *describing the dimension of lattice*. During this analysis, each student's verbal explanation was searched to find the terms 2D or 3D. If the student did not describe the shape of the lattice or describe the lattice in 2D planar views, it was categorized as 1 and if the student described the lattice in 3D cubic view, it was categorized as 2. Figure 6.4 presents one of the student's verbal explanation from Group CP during WP1 with respect to describing the dimension of lattice. The student indicated that this lattice structure is cubic and categorized as 2 during the analysis.

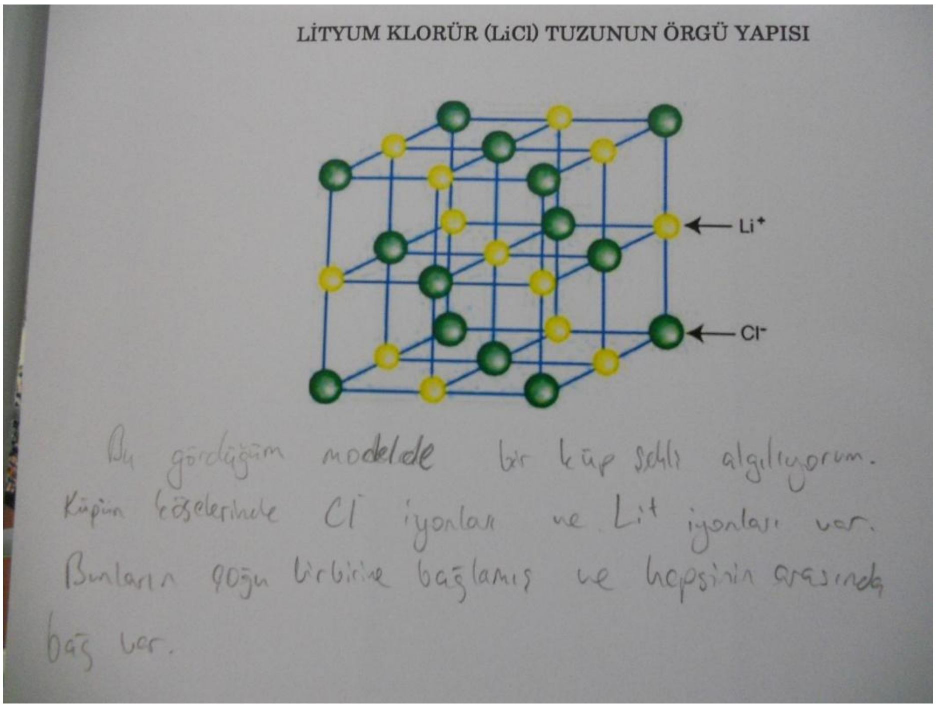


Figure 6.4. An Example of Student Generated Verbal Explanation with respect to Describing the Dimension of Lattice Structure.

As mentioned in the previous analysis, first the tabulation process was carried out which outlined in Table 6.45 and the chi square analysis was conducted.

Table 6.45. Frequencies with Respect to Describing the Dimensions of the Lattice.

Group Name	Measurement Name	Number of Observed Frequencies for Each Subcategory	
		Students did not describe the shape of the lattice in 2D views	Students described the lattice in 3D cubic view
Group CP	WP1	14	7
	WP2	11	10
	WP3	12	9
Group PC	WP1	20	2
	WP2	21	1
	WP3	18	4

The results of analyses for Group PC between WP1-WP2, WP2-WP3 and WP1-WP3 and the mutual comparisons of frequencies for Group CP and Group PC between WP1 scores did not satisfy the basic requirement of chi square analysis where there should be at least 5 expected frequencies for each cell and they were not included in the study. Table 6.46 and Table 6.47 were used to summarize the results of this analysis.

Table 6.46. Chi Square Analysis for Describing the Shape of Lattice within the Group.

Compared Tests	Groups	X^2	df	Asymp. Sig. (2-sided)
WP1 & WP2	Group CP	0.889	1	0.346
	Group PC	Not calculated		
WP2 & WP3	Group CP	0.096	1	0.757
	Group PC	Not calculated		
WP1 & WP3	Group CP	0.404	1	0.525
	Group PC	Not calculated		

Table 6.46 indicated that there was no statistically significant effect of any treatments on both groups with respect to describing the shape of lattice. The first row

of table shows the effects of first treatments where Group CP studied with computer based models and Group PC studied with physical models. It can be concluded from the first row that the chi square was not significant for both Group CP where (X^2 (1, n=21) = 0.889, $p < 0.05$). The second row of table shows the effects of second treatment where Group CP studied with physical models and Group PC studied with computer based models on both groups. As it is seen from the second row that the chi square was not significant for Group CP where (X^2 (1, n=21) = 0.096, $p < 0.05$). The third row of the table indicates the overall changes from WP1-WP3. It can be drawn from the third row that the chi square was not significant for Group CP where (X^2 (1, n= 21) = 0.404, $p < 0.05$). These results revealed that the proportion of the students who accurately described the lattice in 3D structure did not increase statistically significantly from WP1 to WP3 for both treatment groups.

Table 6.47. Chi Square Analysis for Describing the Shape of Lattice between Groups.

Compared Tests	Compared Groups	X^2	df	Asymp. Sig. (2-sided)
WP1	Group CP & Group PC	Not calculated		
WP2		10.471	1	0.001
WP3		3.101	1	0.078

The analysis of Table 6.47 revealed that the mutual frequency comparisons of Group CP and Group PC with respect to describing the shape of the lattice. As it was mentioned above, the comparison for WP1 frequencies did not meet the chi square requirements, it was not included in the study. Table 6.47 suggested that there is a statistically significant differences between the observed frequencies of Group CP and Group PC with respect to describing the shape of the lattice between the scores of WP2 where Group CP studied with computer based modeling and group PC studies with physical modeling, (X^2 (1, n=43) = 10.471, $p < 0.05$). This can be inferred from Table 6.47. It can be drawn that number of students who wrote down that the lattice structure has 3D shape instead of 2D shape gradually increased from WP1, 7 students, to WP2, 10 students, in Group CP where students just received the computer based modeling. However, in Group PC where students only took the treatment of the physical modeling, it appeared that number of students who described that the lattice structure has 3D shape decreased from 2 students in WP1 to 1 student in WP2. This change between the treatment groups from WP1 to WP2 yielded statistically significant difference as it was evidenced in chi square analysis. In addition, the analysis of data showed that the result of analysis between WP3 (X^2 (1, n=43) = 3.101, p= 0.078) scores did not result in the statistically significant results. These results indicated that only first treatments, where Group CP received computer based modeling and Group PC received physical modeling, led to statistically significant difference between both treatment groups with respect to representation of ion in the lattice.

Second category of this analysis was *describing the locations of ions relative to each other using spatial terms*. Students' verbal explanations were analyzed to find the spatial terms that indicates the distance, connection or space between the ions in the crystal structure. If the student did not use spatial terms to describe the locations of ions in the lattice, it was categorized as 1 and if the student used the spatial terms such as above, below, near, under to describe the locations of ions in the lattice, it is categorized as 2. Figure 6.5 presents one of the students' verbal explanation from Group PC during WP2 with respect to describing the dimension of lattice. The student wrote down that anions have bigger size than the cations and the cations fill the space between the anions. Then, this student was categorized as 2.

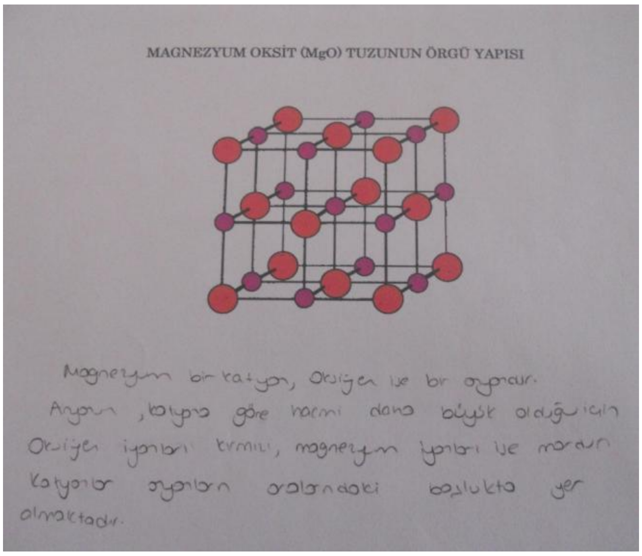


Figure 6.5. An Example of Student Generated Verbal Explanation Using the Spatial Terms

The results of the tabulation for this category were shown in Table 6.48 as follows.

Table.6.48. Frequencies with Respect to Describing the Location of Ions Relative to Each Other Using the Spatial Terms.

Group Name	Measurement Name	Number of Observed Frequencies for Each Subcategory	
		Students did not use spatial terms to describe the locations of ions in the lattice.	Student used the spatial terms such as above, below, near, under to describe the locations of ions in the lattice.
Group CP	WP1	15	6
	WP2	13	8
	WP3	16	5
Group PC	WP1	15	7
	WP2	20	2
	WP3	17	5

After conducting the chi square analysis, the contingency tables displayed that the results of analyses for Group CP between WP1-WP2, WP2-WP3 and WP1-WP3, for Group PC between WP1-WP2 and WP2-WP3 and the mutual comparison of frequencies for Group CP and Group PC for WP2 and WP3 did not satisfy the basic requirement of chi square analysis where there should be at least 5 expected frequencies for each cell and they were not evaluated quantitatively.

The last category of this analysis was the *describing the* relative *sizes of ion in the lattice*. If the student did not make explanations about the proportional measures of ions or described the size of cation was bigger than anion, it was categorized as 1, and if the student described the size of anion was bigger than cation, it was categorized as 2. Figure 6.6 presents one of the students’ verbal explanations from Group CP during WP3 with respect to describing the relative sizes of ions in the lattice. The student explained that anions have relatively bigger sizes than cations. Then, this student was categorized as 2.

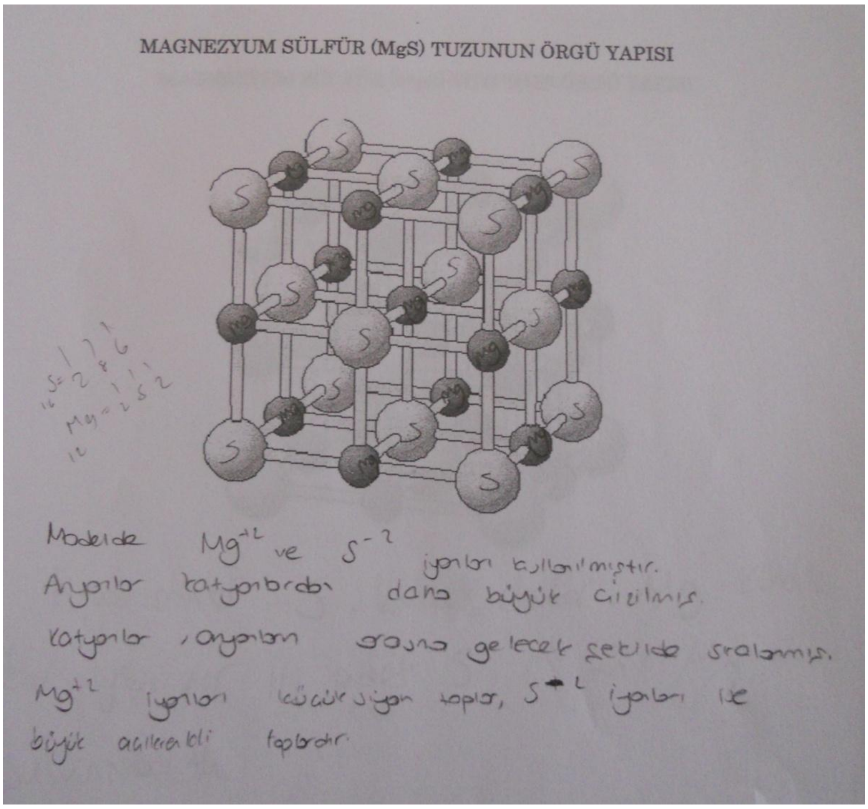


Figure 6.6. An Example of Student Generated Verbal Explanation Describing the Relative Sizes of Ions.

The results of tabulation were reported below in Table 6.49.

Table 6.49. Frequencies with Respect to Describing the Relative Sizes of Ions.

Group Name	Measurement Name	Number of Observed Frequencies for Each Subcategory	
		Students did not describe the size of cation is bigger than anion.	Students described the size of anion is bigger than cation.
Group CP	WP1	16	5
	WP2	19	2
	WP3	15	6
Group PC	WP1	18	4
	WP2	17	5
	WP3	13	9

Following the tabulation process, the chi square analysis was performed. The results were indicated in Table 6.50 and Table 6.51 respectively.

Table 6.50. Chi Square Analysis for Describing the Size of Ions in Lattice within the Same Group.

Compared Tests	Groups	X^2	df	Asymp. Sig. (2-sided)
WP1 & WP2	Group CP	1.543	1	0.214
	Group PC	0.140	1	0.709
WP2 & WP3	Group CP	2.471	1	0.116
	Group PC	1.676	1	0.195
WP1 & WP3	Group CP	0.123	1	0.726
	Group PC	2.730	1	0.099

Table 6.50 showed that there were no statistically significant effects of treatments on both treatment groups with respect to describing the sizes of ions in a lattice. The first row of table indicates the effects of first treatments where Group CP studied with computer based models and Group PC studied with physical models. It can be concluded from the first row that the chi square was not significant for both groups where (X^2 (1, n=21) = 1.543, $p < 0.05$) for Group CP and (X^2 (1, n=22) = 0.140 $p < 0.05$). The second row of table shows the effects of second treatments where Group CP studied with physical models and Group PC studied with computer based models on both groups. It can be concluded from the second row that the chi square was not significant for both groups where (X^2 (1, n=21) = 2.471, $p < 0.05$) for Group CP and where (X^2 (1, n=22) = 1.676, $p < 0.05$) for Group CP. The third row of the table indicates the overall changes from WP1 to WP3. As it can be seen from the third row that the chi square was not significant for both treatment groups where (X^2 (1, n = 21) = 0.123, $p < 0.05$) for Group CP and (X^2 (1, n = 22) = 2.730, $p < 0.05$) for Group PC. These results revealed that the proportion of the students who accurately described the

relative sizes of ions in lattice did not increase statistically significant from WP1 to WP2.

Table 6.51. Chi Square Analysis for Describing the Size of Ions between Groups.

Compared Tests	Groups	X^2	df	Asymp. Sig. (2-sided)
WP1	Group CP & Group PC	0.206	1	0.650
WP2		1.374	1	0.241
WP3		0.720	1	0.396

Table 6.51 presented the mutual frequency comparisons of Group CP and Group PC with respect to describing the sizes of ions. As it is seen in Table 6.51, the analysis of data showed that there was no statistically significant differences between the Group CP and Group PC with respect to describing the sizes of ions in the lattice between the observed frequencies of WP1 (X^2(1, n=43) = 0.310, p=0.578), WP2 (X^2 (1, n=43) = 0.568, p=0.451) and WP3 (X^2 (1, n=43) = 0.029, p= 0.864).

6.6.3. Analysis of Student Generated Models

Students from each group completed two different modeling treatments which were computer base modeling with ChemSense and physical modeling with Play Doughs. The Figure 6.7 and 6.8 show the examples of participants' ChemSense and physical models.

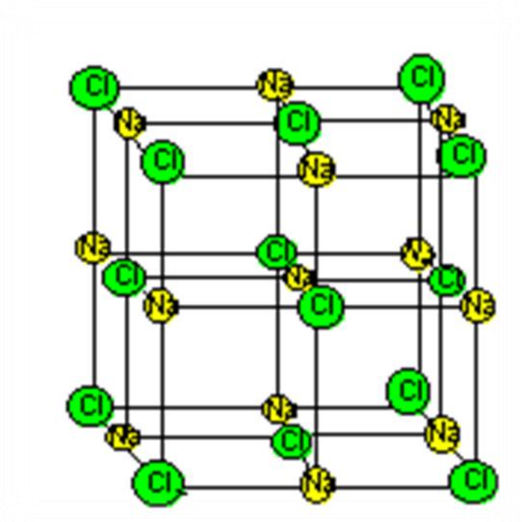


Figure 6.7. An Example of Student Generated Computer Based Modeling of NaCl with ChemSense

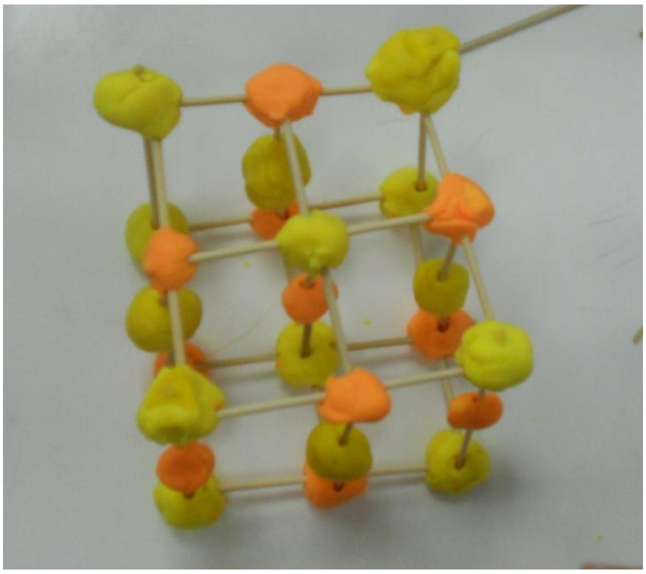


Figure 6.8. An Example of Students Generated Physical Modeling of NaCl with Play Doughs

The first category of analysis of the student generated drawings was *describing the dimension of lattice*. During this analysis, each student's salt crystal model was evaluated with respect to appearance as 2D or 3D. If the student does not form the shape of the lattice or form the lattice in 2D planar views, it was categorized as 1 and if the student described the lattice in 3D cubic view, it was categorized as 2. After the tabulation of the data which presented in Table 6.52, chi square analysis was carried out. The result of analysis of this category revealed that it did not satisfy the requirement of the chi square analysis where the expected frequencies in each cell should be greater than or equal to 5. Therefore this subcategory was not included in the analysis part.

Table 6.52. Frequencies with Respect to Dimension of the Lattice.

Group Name	Treatment	Number of Observed Frequencies for Each Subcategory	
		Students did not form the shape of the lattice in 2D planar views.	Students described the lattice in 3D cubic view.
Group CP	ChemSense	3	18
	Physical	0	21
Group PC	ChemSense	1	21
	Physical	7	15

Second subcategory of this analysis was the *representation of the type of connection between ions*. If a student constructed the lattice using vertical connections, that is to say if the ions were joined diagonally or they did not use the systematic connection type, it was categorized as 1 and if the student constructed the lattice using straight connections, it was categorized as 2. The observed frequencies after the tabulation were presented in Table 6.53.

Table 6.53. Frequencies with Respect to Connection of ions.

Group Name	Treatment	Number of Observed Frequencies for Each Subcategory	
		Student constructed the lattice using vertical connections.	Student constructed the lattice using straight connections.
Group CP	ChemSense	4	17
	Physical	3	18
Group PC	ChemSense	16	6
	Physical	6	16

After this tabulation, the chi square analysis was conducted to these frequencies and the results of this analysis was displayed below in Table 6.54.

Table 6.54. Chi Square Analysis for Representation of Connection Types in Lattice.

Compared Treatments	X^2	df	Asymp. Sig. (2-sided)
Group CP (Chem Sense Model) & Group CP (Physical Model)	Not calculated		
Group PC (Physical Model)& Group PC (Chem Sense Model)	9.091	1	0.003

Table 6.54 presents the results about representing the type of connection in lattice. This analysis revealed that the observed frequencies of Group CP did not meet the chi square requirement where there should be at least 5 expected frequencies in each cell. Therefore, this analysis was not included in the evaluation part. However, the chi-square was statistically significant for comparing the second treatments where Group CP used physical models and Group PC used ChemSense models (X^2 (1, n=22) = 9.091, $p < 0.05$). This can be found from Table 6.53 that number of students who used the straight connections increased from 6 students to 16 students in Group PC. This evidenced that the number of students who constructed the ionic lattice using the straight connection instead of vertical connections improved statistically significant for Group PC that received the physical modeling first and then the computer based modeling.

The last category of this analysis was the *accuracy of the completed crystal lattice*. If students accurately finished the formation of the lattice according to the scientifically acceptable way, the response was categorized as 2; otherwise it was categorized as 1.The tabulated values for observed frequencies were presented in Table 6.55.

Table 6.55. Tabulation of Frequencies with Respect to Accuracy of the Models.

Group Name	Measurement Name	Number of Observed Frequencies for Each Subcategory	
		Students did not form the shape of the lattice in 2D views.	Students described the lattice in 3D cubic view.
Group CP	ChemSense	18	3
	Physical	19	3
Group PC	Physical	21	1
	ChemSense	3	18

After completing the chi square analysis, it was realized that Group PC did not meet the basic requirement of the chi square analysis where there should be at least 5 expected frequencies for each cell. Therefore, this analysis was not reported. Moreover the analysis for Group CP presented in the Table 6.56 and the results of analysis for Group CP revealed that chi square analysis did not yield the statistically significant differences between two treatment groups after the second treatments.

Table 6.56. Chi Square Analysis for Describing the Structure of the Ionic Lattice Accurately.

Compared Category	X^2	df	Asymp. Sig. (2-sided)
Group CP (Chem Sense Model) & Group PC (Physical Model)	3.079	1	0.079
Group CP (Physical Model) & Group PC (Chem Sense Model)	Not calculated		

7. DISCUSSION AND CONCLUSION

7.1. Discussion

This study investigated the effects of conducting two student generated modeling activities and their mutual effect by switching the order of treatments on conceptual understanding of the ionic lattice structure and the spatial ability of 9^{th} grade students. There were two main objectives of this current study. The first objective was to develop two instructional sequences that combined the same instructional methods which were computer-based modeling by using ChemSense and physical modeling by using Play Doughs for two treatment groups. The groups received both treatments in different orders. In other words, one of the groups first received computer-based modeling and then worked with physical models while the second group followed the reverse order. The second objective of the study was to compare the effects of these instructional experiences on promoting conceptual understanding of lattice structures of ionic salts and spatial ability of 9^{th} grade students.

The main constructs under the investigation were conceptual understanding of ionic lattice structures and spatial ability of 9^{th} grade students after the implementation of computer-based modeling and physical modeling treatments. The learning gains of students with respect to these constructs were analyzed quantitatively by using five different instruments. The conceptual understanding of the lattice structures was measured by the total scores gained in the conceptual tests (CT1, CT2 and CT3). The spatial ability was measured in terms of the total scores in Purdue Spatial Visualization Test: Rotations (ROT). In addition, student generated drawings (DT1, DT2 and DT3), student generated written explanations (WT1, WT2 and WT3) and student generated computer and physical models were analyzed to find the common patterns about the spatial ability and the conceptual understanding of the ionic lattice.

At the beginning of the study, before the implementation, students were given four tests as pretests: CT1, ROT, DT1, and WT1. After the first treatments, CT2, ROT, DT2, and WT2 were administered as posttest 1. Following the second treatments, CT3, ROT, DT3, and WT3 were administered as posttest 2.

Forty-three 9^{th} grade students who were conveniently selected from private high school participated in this study. The researcher has been teaching in the same school for 11 years. There were only two 9^{th} grades in the school. Although they were assigned in two treatment groups randomly due to convenient sampling method, the results of the study cannot be generalized to the whole population. As it is mentioned above, two groups received the both treatment by switching the order. One of the groups named as Group CP first received the computer-based instruction, and then worked on physical modeling. The other group called Group PC completed these two treatments in reverse order. After each treatment, students were tested to measure the effects of treatments. There were two learning environments. Physical modeling sections were carried out in the chemistry lab and computer modeling sections were conducted in the computer lab where in both places all students had their own seats.

The analysis part of the study mainly consisted of three main sections. Firstly the effect of the first treatments on the spatial ability and the conceptual understanding of the ionic lattice were analyzed using the research questions 1, 2, 3, 4, 5, and 6. Then the combined effect of the first and second treatments on the spatial ability and the conceptual understanding of the ionic lattice were analyzed using the research questions 7, 8, 9, 10, 11, and 12. Finally, student generated materials were analyzed using the research question 13. In order to analyze the data gained through the study, three different inferential statistical methods were carried out. First, the effects of each treatment on each dependent variable, namely conceptual understanding of the ionic lattice and spatial ability were examined using paired samples t-test. Next, as both groups were exposed to two different treatments in reverse order, both groups were compared with each other with respect to the changes in conceptual understanding and spatial ability using independent samples t-test. Finally, student generated drawings, verbal explanations and models were analyzed to grasp how the students use their spatial ability before and after each treatment by using chi square analysis.

The analysis of research questions 1 and 3 revealed that conducting the physical models using Play Doughs is effective to improve conceptual understanding of the ionic lattice structure. More specifically, it was found that students in Group PC showed the statistically significant gains using. The rationale behind this finding would be that the students in both treatment groups did not have the prior knowledge about the structure of ionic lattice before the study and they spent excessive efforts to construct their initial crystal lattices. Although both treatment groups were given the same amount of time to construct their own models, the participants in Group PC, because of hands on and tactile nature of the physical modeling had to spend more mental and physical effort to complete their tasks (Herman, 2006). Namely, this feature of physical modeling enhanced higher order thinking to construct more lattice structure. In other words, students in Group PC had to complete many hands on activities like squashing and rolling the play doughs to create the balls to indicate the ions, cutting the tooth sticks in equal length to create the bonds and assembling the balls and tooth sticks to form the unit cell which was difficult because of the flexibility of the play doughs. However, students in Group CP established the unit cell just clicking on the ChemSense software. With the aid of tactile models, structure of the ionic lattice was made tangible to students in Group PC and this may facilitated their conceptual understanding of spatial orientations in the lattice structure. This condition may favor Group PC during the conceptual tests as it was compared to Group CP in terms of holding and recalling information about the presented new information about the inner structure of the ionic salts.

Secondly, the results of analyses with regard to second and fourth research questions were discussed. These analyses suggested that using the computer based models has significant impact on promoting the spatial ability. The findings from the analysis of research question 2 and 4 implied that Group CP who studied with the computer based modeling using ChemSense program yielded statistically significant improvement in their spatial ability. On the contrary, no significant effect was found with respect to studying with the physical modeling using play doughs on promoting the spatial ability. The reason why Group PC got the better results than Group CP might be explained by referring the benefits of using computers such as they created the virtual environments that enable students to use plenty of colors and sizes which were arranged tidily and generate the appearances from different views quickly (Kozma and Russell, 1997). As it was mentioned earlier, both groups had to complete the modeling tasks at the same time duration. As all the students were very familiar with using computers, the students in Group PC finished their tasks earlier compared to the students in Group CP. In addition, it was observed that although it was not required and planned to add animations to the static pictures of the crystal lattices of ionic salts, 12 students succeeded adding the animations to their tasks using ChemSense program. Moreover, 8 students from this group created 3D lattice structures and 4 of them formed 2D structures using dynamic animations. This might be one of the possible explanations for the statistically significant improvement in Group CP. Another possible reason might be the medium of treatment that favored the performance of the students in Group CP during ROT tests. The medium of ChemSense modeling was 2D and ROT was administered in 2D medium. However, students in Group PC had to complete the physical models in 3D environment and received ROT tests in 2D environment. This condition might prevent the students in Group PC to reach the statistically significant improvement.

The analyses of research questions 5 and 6 examined whether there exist statistically significant differences between Group CP and Group PC with respect to spatial ability and conceptual understanding of ionic lattice. This was carried out comparing the initial mean scores at CT1 and ROT1 and the mean scores at CT2 and ROT2. In other words, these analyses were aimed to conclude whether or not the first treatments caused to the differences between two treatment groups with respect to the conceptual understanding of ionic lattice and spatial ability.

The findings of research question 5 and 6 revealed that both groups did not differentiate after the first treatments with respect to the conceptual understanding of the ionic lattice and the spatial ability. These findings can be explained with respect to the nature of the participants. Students in both groups were in the same school together for about ten years and they were taught with the same materials and teacher during that time. Therefore, it was not expected to observe the conceptual difference between both groups in this short time interval. Another possibility might be explained with respect to the time intervals between the treatments and the administration of tests. Students were posttested one day after the first treatments. Because of this immediate testing condition without anything coming between two events like additional homework or exam, the participants in both groups have observed to be highly motivated and may have easily remembered what they experienced one day before. This situation may suggest that short time intervals between the treatments and the measurements may have favored the effects of memorization rather than understanding. Therefore, in order to compare the effects of treatments on both groups properly, it would be plausible to expand the time interval between the treatments and the administrations of the posttests.

After the analysis of the first treatments, the second categories of analyses were passed in order to investigate the combined effects of the first and second treatments on the dependent variables. Both groups performed both treatments in reverse order, may be these treatments impacted both groups in different degree. The results of research questions 7, 8, 9, and 10 examined this situation to conclude whether or not the different order of the treatments result in the statistically significant differences in both treatment groups with respect to the conceptual understanding of the ionic lattice and the spatial ability.

The results of the analysis of research question 7 and 9 pointed out the very impressive finding. These analyses revealed that regardless of the treatment order and without the instruction during the regular class hours, the conceptual understanding of both groups improved statistically significant after conducting two modeling treatments. The results of research question 7 implied that students in Group CP who took the computer based modeling first and then the physical modeling improved their conceptual understanding of ionic lattice in CT3 compared to CT1. Similarly, the results of the research question 9 showed the significantly higher learning gains in CT3 as it was compared to CT1. Similarly, the results of analysis for research questions 8 and 10 were in line with to the analysis of research question 7 and 9 and suggested that regardless of the treatment order, both possible combinations of the computer based modeling with ChemSense and the physical modeling with Play Dough led to the statistically significant differences with respect to the spatial ability. These findings indicated that as the number of different experiences with modeling practices increases in definite time intervals, this enhances the conceptual understanding of the ionic lattice and the spatial ability. Also, the presence of the significant increases in both treatment groups proposed that using two different modeling activities together complement each other to promote the spatial ability and the conceptual understanding of the ionic lattice.

The results of analyses for the research questions 11 and 12 revealed that both groups were similar at the beginning of the study and after the receiving two treatments.

That is to say, reversing the treatment orders did not lead to the statistically significant differences between both treatment groups. The reason behind the absence of the significant differences between the groups at the end of the study with respect to conceptual understanding of ionic lattice and the spatial ability seems likely because of the short time interval of conducting the all study where all the treatments and evaluations were happened in 2 weeks because of the time constrains of the school curriculum.

Finally, the third category of the analysis was carried out to evaluate the student generated materials using the research question 13. As it was discussed at the beginning of this chapter, analysis part of this study consisted of three main sections. The third section of the analysis aimed to find whether there was a significant effect of student generated drawings, student generated verbal explanations and student generated models on the spatial ability of the students in two treatment groups. In order to reach this aim, first, student generated drawings, students generated verbal explanations and students generated models were subcategorized under three groups. Namely, student generated drawings were examined with respect to the representation of the shape of the lattice, the representation of chemical bonds in the lattice and representation of sizes of ions. Likewise, student generated verbal explanations were investigated with respect to describing the shape of the lattice, describing the locations of ions relative to each other and describing the sizes of ions. Finally, student generated models were evaluated with respect to the constructing the shape of the lattice, describing the connection types and the accuracy. After this subcategorisation, frequency counts for the each variable under the each subgroup were performed to form 2x2 contingency tables. As the data analyzed in this part of analysis, chi square analysis was performed to infer the conclusions. Before the analysis two basic requirements of the chi square analysis were fulfilled where the data were categorized and the analyzed data in the contingency tables were checked where there should be at least 5 expected frequencies for each cell. Then, nine chi square analyses were performed for first and second subcategories and four chi square analyses were conducted for third subcategories. Namely , for the first and second subcategories , firstly the frequency counts of each test from each treatment group was compared using the following chi square order the DT1-DT2, DT2-DT3, DT1-DT3 and WP1-WP2, WP2-WP3 and WP1-WP3. This yielded 3 analyses for each treatment group, totally 6 analyses. After this, the frequency counts of both groups in three subsequent drawing tests (DT1, DT2, DT3) and writing tests (WP1, WP2, WP3) were compared mutually using 3 chi square analyses. For the third category, comparing the physical and computer models, only the comparisons within the same group were carried out. As each group performed two different modeling studies, this led to 3 comparisons for 3 categories for each group, totally 6 analyses.

The analysis of the student generated drawings revealed that the frequency of spatially related terms increased significantly after the treatments. In order to evidence this situation, first of all the student generated drawings were examined under three subcategories which were representation of shape of lattice, representation of orientation of ions in the lattice and representation of sizes of ions.

First analysis was the examination of student generated drawings with respect to the representation of shape of the lattice. The outcomes of the chi square analysis for Group CP and Group PC revealed that the first treatments led to a statistically significant improvement with respect to the representation of the shape of the lattice. The analysis for the effect of the second treatments on the representation of the shape of the lattice did not present the statistically significant results. Finally, the analysis that compared the frequency counts from DT1 to DT3 yielded statistically significant results. These analyses revealed that regardless of the treatment groups, both treatment orders promoted the usage of 3D representations instead of 2D representations to draw the lattice structure of the ionic salts at the end of the study as they were compared to the beginning of the study. Lastly, the analysis of mutual comparisons of DT1, DT2 and DT3 frequencies with respect to the representation of the ionic lattice did not produce the statistically significant results. As it was appeared after the analyses of the first treatments, this analysis also suggested even a single treatment can enable the students to use more 3D representations in favor of 2D representations.

Second subcategory for the analysis of student generated drawings was the representation of orientation of ion in the lattice. This analysis revealed that switching the order of the treatments led to statistically significant differences in Group CP when DT3 frequencies were compared to DT1 frequencies. This suggested that using computer-based models first and then the physical models led to statistically significant results in terms of the representation of the ions in the ionic lattice. That is to say, student' preferences to use different symbols to indicate chemical bonds in the crystal lattice only improved significantly from DT1 to DT3 in Group CP. However, remaining eight analyses for this subcategory did not indicate the significant differences. This meant that students in Group PC where they first used physical modeling and then the computer-based modeling did not show any significant increase with respect to the representation of orientation of ion in the lattice which was evidenced using DT1, DT2 and DT3 frequencies. Similarly, the mutual comparisons of the group frequencies indicated that the groups were not different at DT1, DT2 and DT3 with respect to the representation of the ions in the ionic lattice.

Last subcategory for the analysis of the student generated drawings was the investigation of the representation of sizes of ions. Students' drawings were analyzed to find out whether they were able to draw different spaces or dimensions for different ions. The nine analyses for this subcategory did not provide statistically significant differences. The analysis of the representation of sizes of ions pointed out that the concept of atomic and ionic size was the prerequisite for this study and without the plausible conception of this compulsory concept, it was impossible for the students to use the different dimensions for the different ions. That is to say, students were unable to understand that sizes of atom are one of the main features of the ions that effect the shape and formation of the ionic lattice. As this concept was not included in the any curriculum documents in Turkey, the student were not taught about this concept before this study. Therefore, they did not give attention the relative sizes of ions in their drawings.

Second step of the analysis was to evaluate the student generated explanations. After the analysis of the three subcategories of the student generated drawings, it was proceeded to investigate the function of student generated verbal explanations to use more spatial terms. Firstly, students' verbal explanations were analyzed to find out to what extent students preferred to write the explanations in terms of describing the shape of the lattice when they were expected to explain the inner relations in the crystal lattice structure. The analysis results for Group CP and Group PC suggested that students in both groups did not show statistically significant differences in terms of describing the shape of the lattice. This meant that students did not include explanations to depict the inner structure of the ionic lattices. Moreover, the mutual comparison results revealed that only the first treatments where Group CP studied with computer-based modeling and Group PC used the physical modeling led to statistically significant difference between the treatment groups. This result indicated that after the first treatments, students in both groups begun to envision the lattice of the ionic salts as having 3D structures.

Second part of the analysis considered the analysis of student generated verbal explanations with respect to describing the locations of ions relative to the each other. In the first analysis of the student generated verbal explanations, students' explanations were evaluated how they described the dimensions of the lattice. In addition, the second analysis studied the student generated verbal explanations to find out how they described the directions in the lattice structure. Namely, this analysis was aimed to understand how students described the relative locations of the interacting particles in the lattice structure. The results of the nine analyses for this subcategory revealed that both treatment orders did not lead to a statistically significant difference within and between both treatment groups. The reason of these results can be explained with respect to the students' tendency to count the number of different colored ions in the lattice instead of indicating the relative positions during the writing sections. In other words, as the researcher realized, they mainly preferred to write what they saw looking at the entire lattice superficially like writing down 'there are ten red and ten white colored ions in the lattice' instead of trying to decompose the lattice to smaller parts to indicate the inner connections. This result obtained from the analysis of students generated explanations suggested that this study did not promote to describe the lattice structure using the spatial terms.

Lastly, student generated verbal explanation were investigated to infer to what degree the students in the study described the relative sizes of ions in the crystal lattice. This analysis was in line with the drawing analysis. Both treatment groups did not show the statistically significant improvements to write the relative sizes of ions. This result evidenced that this study did not led to statistically significant increase with respect to the relative sizes of ions.

Following the analysis of the student generated verbal explanations; the last section of the analysis was the investigation of the student generated models. As it was mentioned earlier, student generated models were studied under three subcategories.

These were constructing the shape of the lattice, describing the connection types and the accuracy. Through this analysis only the mutual frequencies of the both treatment groups were compared using the chi square analysis. The analyses for all subcategories revealed that the treatments did not lead to statistically significant differences between Group CP and Group PC. That is to say switching the treatment order did not yield any differences between two treatment groups with respect to the constructing the computer and physical models.

7.2. Limitations of the Study

First of all, the findings will be nongeneralisable and applicable to other situations. Because the target population of this study was small, namely 43 students, due to using purposive sampling. In addition, the participants of this study were from the same private school where they had been attending the same school for ten years. Therefore, in order to generalize the results of this study to a whole population, this study should be replicated using a larger sample who selected from a private and state schools and a random sampling method that has a more chance to represent whole population.

Second limitation of this study was about the internal validity which stemmed from the switching nature of the study. This limitation also strictly related to the type of the school where the sample was drawn. All treatments and data collection sections took place in the same school. Although the participants were asked not to mention about the study with the students in other treatment group and even they were so careful about this aspect of the study, this appeared as a possible threat to the internal validity. Therefore, the replication of this current study should be implemented with the treatment groups which selected randomly from different schools using cluster sampling method.

Third limitation of this study was a short implementation and evaluation period without given any break which lasted three weeks. Development of spatial ability can be achieved over a period of time and more valid results would be obtained with the longitudinal studies that continue through a school term or a year.

Fourth, this study did not include a pilot study. It would be beneficial to reduce the number of unexpected difficulties and to save time to implement the proposed procedures on time.

Fifth, ROT was translated to Turkish before the study and the split half reliability value was calculated as 0.57 which decreased the internal consistency of the instrument.

7.3. Suggestions for Further Research

This study was carried out using the purposive sampling method. Therefore the results of this study cannot be generalized to the entire population. In order to obtain the generalisable results, a similar might be performed with random sampling methods.

The sample size of this study was small and restricted 43 participants who were selected narrowly defined population. This limited the generalizability of the results. Future studies can be replicated using the larger sample which is representative of whole population.

This study was conducted to develop and implement the instructional sequences combined the computer based and the physical modeling treatments. The results of this study revealed that mixing two modeling methods promoted the spatial ability and the conceptual understanding of the ionic lattice. This result supported the value of the blending learning activities for the domain of chemistry. Moreover, other practitioners from the different domains can benefit from this result to develop the similar instructional sequences.

Shifting the order of treatments was one of the distinct feature of this study and can be used a model for the different learning environments.

The implementation period of this study lasted about three weeks. In order to observe the effects of the treatments deeply, further research with long implementation period can be conducted.

Before the study the researcher translated the Purdue Spatial Visualization Test: Rotations to Turkish. The instrument was used without conducting a pilot study. Similar studies could include the pilot study of this instrument immediately after the translation to another language.

The researcher only used the Purdue Spatial Visualization Test: Rotations to assess the students' spatial ability. Similar study may be carried out using other standardized spatial ability tests.

Finally, all the participants involved in this study as a part of their regular chemistry lessons without gaining any additional points for chemistry grades. Moreover, they participated actively and eagerly all the activities. Therefore, it would have been better to grade the students' work to keep them highly motivated.

7.4. Conclusion

Overall, the results of the present study revealed that mixing two tools of the modeling promote the conceptual understanding of the ionic lattice structure and the spatial ability of the students. The findings of the study revealed that after receiving two different modeling tools the average mean scores of the students in Group CP and Group PC increased 35% and 41% respectively from CT1 to CT3. Similarly, the findings revealed that ROT mean scores of the students in Group CP and Group PC improved 27% and 14% and respectively from ROT1 to ROT3.

This study also used the crossover design where both groups took the same treatments in reverse order. The results of the study also indicated that regardless of the treatment order, the spatial ability and the conceptual understanding of the both treatment groups promoted significantly. This suggested that using two modeling tools together in the blending learning environment enhance the conceptual understanding of the ionic lattice and the spatial ability.

Finally, the results of this study proposed that the spatial ability and the conceptual understanding of the participants can be promoted using two modeling tools or media together. It could be suggested that these two media supported and complemented each other regardless of the order of the media given. Therefore, computer-based and physical modeling could be used in a blended way to support chemistry instruction.

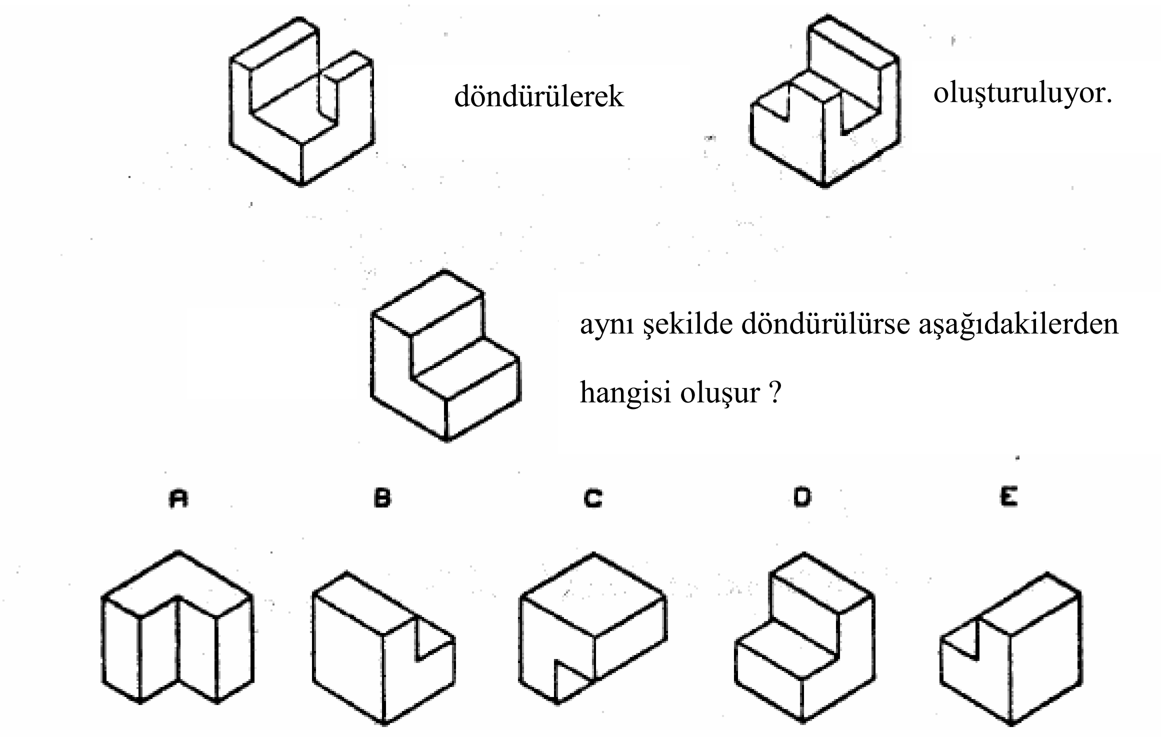
APPENDIX A: THE PURDUE VISUALIZATION OF ROTATIONS TEST (ROT)

Bu kitapçığa herhangi bir işaretleme yapmayınız.

Cevaplarınızı cevap anahtarlarına işaretleyiniz.

YÖNERGELER

20 sorudan oluşan bu test 3 boyutlu nesnelerin döndürülmesini ne kadar iyi canlandırdığınızı ölçmek üzere hazırlanmıştır. Bu testte bulunan soruların bir örneği aşağıda verilmiştir.



Verilen her soru için aşağıdaki aşağıda verilen aşamaları takip etmelisiniz.

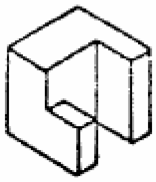
1) En üstte verilen nesnenin nasıl döndürüldüğünü inceleyiniz.
2) Orta sırada verilen nesnenin üst sıradaki nesneyle tamamen aynı şekilde döndürüldüğünü zihninizden canlandırınız.
3) En alt sırada verilen beş çizim arasından (A,B,C,D,E) doğru şekilde döndürülmüş olanı seçiniz.

Yukarıda verilen örnek sorunun cevabı nedir?

A,B,C ve E şıklarında verilen cevaplar yanlış. Sadece D şıkkında verilen çizim döndürme işlemi sonucu elde edilecek nesneyi verir.

Her sorunun sadece bir cevabı vardır!

Şimdi de aşağıda verilen örneğe bakınız ve örnekte verilen döndürme işlemi orta sırada verilen şekle uygulayınız.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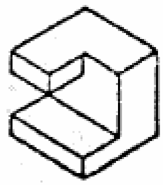
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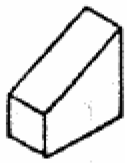
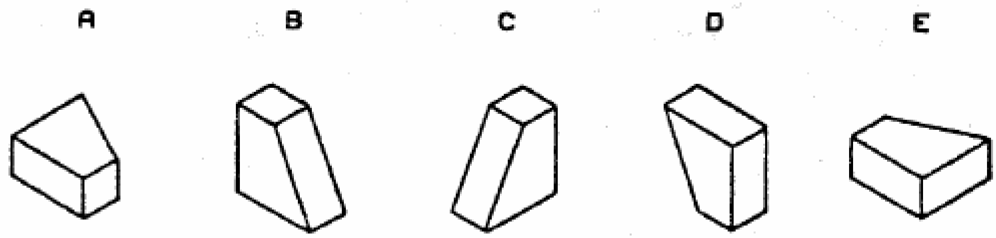

aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur?



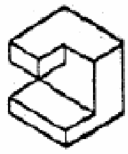
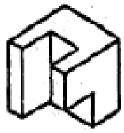
Bu örnekteki döndürme işleminin daha karmaşık olduğuna dikkat edin. Bu örneğin doğru cevabı B şıkkıdır.

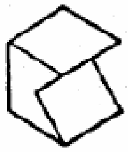
Bu kitapçığa herhangi bir işaretleme yapmayınız.

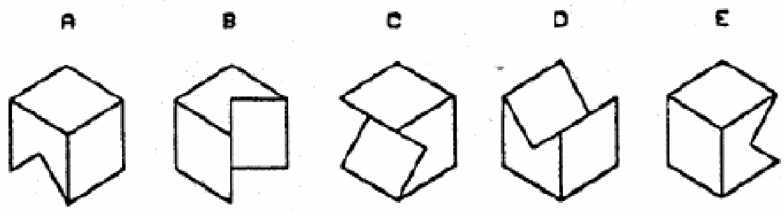
Cevaplarınızı cevap anahtarlarına işaretleyiniz.

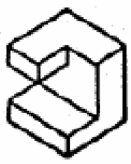
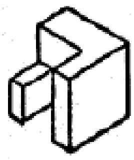
Bu çalışmaya tüm katılımcılar aynı anda başlayacaktır.

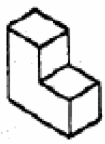
Bu çalışma 10 dakika sürecektir.

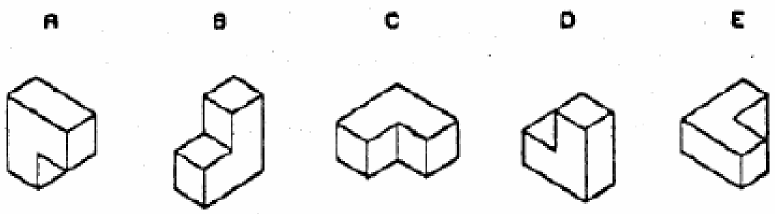
1  döndürülerek  oluşturuluyor.

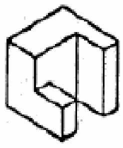
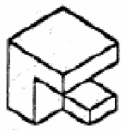
 aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur ?



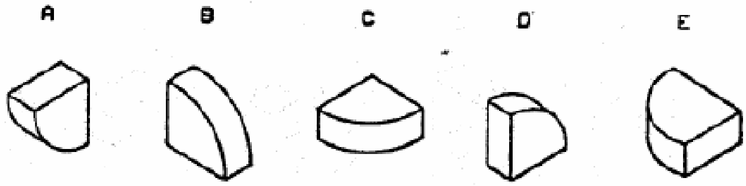
2  döndürülerek  oluşturuluyor.

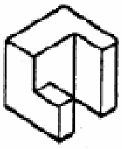
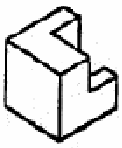
 aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur ?

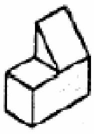


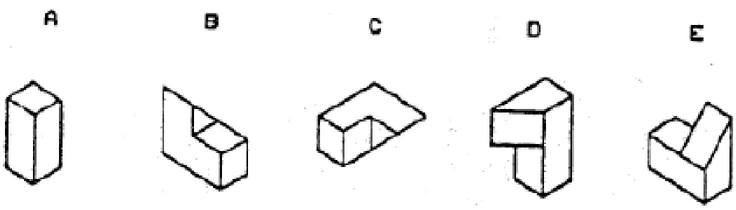
3  döndürülerek  oluşturuluyor.

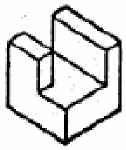
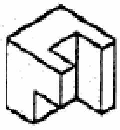
 aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur ?

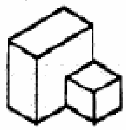


4  döndürülerek  oluşturuluyor.

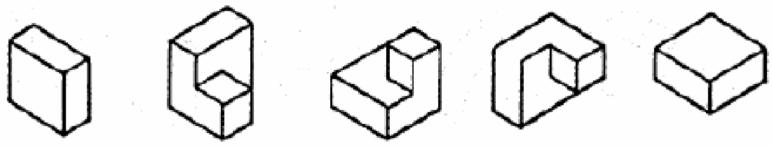
 aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur ?

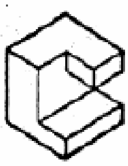
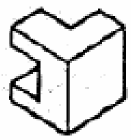


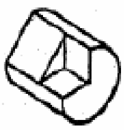
5  döndürülerek  oluşturuluyor.

 aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur ?

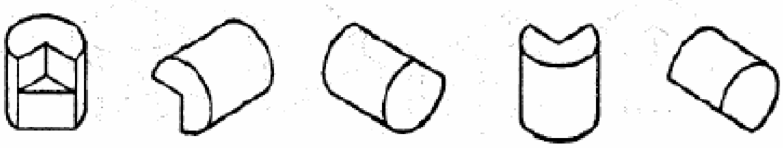
A B C D E

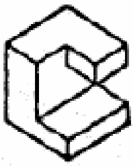


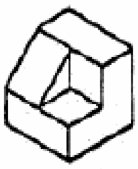
6  döndürülerek  oluşturuluyor.

 aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur ?

A B C D E



7  döndürülerek  oluşturuluyor.

 aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur ?

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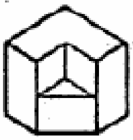
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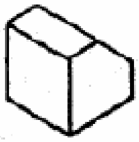
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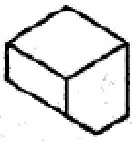
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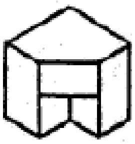
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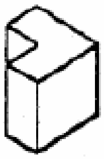
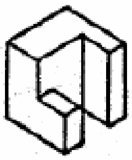
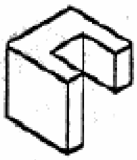
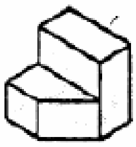
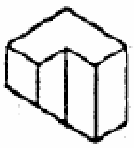


8  döndürülerek  oluşturuluyor.

 aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur ?

A

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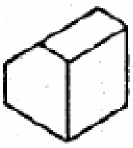
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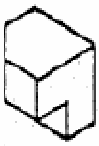
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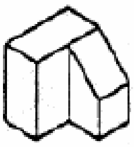
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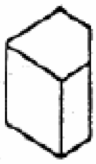
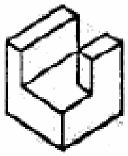
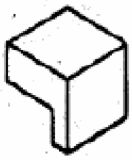
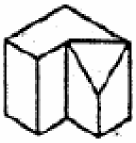
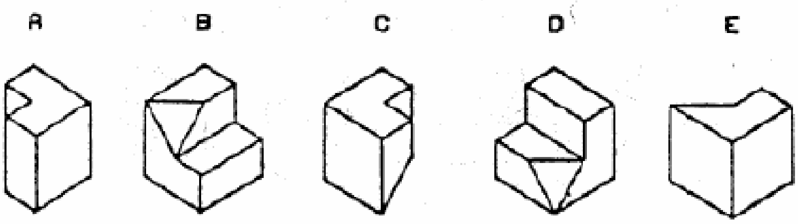
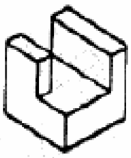
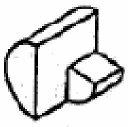


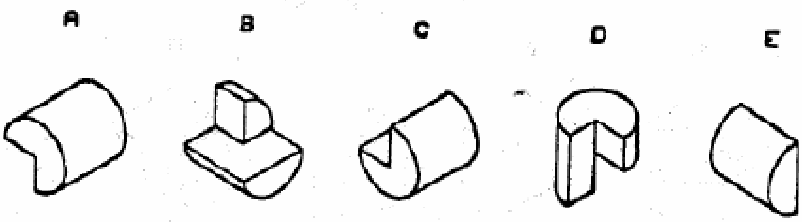
9  döndürülerek  oluşturuluyor.

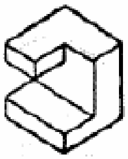
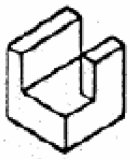
 aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur ?

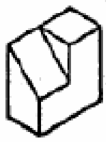


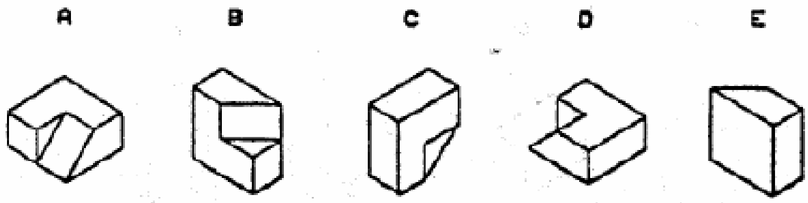
10  döndürülerek  oluşturuluyor.

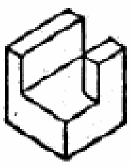
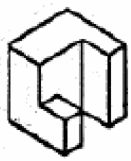
 aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur ?

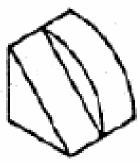


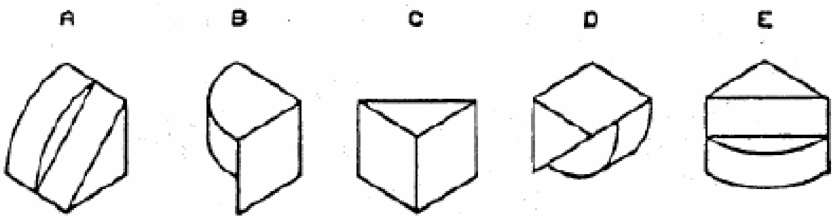
11  döndürülerek  oluşturuluyor.

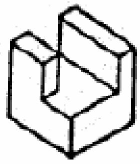
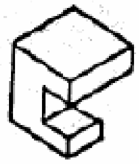
 aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur ?

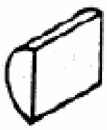


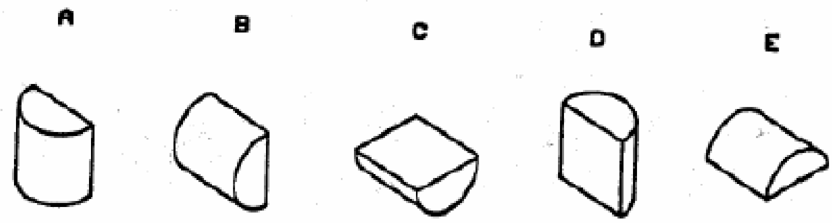
12  döndürülerek  oluşturuluyor.

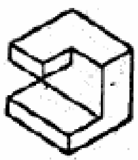
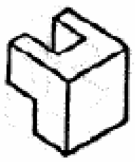
 aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur ?

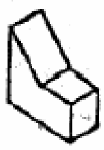


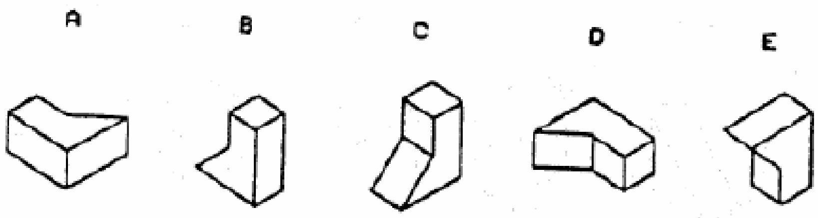
13  döndürülerek  oluşturuluyor.

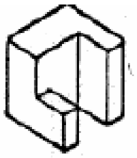
 aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur ?



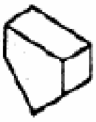
14  döndürülerek  oluşturuluyor.

 aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur ?



15  döndürülerek  oluşturuluyor.

 aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur ?

A 

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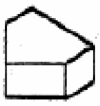
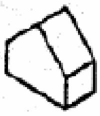
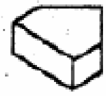
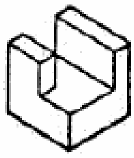
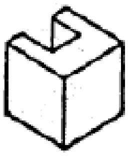
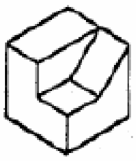
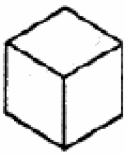
C 

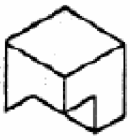
D 

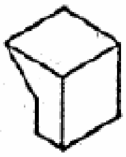
E 

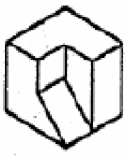
16  döndürülerek  oluşturuluyor.

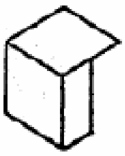
 aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur ?

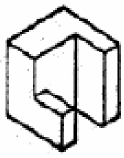
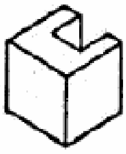
A 

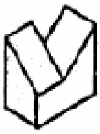
B 

C 

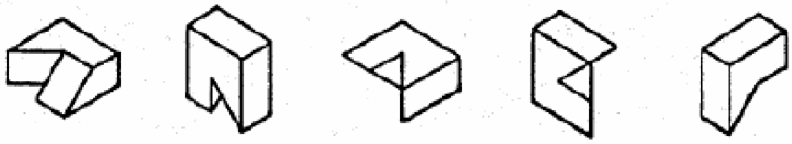
D 

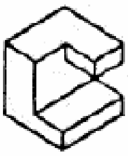
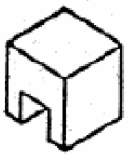
E 

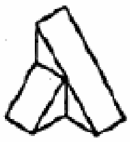
17  döndürülerek  oluşturuluyor.

 aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur ?

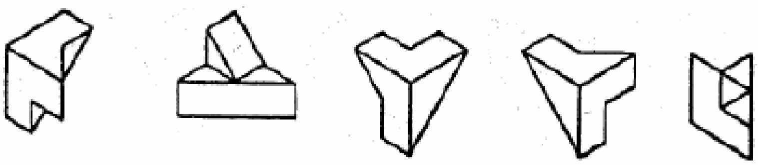
A B C D E

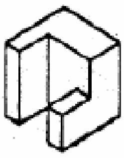
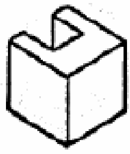


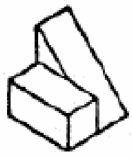
18  döndürülerek  oluşturuluyor.

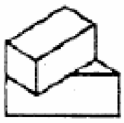
 aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur ?

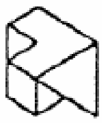
A B C D E

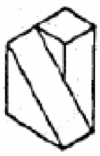


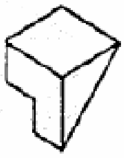
19  döndürülerek  oluşturuluyor.

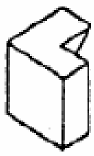
 aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur ?

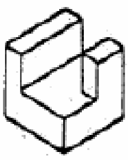
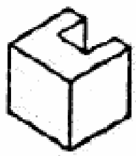
A 

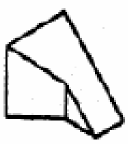
B 

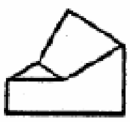
C 

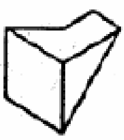
D 

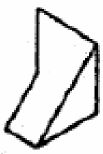
E 

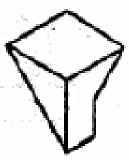
20  döndürülerek  oluşturuluyor.

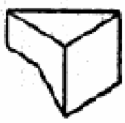
 aynı şekilde döndürülürse aşağıdakilerden hangisi oluşur ?

A 

B 

C 

D 

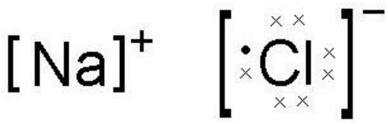
E 

APPENDIX B: CONCEPTUAL TEST – 1 (CT1)

Adı	Soyadı	Sınıf
……………………...	……………………...	……………………...

Bu testi cevaplamak için 10 dakika süreniz vardır.

1) Aşağıda verilen şekil Sodyum (Na) ve Klor (Cl) elementlerinden oluşan sodyum klorür (NaCl) bileşiğinin Lewis gösterimidir. Bu gösterimi kullanarak aşağıdaki soruları cevaplayınız. ($_{11}$Na, $_{17}$ Cl)

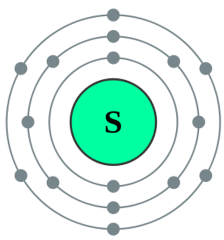


   a) Na elementi periyodik tabloda hangi grupta bulunur?

   b) Bağ yaptıktan sonra Na elementinin son yörüngesinde kaç elektron bulunur?

   c) Cl elementinin değerlik elektron sayısı nedir?

2) Yanda Kükürt (S) elementine ait katman elektron dağılımı verilmiştir. Bu şekli kullanarak aşağıdaki soruları cevaplayınız.



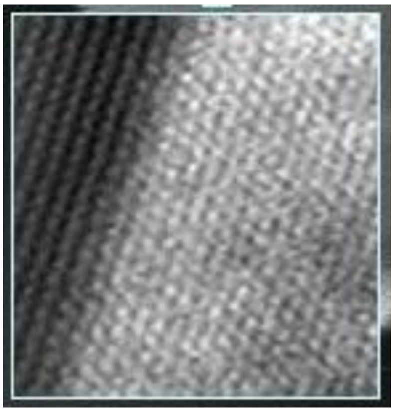
   a) S elementinin atom numarası nedir?
   b) S elementinin değerlik elektron sayısı nedir?
   c) S elementinin iyon yükü nedir?
   d) S elementi periyodik tabloda hangi grupta bulunur?

3) Na^{+1} ve Cl^{-1} iyonlarını göstermek üzere iki farklı top veriliyor. Hangi iyon için hangi topu seçerdiniz? Açıklayınız ($_{11}Na$, $_{17}Cl$)

4) Aşağıdaki görüntü taramalı tünelleme mikroskobu ile alınmıştır. Bu görüntü NaCl tuzuna aittir.

   a) NaCl tuzunu bu şekildeki gibi bir arada tutan kuvvetin adı nedir?

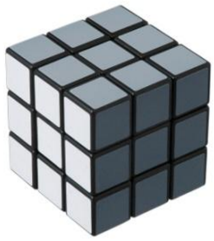
   b) Bu kuvvetin oluşumunu tuzun iç yapısını çizerek açıklayınız.



5) Aşağıda verilen boş kutucuklara sırayla sizden beklenen çizimleri yapınız.

1’er tane sodyum ve klor atomunun tuz oluşturmak üzere tepkimeye girdiklerini düşünelim. Bu atomların yapabileceği tuzun şeklini çizim yaparak açıklayınız.
5’er tane sodyum ve klor atomunun tuz oluşturmak üzere tepkimeye girdiklerini düşünelim. Bu atomların yapabileceği tuzun şeklini çizim yaparak açıklayınız.
10’ar tane sodyum ve klor atomunun tuz oluşturmak üzere tepkimeye girdiklerini düşünelim. Bu atomların yapabileceği tuzun şeklini çizim yaparak açıklayınız.

6) NaCl'nin içini taramalı tünelleme mikroskobu ile incelediğimizi düşünelim. Aşağıda verilen fotoğraflardan hangisinin NaCl içerisinde bulunan iyonların diziliş biçimlerine en yakın olduğunu tahmin ediniz? Tahmininizin sebebini açıklayınız.



APPENDIX C: CONCEPTUAL TEST – 2 (CT2)

Adı ……………………... Soyadı ……………………... Sınıf ……………………...

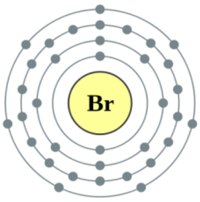
Bu testi cevaplamak için 10 dakika süreniz vardır.

1) Magnezyum oksit (MgO) bileşiği ile ilgili aşağıdaki soruları cevaplayınız. ($_{12}Mg$, $_{8}O$)

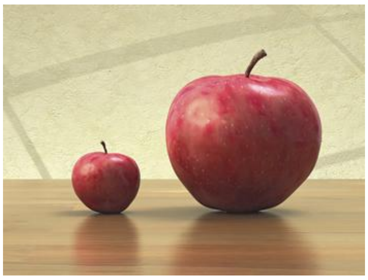
   a) Magnezyum (Mg) elementi periyodik tabloda hangi grupta bulunur?
   b) Oksijen (O) elementinin değerlik elektron sayısı nedir?
   c) MgO bileşiğinin Lewis gösterimini yapınız.

2) Yanda brom (Br) elementine ait katman elektron dağılımı verilmiştir. Bu şekli kullanarak aşağıdaki soruları cevaplayınız.

   a) Br elementinin atom numarası nedir?
   b) Br elementinin değerlik elektron sayısı nedir
   c) Br elementinin iyon yükü nedir?
   d) Br elementi periyodik tabloda hangi grupta bulunur?



3) Aşağıda verilen elmalardan bir tanesi sodyum klorür (NaCl) tuz kristalindeki katyonu diğeri de anyonu temsil etmektedir. Hangi elmanın anyonu hangisinin katyonu temsil edebileceğini nedeniyle açıklayınız.



4) Sodyum klorür (NaCl) kristalini ortadan ikiye ayırdığımızı düşünelim. Ortaya nasıl bir kesit çıkar? Çizerek açıklayınız.

5) Aşağıda verilen boş kutucuklara sırayla sizden beklenen çizimleri yapınız.

1'er tane sodyum ve klor atomunun tuz oluşturmak üzere tepkimeye girdiklerini düşünelim. Bu atomların yapabileceği tuzun şeklini çizim yaparak açıklayınız.
5'er tane sodyum ve klor atomunun tuz oluşturmak üzere tepkimeye girdiklerini düşünelim. Bu atomların yapabileceği tuzun şeklini çizim yaparak açıklayınız.
10'ar tane sodyum ve klor atomunun tuz oluşturmak üzere tepkimeye girdiklerini düşünelim. Bu atomların yapabileceği tuzun şeklini çizim yaparak açıklayınız.

6) NaCl’nin içini taramalı tünelleme mikroskobu ile incelediğimizi düşünelim. Aşağıda verilen fotoğraflardan hangisinin NaCl içerisinde bulunan iyonların diziliş biçimlerine en yakın olduğunu tahmin ediniz? Tahmininizin sebebini açıklayınız.

APPENDIX D: CONCEPTUAL TEST – 3 (CT3)

Adı	Soyadı	Sınıf
……………………...	……………………...	……………………...

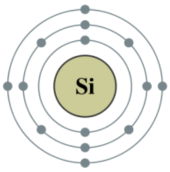
Bu testi cevaplamak için 10 dakika süreniz vardır.

1) Potasyum klorür (KCl) bileşiği ile ilgili aşağıdaki soruları cevaplayınız. ($_{19}K$, $_{17}Cl$)

   a) Potasyum (K) elementi periyodik tabloda hangi grupta bulunur?
   b) Potasyum (K) elementinin değerlik elektron sayısı nedir?
   c) KCl bileşiğinin Lewis gösterimini yapınız.

2) Yanda silisyum (Si) elementine ait katman elektron dağılımı verilmiştir. Bu şekli kullanarak aşağıdaki soruları cevaplayınız.

   a) Si elementinin atom numarası nedir?
   b) Si elementinin değerlik elektron sayısı nedir
   c) Si elementinin iyon yükü nedir?
   d) Si elementi periyodik tabloda hangi grupta bulunur?



3) Aşağıda fotoğrafı verilen küçük kızlar ellerindeki karpuzları kullarak sodyum klorür (NaCl) tuz kristali oluşturmak istemektedirler. Hangi karpuzu hangi iyon için kullanmalıdırlar? Açıklayınız.

4) Bezelyenin yeşil kabuğunu ayırdığımızda şekildeki gibi tohumlarından oluşan bir yapıyla karşılaşırız. Aynı şekilde Sodyum klorür (NaCl) kristalini ortadan ikiye ayırdığımızı düşünelim. Ortaya nasıl bir yapı çıkar? Çizerek açıklayınız.

5) Aşağıda verilen boş kutucuklara sırayla sizden beklenen çizimleri yapınız.

1'er tane sodyum ve klor atomunun tuz oluşturmak üzere tepkimeye girdiklerini düşünelim. Bu atomların yapabileceği tuzun şeklini çizim yaparak açıklayınız.
5'er tane sodyum ve klor atomunun tuz oluşturmak üzere tepkimeye girdiklerini düşünelim. Bu atomların yapabileceği tuzun şeklini çizim yaparak açıklayınız.
10'ar tane sodyum ve klor atomunun tuz oluşturmak üzere tepkimeye girdiklerini düşünelim. Bu atomların yapabileceği tuzun şeklini çizim yaparak açıklayınız.

6) NaCl'nin iç yapısının taramalı tünelleme mikroskobu görüntüsünü açıklamak için aşağıda verilen fotoğraflardan hangisini kullanırsınız? Tahmininizin sebebini açıklayınız.

APPENDIX E: DRAWING FROM TEXT – 1 (DT1)

ADI – SOYADI:

SINIFI:

YÖNERGELER

1) Aşağıda iyonik bileşiklerin örgü yapısının açıklandığı bir metin verilmiştir.
2) Sizlerden beklenen bu metni dikkatlice okumanız ve metinle birlikte verilen tablodaki soruları cevaplamanızdır.
3) Bu çalışmayı tamamlamak için toplam 10 dakika süreniz vardır.
4) Bu süre içerisinde metni istediğiniz kadar okuyabilirsiniz.
5) Tablonun tamamlanmasında sadece siyah kurşun kalem kullanınız.

İYONİK BİLEŞİKLERİN ÖRGÜ YAPISI

İyonik bileşikleri oluşturan birimler atomlar değil iyonlardır. Anyon ve katyonlar elektriksel itme ve çekme kuvvetlerini dengeleyecek şekilde bir araya gelerek düzenli bir kristal örgü yapısı oluştururlar.

İyonik yapılı bileşikler çeşitli tiplerde düzenli örgü yapısı oluşturur. Çoğu iyonik bileşikte anyonlar katyonlardan çok büyük olduğundan anyonların oluşturduğu bir örgüdeki aradaki boşluklara katyonlar girmiştir.

Kristal yapıda her iyon, belirli sayıda komşu ve zıt yüklü iyonun çekim etkisindedir. Örneğin sodyum klorürde her Na^+ iyonu 6 Cl^- iyonu tarafından ve her Cl^- iyonu da 6 Na^+ iyonu tarafından çekilerek meydana gelen birimlerden iyonik kristal yapı oluşur. İyonik kristalde tekrarlayan bu yapısal birimlere **birim hücre** adı verilir.

APPENDIX E: DRAWING FROM TEXT – 1 (DT1)

ADI - SOYADI :

SINIFI :

Bir tane sodyum klorür (NaCl) tuzu kristali çiziniz.	Bir tane sodyum klorür (NaCl) tuzu kristalinin iç yapısını çiziniz.	Bir tane sodyum klorür (NaCl) tuzu kristalinin oluşumunu element sembolleri kullanarak çiziniz.

APPENDIX F: DRAWING FROM TEXT – 2 (DT2)

ADI – SOYADI:

SINIFI:

YÖNERGELER

1) Aşağıda iyonik bileşiklerin örgü yapısının açıklandığı bir metin verilmiştir.
2) Sizlerden beklenen bu metni dikkatlice okumanız ve metinle birlikte verilen tablodaki soruları cevaplamanızdır.
3) Bu çalışmayı tamamlamak için toplam 10 dakika süreniz vardır.
4) Bu süre içerisinde metni istediğiniz kadar okuyabilirsiniz.
5) Tablonun tamamlanmasında sadece siyah kurşun kalem kullanınız.

İYONİK BİLEŞİKLERİN ÖRGÜ YAPISI

İyonik bileşikleri oluşturan birimler atomlar değil iyonlardır. Anyon ve katyonlar elektriksel itme ve çekme kuvvetlerini dengeleyecek şekilde bir araya gelerek düzenli bir kristal örgü yapısı oluştururlar.

İyonik yapılı bileşikler çeşitli tiplerde düzenli örgü yapısı oluşturur. Çoğu iyonik bileşikte anyonlar katyonlardan çok büyük olduğundan anyonların oluşturduğu bir örgüdeki aradaki boşluklara katyonlar girmiştir.

Kristal yapıda her iyon, belirli sayıda komşu ve zıt yüklü iyonun çekim etkisindedir. Örneğin sezyum klorürde (CsCl) her Cs^{+} iyonu 6 Cl^{-} iyonu tarafından ve her Cl^{-} iyonu da 6 Cs^{+} iyonu tarafından çekilerek meydana gelen birimlerden iyonik kristal yapı oluşur. İyonik kristalde tekrarlayan bu yapısal birimlere **birim hücre** adı verilir.

APPENDIX F: DRAWING FROM TEXT – 2 (DT2)

ADI - SOYADI :

SINIFI:

Bir tane sezyum klorür (CsCl) tuzu kristali çiziniz.	Bir tane sezyum klorür (CsCl) tuzu kristalinin iç yapısını çiziniz.	Bir tane sezyum klorür (CsCl) tuzu kristalinin oluşumunu element sembolleri kullanarak çiziniz.

APPENDIX G: DRAWING FROM TEXT – 3 (DT3)

ADI – SOYADI:

SINIFI:

YÖNERGELER

1) Aşağıda iyonik bileşiklerin örgü yapısının açıklandığı bir metin verilmiştir.
2) Sizlerden beklenen bu metni dikkatlice okumanız ve metinle birlikte verilen tablodaki soruları cevaplamanızdır.
3) Bu çalışmayı tamamlamak için toplam 10 dakika süreniz vardır.
4) Bu süre içerisinde metni istediğiniz kadar okuyabilirsiniz.
5) Tablonun tamamlanmasında sadece siyah kurşun kalem kullanınız.

İYONİK BİLEŞİKLERİN ÖRGÜ YAPISI

İyonik bileşikleri oluşturan birimler atomlar değil iyonlardır. Anyon ve katyonlar elektriksel itme ve çekme kuvvetlerini dengeleyecek şekilde bir araya gelerek düzenli bir kristal örgü yapısı oluştururlar.

İyonik yapılı bileşikler çeşitli tiplerde düzenli örgü yapısı oluşturur. Çoğu iyonik bileşikte anyonlar katyonlardan çok büyük olduğundan anyonların oluşturduğu bir örgüdeki aradaki boşluklara katyonlar girmiştir.

Kristal yapıda her iyon, belirli sayıda komşu ve zıt yüklü iyonun çekim etkisindedir. Örneğin gümüş klorürde ($AgCl$) her Ag^+ iyonu 6 Cl^- iyonu tarafından ve her Cl^- iyonu da 6 Ag^+ iyonu tarafından çekilerek meydana gelen birimlerden iyonik kristal yapı oluşur. İyonik kristalde tekrarlayan bu yapısal birimlere **birim hücre** adı verilir.

APPENDIX G: DRAWING FROM TEXT – 3 (DT3)

ADI - SOYADI :

SINIFI:

Bir tane gümüş klorür (AgCl) tuzu kristali çiziniz.	Bir tane gümüş klorür (AgCl) tuzu kristalinin iç yapısını çiziniz.	Bir tane gümüş klorür (AgCl) tuzu kristalinin oluşumunu element sembolleri kullanarak çiziniz.

APPENDIX H: WRITING FROM TEXT – 1 (WT1)

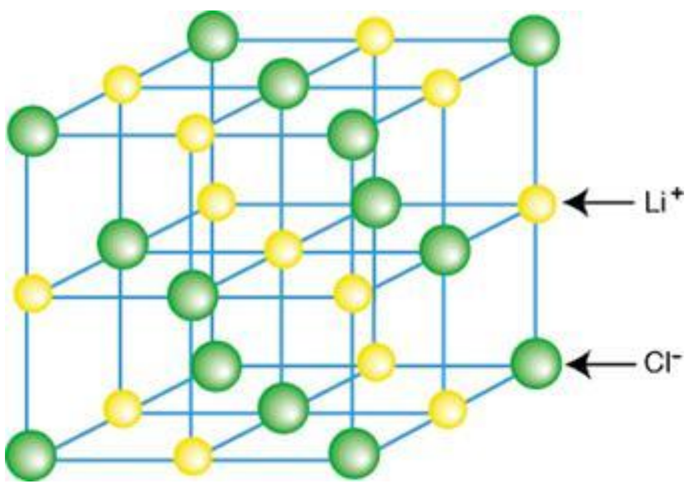
ADI – SOYADI:

SINIFI:

YÖNERGELER

1) Aşağıda sizlere lityum klorür (LiCl) tuzunun örgü yapısı verilmiştir.
2) Sizlerden beklenen bu görsel modeli dikkatlice incelemeniz ve daha sonra modelin altında bırakılan boşluğa bu modelde gördüklerinizi yazmak ve anladıklarınızı açıklamaktır.
3) Bu çalışmayı tamamlamak için toplam 10 dakika süreniz vardır.
4) Açıklama için sadece siyah kurşun kalem kullanınız.

LİTYUM KLORÜR (LiCl) TUZUNUN ÖRGÜ YAPISI



APPENDIX I: WRITING FROM TEXT – 2 (WT2)

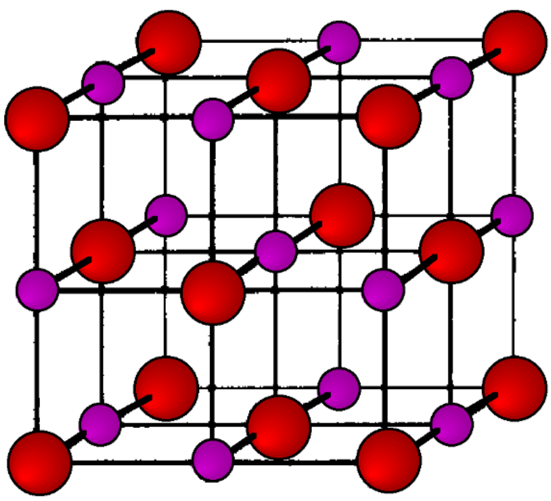
ADI – SOYADI:

SINIFI:

YÖNERGELER

1) Aşağıda sizlere magnezyum oksit (MgO) tuzunun örgü yapısı verilmiştir.
2) Sizlerden beklenen bu görsel modeli dikkatlice incelemeniz ve daha sonra modelin altında bırakılan boşluğa bu modelde gördüklerinizi yazmak ve anladıklarınızı açıklamaktır.
3) Bu çalışmayı tamamlamak için toplam 10 dakika süreniz vardır.
4) Açıklama için sadece siyah kurşun kalem kullanınız.

MAGNEZYUM OKSİT (MgO) TUZUNUN ÖRGÜ YAPISI



APPENDIX J: WRITING FROM TEXT – 3 (WT3)

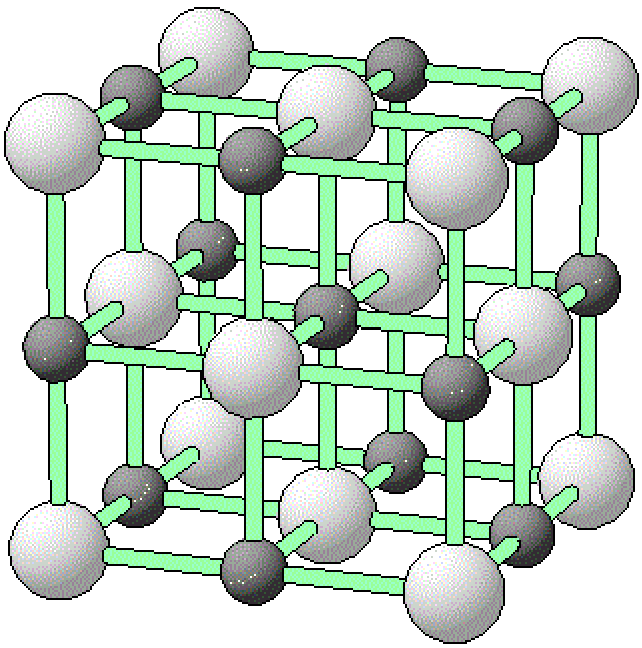
ADI – SOYADI:

SINIFI:

YÖNERGELER

1) Aşağıda sizlere magnezyum sülfür (MgS) tuzunun örgü yapısı verilmiştir.
2) Sizlerden beklenen bu görsel modeli dikkatlice incelemeniz ve daha sonra modelin altında bırakılan boşluğa bu modelde gördüklerinizi yazmak ve anladıklarınızı açıklamaktır.
3) Bu çalışmayı tamamlamak için toplam 10 dakika süreniz vardır.
4) Açıklama için sadece siyah kurşun kalem kullanınız.

MAGNEZYUM SÜLFÜR (MgS) TUZUNUN ÖRGÜ YAPISI



APPENDIX K: HANDOUT OF COMPUTER BASED MODELING TREATMENT

ADI – SOYADI:

SINIFI:

YÖNERGELER

Bu çalışma 2 aşamadan oluşmaktadır. Aşağıda verilen yönergeler her aşamada yapılacak işleri açıklamaktadır.

I. AŞAMA

1) Sizlere sodyum klorür (NaCl) kristalinin örgü yapısının açıklandığı bir metin verilecektir.
2) Sizlerden beklenen bu metni dikkatlice okumanız ve daha sonra metinde belirtilen sodyum klorür (NaCl) kristalinin örgü yapısını ChemSense programını kullanarak yapmanızdır.
3) Çalışma sonunda hazırladığınız modelleri sınıfınız, adınız ve soyadınız bir arada olacak şekilde aşağıdaki örnekte olduğu gibi kullandığınız bilgisayarın masaüstüne kaydediniz.
   - Örnek: 9_A_DENİZ_YILMAZ
4) Çalışmanın bu aşamasını tamamlamak için toplam 35 dakika süreniz vardır.

II. AŞAMA

1) Bu aşamada verilen soruları yapacağınız sodyum klorür (NaCl) kristal modellerine göre cevaplamanız beklenmektedir.
2) Bu aşamada 3 soru vardır.
3) Çalışmanın bu aşamasını tamamlamak için toplam 30 dakika süreniz vardır.

I.AŞAMA

SODYUM KLORÜR (NaCl) TUZUNUN ÖRGÜ YAPISI

İyonik bileşikleri oluşturan birimler atomlar değil iyonlardır. Anyon ve katyonlar elektriksel itme ve çekme kuvvetlerini dengeleyecek şekilde bir araya gelerek düzenli bir kristal örgü yapısı oluştururlar.

İyonik yapılı bileşikler çeşitli tiplerde düzenli örgü yapısı oluşturur. Çoğu iyonik bileşikte anyonlar katyonlardan çok büyük olduğundan anyonların oluşturduğu bir örgüdeki aradaki boşluklara katyonlar girmiştir.

Kristal yapıda her iyon, belirli sayıda komşu ve zıt yüklü iyonun çekim etkisindedir. Örneğin sodyum klorürde her Na^+ iyonu 6 Cl^- iyonu tarafından ve her Cl^- iyonu da 6 Na^+ iyonu tarafından çekilerek meydana gelen birimlerden iyonik kristal yapı oluşur. İyonik kristalde tekrarlayan bu yapısal birimlere **birim hücre** adı verilir.

II. AŞAMA

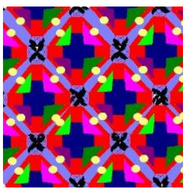
1) Aşağıda verilen tabloyu yaptığınız sodyum klorür (NaCl) kristal modellerine göre doldurunuz.

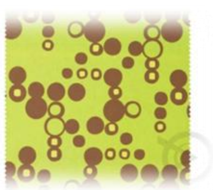
Yaptığınız sodyum klorür (NaCl) kristal modelini çiziniz.
Sodyum klorür (NaCl) kristal modelini nasıl yaptığınızı açıklayınız.

2) Aşağıdaki soruları yaptığınız sodyum klorür (NaCl) kristal modelline göre cevaplayınız.

   a) Kristal örgü yapısı nedir?

   b) Aşağıdakilerden hangisinin yapısı bir kristal yapıya benzemektedir? Açıklayınız.





c) Birim hücre nedir? Açıklayınız

d) Bir tane NaCl kristali oluşturmak için en az kaçar tane Na^+ ve Cl^- iyonu gereklidir?

3) Aşağıda verilen tabloyu sodyum klorür (NaCl) kristal modelini hazırlarken geçirdiğiniz aşamaları düşünerek cevaplayınız.

Bu çalışmadan önce sodyum klorür kristal örgüsü hakkında **BİLDİKLERİNİZ** nelerdi?
Bu çalışmadan sonra sodyum klorür kristal örgüsü hakkında **ÖĞRENDİKLERİNİZ** nelerdir?
Bu modeli hazırladıktan sonra sodyum klorür kristal örgüsü hakkında **MERAK ETTİKLERİNİZ** nelerdir?

APPENDIX L: HANDOUT OF PHYSICAL MODELING TREATMENT

ADI – SOYADI:

SINIFI:

<u>YÖNERGELER</u>

Bu çalışma 2 aşamadan oluşmaktadır. Aşağıda verilen yönergeler her aşamada yapılacak işleri açıklamaktadır.

<u>I. AŞAMA</u>

1) Sizlere sodyum klorür (NaCl) kristalinin örgü yapısının açıklandığı bir metin verilecektir.
2) Sizlerden beklenen bu metni dikkatlice okumanız ve daha sonra metinde belirtilen sodyum klorür (NaCl) kristalinin örgü yapısını oyun hamurlarını ve bakır telleri kullanarak yapmanızdır.
3) Modelin yapımında sadece bu iki malzeme kullanılacaktır.
4) Oyun hamuru kullanırken istediğiniz rengi istediğiniz kadar kullanabilirsiniz.
5) Bakır teli istediğiniz uzunlukta kullanabilirsiniz.
6) Çalışma bitiminde hazırlayacağınız modelleri sizlere verilecek boş beyaz kâğıtlarının üzere dikkatlice yerleştiniz.
7) Kâğıdın sağ alt köşesine adınızı, soyadınızı ve sınıfınızı yazınız.
8) Çalışmanın bu aşamasını tamamlamak için toplam 35 dakika süreniz vardır.

<u>II. AŞAMA</u>

1) Bu aşamada verilen soruları yapacağınız sodyum klorür (NaCl) kristal modellerine göre cevaplamanız beklenmektedir.
2) Bu aşamada 3 soru vardır.
3) Çalışmanın bu aşamasını tamamlamak için toplam 30 dakika süreniz vardır.

I.AŞAMA

SODYUM KLORÜR (NaCl) TUZUNUN ÖRGÜ YAPISI

İyonik bileşikleri oluşturan birimler atomlar değil iyonlardır. Anyon ve katyonlar elektriksel itme ve çekme kuvvetlerini dengeleyecek şekilde bir araya gelerek düzenli bir kristal örgü yapısı oluştururlar.

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Kristal yapıda her iyon, belirli sayıda komşu ve zıt yüklü iyonun çekim etkisindedir. Örneğin sodyum klorürde her Na^+ iyonu 6 Cl^- iyonu tarafından ve her Cl^- iyonu da 6 Na^+ iyonu tarafından çekilerek meydana gelen birimlerden iyonik kristal yapı oluşur. İyonik kristalde tekrarlayan bu yapısal birimlere **birim hücre** adı verilir.

II.AŞAMA

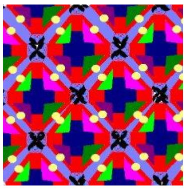
1) Aşağıda verilen tabloyu yaptığınız sodyum klorür (NaCl) kristal modellerine göre doldurunuz.

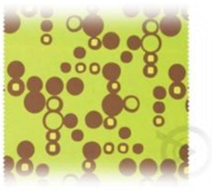
Yaptığınız sodyum klorür (NaCl) kristal modelini çiziniz.
Sodyum klorür (NaCl) kristal modelini nasıl yaptığınızı açıklayınız.

2) Aşağıdaki soruları yaptığınız sodyum klorür (NaCl) kristal modelline göre cevaplayınız.

   a) Kristal örgü yapısı nedir?

   b) Aşağıdakilerden hangisinin yapısı bir kristal yapıya benzemektedir? Açıklayınız





c) Birim hücre nedir? Açıklayınız

d) Bir tane NaCl kristali oluşturmak için en az kaçar tane Na^+ ve Cl^- iyonu gereklidir?

3) Aşağıda verilen tabloyu sodyum klorür (NaCl) kristal modelini hazırlarken geçirdiğiniz aşamaları düşünerek cevaplayınız.

Bu çalışmadan önce sodyum klorür kristal örgüsü hakkında **BİLDİKLERİNİZ** nelerdi?
Bu çalışmadan sonra sodyum klorür kristal örgüsü hakkında **ÖĞRENDİKLERİNİZ** nelerdir?
Bu modeli hazırladıktan sonra sodyum klorür kristal örgüsü hakkında **MERAK ETTİKLERİNİZ** nelerdir?

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