PRE-SERVICE SCIENCE TEACHERS' EXPERIENCES OF COMPUTER SIMULATION AND VIRTUAL REALITY APPLICATION DESCRIBING ATOMS AND MOLECULES AND THEIR COMBINED EFFECTS ON REPRESENTATIONAL COMPETENCE SKILLS

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To my sister and brother...

ABSTRACT

PRE-SERVICE SCIENCE TEACHERS' EXPERIENCES OF COMPUTER SIMULATION AND VIRTUAL REALITY APPLICATION DESCRIBING ATOMS AND MOLECULES AND THEIR COMBINED EFFECTS ON REPRESENTATIONAL COMPETENCE SKILLS

This qualitative case study investigated the combined effects of computer simulations and virtual reality applications on pre-service science teachers' representational competence skills. A workshop which consisted of three consecutive sessions was designed to investigate the purpose of the study. The following questions guided the study: (1) What are the effects of using computer simulations on pre-service science teachers' representational competence skills? (2) What are the combined effects of using computer simulations and virtual reality applications on pre-service science teachers' representational competence skills? (3) What are the experiences of pre-service science teachers using computer simulation in describing atoms and molecules? (4) What are the experiences of pre-service science teachers using virtual reality applications in describing atoms and molecules? The study utilized the set of skills determined by Kozma and Russell (2005) as representational competence skills and sample included five third year and five fourth year pre-service science teachers in Turkey. Pre-tests, post-tests, and semi-structured interviews were used as data collection instruments, and thematic analysis was applied to analyze data. Strengths and weaknesses of computer simulations and virtual reality applications were revealed in this study. The findings highlighted that representational competence skills could be improved from first level to fifth level by both technological tools: computer simulations and virtual reality applications.

ÖZET

FEN BİLGİSİ ÖĞRETMEN ADAYLARININ ATOM VE MOLEKÜLLERİ TANIMLAYAN BİLGİSAYAR SİMÜLASYONU VE SANAL GERÇEKLİK UYGULAMASI KULLANIM DENEYİMLERİ VE BUNLARIN GÖSTERİM YETERLİLİK BECERİLERİ ÜZERİNDEKİ BİRLEŞİK ETKİLERİ

Bu nitel vaka çalışmasında, bilgisayar simülasyonları ve sanal gerçeklik uygulamalarının fen bilgisi öğretmen adaylarının gösterim yeterlilik becerileri üzerindeki birleşik etkilerini araştırılmıştır. Bu amaçla üç oturumdan oluşan bir çalıştay tasarlanmıştır. Aşağıdaki sorular çalışmaya yön vermiştir: (1) Bilgisayar simülasyonlarını kullanmanın fen bilgisi öğretmen adaylarının gösterim yeterlilik becerileri üzerindeki etkileri nelerdir? (2) Bilgisayar simülasyonları ve sanal gerçeklik uygulamalarının kullanılmasının fen bilgisi öğretmen adaylarının gösterim yeterlilik becerileri üzerindeki birleşik etkileri nelerdir? (3) Fen bilgisi öğretmen adaylarının atom ve moleküllerini tanımlayan bilgisayar simülasyonunu kullanım deneyimleri nelerdir? (4) Fen bilgisi öğretmen adaylarının atom ve moleküllerini tanımlayan sanal gerçeklik uygulamalarını kullanım deneyimleri nelerdir? Araştırmada Kozma ve Russell (2005) tarafından gösterim yeterlilik becerileri olarak belirlenen beceriler kümesinden yararlanılmış ve örneklem Türkiye'deki beş üçüncü ve beş dördüncü sınıf fen bilgisi öğretmeni adayından oluşmuştur. Bu çalışmada ön test, son test ve yarı-yapılandırılmış görüşmeler kullanılmış olup, verilerin analizinde tematik analiz uygulanmıştır. Bilgisayar simülasyonları ve sanal gerçeklik uygulamalarının güçlü ve zayıf yönlerini açığa çıkarmıştır. Bulgular, gösterim yeterlilik becerisinin bilgisayar simülasyonları ve sanal gerçeklik uygulamaları ile birinci seviyeden beşinci seviyeye kadar geliştirilebileceğini vurgulamıştır.

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LIST OF SYMBOLS

Δ	A change in the value of a variable in calculus

LIST OF ACRONYMS/ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
AR	Augmented Reality
CS	Computer Simulation
IVR	Immersed Virtual Reality
P	Participant
PhET	Physics Education Technology
PsST	Pre-Service Science Teachers
VR	Virtual Reality

1. INTRODUCTION

1.1. Background

There are many determining skills needed for the teaching profession. Departments in the faculty of education around the world prepare pre-service teachers to be professionals in their fields. In order to be a teacher, one should have knowledge in many areas such as educational psychology knowledge, curricula of the area, content knowledge, pedagogical knowledge, pedagogical content knowledge, and so on (Barba and Rubba, 1992). Pre-service teachers constantly study to improve their knowledge and skills. They learn new methods for teaching, assessment, and instruments that can be used in their lessons. Although there are many teaching methods, there is not just one "best" method because it depends on students' needs. Yet, visualization, such as representations, can be a useful way of teaching.

There are various kinds of representations. Different representations are highly important in teaching because students' needs can differ. Visual learning has massive importance in science education because models and media are highly used in science (Mayer and Moreno, 1998). For instance, models are highly used to identify subatomic particles such as electrons, protons, and neutrons if the concept is the atom. Thus, teachers use representations in teaching to help students better understand the concept of the atom. Nowadays, these representations are delivered via technological tools such as computer simulations and virtual reality applications. Teachers are expected to be mastered in technology, especially in the area of science education, because of extensive usage of technology.

Moreover, teachers have some skills to be professionals in teaching, one of them is representational competence skills. Representational competence is the capacity of teachers as owners of knowledge and a part of pedagogical content knowledge to create and apply precise descriptive representations of a situation or issue in a com-

petent and linked manner (Cooper, *et al.*, 2010; Kozma and Russell 1997) identified a list of representational competence skills as "identifying and analyzing features of a particular representation, transforming one representation into another, generating or selecting an appropriate representation, explaining why a particular representation or set of representations is more relevant, and describing how different representations might say the same thing". Improving representational competence is a very important achievement of a teacher because teachers should have the capacity to create and apply representations of a concept frequently.

1.2. Statement of the Problem

The subject of science education over utilizes representations and visualizations. The use of multiple representations as instruments for problem-solving is, in fact, widely acknowledged in science education. It is thought that an organized synthesis of many representations will be useful for the learning process because each type of representation necessitates a particular way of thinking and has benefits and drawbacks (Scheid, 2018). The usage of representations and models is highly used in scientific disciplines such as chemistry. Chemistry demands a greater understanding of the impenetrable and invisible than other sciences, according to (Kozma and Russell, 1997). Moreover, chemists have a specific set of representational skills or competencies needed to practice their profession and understand chemistry (Kozma and Russell, 1997). These skills allow individuals to switch between several representational forms fast and mix them to convey their ideas and understand their subject matter. As chemists use representations in their profession, pre-service science teachers use them in their lessons. Therefore, improving representational competence skills is important for their professional development in teaching science.

Representational competence skills and how to improve this notion are investigated due to their importance for teacher training. It is predicted that developing the skill set listed by (Kozma and Russell, 1997) may be beneficial for teachers and their teaching skills. Moreover, virtual reality has been used in education recently, and

its effects on teachers and students have been investigated. Additionally, it is known that computer simulations have positive effects on improving teachers' representational competence skills.

Although there are research studies conducted to investigate how to improve teachers' and students' representational competence skills in the literature, most of them used simulations and 3 dimensional (3D) concrete models as teaching tools (McCollum *et al.*, 2014; Padalkar and Hegarty, 2015; Patwardhan and Murthy, 2017; Stieff, 2011; Stieff *et al.*, 2016; Stieff and DeSutter, 2021; ¸Stieff, *et al.*, 2014). As the teaching profession is improving, the technological tools involving participants' representational competence are also improving. Many research studies have investigated the integration of virtual reality (VR) and its effects on the field of education in general. Because virtual reality can provide real-life experiences, new designs and models can be created very easily by using virtual reality. Studies conducted in this field mostly sampled secondary school students, university students, and pre-service science teachers. For example, in the studies that pre-service teachers and university students are sampled, effects of VR in teaching are investigated, such as its advantages, disadvantages, and users' attitudes towards using VR as a teaching tool. In these studies, pre-service teachers and university students evaluated virtual reality for teaching purposes (Barmaki, 2015; Dalgarno *et al.*, 2016; Lamb, and Etopio, 2020; Lee, and Shea, 2020; Makransky *et al.*, 2019; Parong and Mayer, 2018; Parong and Mayer, 2020). Moreover, in the research studies that secondary school students sampled, learning advantages, disadvantages, and motivation of students have been investigated. In these studies secondary school students assessed virtual reality as a learning tool (Chang *et al.*, 2020; Chen *et al.*, 2020; Jones *et al.*, 2015; Liu *et al.*, 2020; Makransky *et al.*, 2020).

In this manner, this study aimed to investigate whether virtual reality has an effect on teachers' representational competence skills. Moreover, if virtual reality has an impact on teachers' representational competence, it is important to understand how. In the science education context, to the best of our knowledge, no study has focused on the effects of using virtual reality on pre-service teachers' representational

competence skills. Whereas the improvement in representational competence skills of undergraduate students is measured (Nielsen *et al.*, 2018; Stull and Hegarty, 2016; Stull *et al.*, 2016), there is a gap in the literature on the combined effects of using simulations and virtual reality on representational competence skills. There is a need for investigation of the effects of virtual reality on the representational competence skills of pre-service science teachers in terms of contributing to the literature of science education. This study investigates the combined effects of using simulations and virtual reality applications on pre-service science teachers' representational competence skills.

1.3. Purpose of the Study

The purpose of this case study was to investigate the combined effects of using simulations and virtual reality applications on pre-service science teachers' representational competence skills and their experiences while using computer simulations and virtual reality applications and describing atoms and molecules. The combined effects in this case study were effects of using computer simulations and virtual reality applications. Since virtual reality applications were used after computer simulations, the effects of combination of these two treatments were investigated.

1.4. Research Questions

This study investigated four main research questions to investigate the combined effects of using simulations and virtual reality applications in describing atoms and molecules on pre-service science teachers' representational competence skills and their experiences:

(i) What are the effects of using computer simulations on pre-service science teachers' representational competence skills?
(ii) What are the combined effects of using computer simulations and virtual reality applications on pre-service science teachers' representational competence skills?
(iii) What are the experiences of pre-service science teachers using computer simula-

tion in describing atoms and molecules?

(iv) What are the experiences of pre-service science teachers using virtual reality applications in describing atoms and molecules?

1.5. Significance of the Study

Technology has become an integral part of education since it has many advantages. Especially in science education, teachers should have specific technology skills to integrate specialized tools into their lessons. For instance, to observe a plant cell, the teacher should have the basic knowledge of how to use a microscope. Therefore, in the teacher training programs, pre-service science teachers learn about these tools as well as the content knowledge and pedagogical content knowledge. Virtual reality applications are one of the recent technological tools that have been used nowadays. It is a very new technology, and many types of research have been done to investigate its advantages and disadvantages, as discussed.

Since virtual reality applications are 3-dimensional and reenacted encounters that can be compared to or distinctive from the real world, they might improve the representational competence skills of the pre-service science teachers. Moreover, one of the key affordances they have is giving the opportunity to experience otherwise impossible encounters (mainly due to scope or hazard). However, the effects of virtual reality on pre-service science teachers' representational competence skills have not been investigated before. Virtual reality is expected to be used in the education field more in the future (Checa and Bustillo, 2023; Chen *et al.*, 2020) found that students can build mental models in science by using virtual reality. Moreover, students who used virtual reality formed a cyclical learning pattern that involves hypothesis generation, active learning, and post-activity in science (Plack and Santasier, 2004).

As (Kozma and Russell 1997) stated, more than other sciences, chemistry requires a grasp of the impenetrable and unseen. Even though there are media and representations, students' understanding of the representations such as visuals, pic-

tures, and graphs through media can differ. Therefore, mastering representational competence skills is essential for both students and teachers (Stull and Hegarty 2016) suggest that using virtual reality in representing chemistry may give an opportunity to observe molecules since its more realistic 3D nature rather than computer simulations. For instance, atomical shapes, bonding, and angles of molecular bonding can be observable by using virtual reality. Therefore, virtual reality applications might improve representational competence skills.

1.6. Operational Definition of Key Terms

Representational Competence: is the capacity to create and apply precise descriptive representations of a situation or issue in a competent and linked manner (Cooper *et al.*, 2010).

Representational Competence Skills: are listed by (Kozma and Russell, 2005) as:

> The ability to use representations to describe observable chemical phenomena in terms of underlying molecular entities and processes.
>
> The ability to generate or select a representation and explain why it is appropriate for a particular purpose.
>
> The ability to use words to identify and analyze features of a particular representation (such as a peak on a coordinate graph) and patterns of features (such as the behavior of molecules in an animation).
>
> The ability to describe how different representations might say the same thing in different ways and explain how one representation might say something different or something that cannot be said with another.
>
> The ability to make connections across different representations, to map features of one type of representation onto those of another (such as mapping a peak of a graph onto a structural diagram), and to explain the relationship between them.
>
> The ability to take the epistemological position that representations correspond to but are distinct from the phenomena that are observed.
>
> The ability to use representations and their features in social situations as evidence to support claims, draw inferences, and make predictions about observable chemical phenomena.

Virtual Reality: a reenacted encounter that can be compared to or distinctive from the real world by using special headsets. There are two types of virtual reality:

immersive virtual reality and text-based networked virtual reality (Psotka, 1995).

Simulation: a computer program that aims to replicate a model of a particular system and to allow users to change the variables (Khan, 2008).

2. LITERATURE REVIEW

In this chapter, the literature review regarding using technology in science education and representational competence skills will be investigated. The chapter will start with understanding scientific concepts, teaching science with technology, the types of technological tools, and representational competence skills. Representational competence and using technology in education studies from different disciplines, the importance of representational competence, and the improvement of representational competence will be explored, respectively.

2.1. Understanding Scientific Concepts

Language is written or auditory communication that enables individuals to interact with one another. A specific language is needed to use symbols to express the phenomenological world in chemistry. To prevent misunderstandings, it is essential to use the appropriate language and understand the specific meanings of chemical concepts (Reina, *et al.*, 2022).

Griffiths and Preston, (1992) addressed common misunderstandings of chemical language by Grade 12-level students. The students found that the major misconceptions are the fundamental properties of atoms and molecules. The participants in their study included 30 students with various academic backgrounds, scientific skills, and abilities. According to interviews with the participants, they found and categorized students' misconceptions as; the structure, composition, size, shape, weight, bonding, and energy of molecules; the structure, shape, size, weight, and animistic perceptions of atoms.

Harrison and Treagust, (1996) examined students' mental representations of atoms and molecules in grades 8-10. Fourty-eight students were the participants in this study. According to interviews, the results showed that many of the participants favored mod-

els that are both discrete and concrete. Moreover, they claimed that a significant portion of the scientific process is defined by modeling, yet most younger science students struggle to distinguish between models and reality. For some students, terminology from biology and chemistry, such as the nucleus and shells, were confusing. For instance, electron clouds were seen as structures in which electrons were buried, whereas electron shells were seen as shells that encased and shielded atoms. As a result, they advised teachers to foster their students' modeling abilities and have class discussions about similar models, including shared and unshared features.

Cokelez and Dumon, (2005) identified and described the students' representations and misunderstandings of the notions of atom and molecule. The authors emphasized knowledge of upper secondary school French students (in grades 10 to 12). The school science textbooks and curriculum have been investigated to determine the planned evolution of the conceptualization of these concepts within the school curricula to comprehend the assimilation of information better. The study findings indicated that some students remained confused about the terms of atom and molecule as well as model and reality from grade 10 to grade 12.

In summary, understanding scientific concepts is a crucial part of a lesson. The teachers, in general, constantly work to develop conceptual understanding. Research studies that focus on developing conceptual understanding investigate students' misconceptions and misunderstandings in different grades (Cokelez and Dumon, 2005; Griffiths and Preston, 1992; Harrison and Treagust, 1996). When the literature was reviewed, it was found that the concepts of atoms and molecules have been confusing for students.

2.2. Teaching Science with Technology

Multimedia is increasingly seen as a valuable tool for teaching and learning because of recent technological advancements (Chan, 2015). As technology has developed, using and integrating technology in classes has become more expansive. Students now

learn mostly through visual materials due to technologically enhanced visual tools. This generation of students is frequently referred to as the "digital generation" (Chan, 2015). Technological tools such as augmented reality (AR), animations, computer simulations, and virtual reality applications increase inquiry-based learning (Chan, 2015). There are many benefits of animations in science education such as understanding the process of phenomena. These phenomena range from magnetism to animal migration. Many studies have noted improvements in abstract thinking, communication and problem-solving abilities, cognitive abilities, and learning engagement (Chan, 2015). Visualizing abstract concepts, particularly in science and mathematics, is one of the benefits of animations for student learning (Lipeikiene and Lipeika, 2006; Yang *et al.*, 2003). For instance, animation integrated lectures led to a more complete understanding of certain cell biology concepts than lectures that only use static illustrations (Stith, 2004).

Augmented reality and virtual reality are assumed as newest technology. A real-time direct or indirect picture of a physical environment improved or augmented by adding virtual computer-generated information is augmented reality (AR). AR enhances the user's perspective of and interaction with the natural world; however, users of virtual reality (VR) technologies are entirely submerged in a virtual environment (Furht, 2011). The findings of (Kerawalla *et al.*, 2006) are consistent with earlier research that examined the use of augmented reality (AR) and virtual reality (VR) in the classroom, with an emphasis on creating settings that students can interact with and explore to support inquiry-based learning in science education. Yet, their study also found that flexible AR content will allow teachers to customize it to each student's requirements. They found that elements in AR technology should be able to be added and removed, and animation speeds should be able to be altered.

Even though many technological tools are used in teaching science, two main types of technology in this study have been used: computer simulations and virtual reality applications.

2.2.1. Simulations

A computer program that aims to replicate a model of a particular system is called a computer simulation (Khan, 2008). Users may alter the model to see how it would act in different scenarios, and the application itself will display the results or report them as measurements. Some computer simulations are constructive for science teachers because they enable quick testing of ideas, reveal trends via graphs or other representations, and provide extreme situations to support thought experiments and what-if scenarios. These factors all help students visualize scientific concepts, such as atoms, molecules, and universe that are either too large or small for them to see (Khan, 2008).

The main objective of study by (Khan, 2011) is to explain a methodology for teaching science through computer simulations. The impact of an experienced science teacher's instruction on his students was examined in this case study of how he taught chemistry using computer simulations. In this study, integrated computer simulations were not meant to take the place of the labs; instead, they reflected the outcomes of simulated lab experiments or the behavior of atoms and molecules under circumstances that were not visible to the naked eye. The sample of Khan's study was an introductory chemistry student in an extensive North American public university, and the duration of this study was three semesters. 24 college students and the instructor of the course were the participants of this study. This study showed that science education could benefit specifically from simulation technologies. For instance, students claimed that simulations enhanced their ability to think critically, clarified previously complex processes, and extended the boundaries of traditional textbook learning. The results showed that students studying science might find digital technology, such as computer simulations, very intriguing since they might alter variables in various ways and track changes from this interaction.

The study of (Pinto *et al.*, 2014) aimed to determine how instructors' mediation, combined with computer simulations and experimental activity, might foster the

growth of students' epistemic practices in a classroom setting. The sample of this study involved two science instructors from the university level: both taught physics, the concept of velocity, at the same university in Portugal. The findings implied that using computer simulations as part of instructors' mediation could improve the quantity and quality of students' epistemic practices.

Correia *et al.*, (2019) investigated the simulation-based learning system's helpful features and instructional strategies about the subject gas behavior by using Physics Education Technologies (PhET) simulation. One hundred fourteen secondary school science students were sampled for this study. The study showed that the student's views on the simulation's instructional design elements were highly positive, which included prompt feedback, opportunities to change gas settings, a scaffolding system, and more precise explanations of complex ideas. Moreover, the students preferred the simulation aspects that supported the visualization, guiding questions, integration of various features and instructional methods, and straightforward explanations of challenging ideas. These methods assisted students in overcoming their preexisting misconceptions about gas behavior at the submicroscopic level and accepting alternative views supported by science.

The study of (Ruwiyah *et al.*, 2021) investigated the effects of using simulation as a teaching tool in the field of physics. This research was done to determine how modeling learned through PhET simulation affected students' science process skills. The participants of this study were thirty-six college students. The findings showed that science process skills and manipulative skills increased in participants who used PhET simulation.

Pallant and Tinker, (2004) explored the outcomes of using a potent molecular dynamic model in curricula that cover the phases of matter by middle and high school students. This study was conducted in 10 heterogeneous physical science courses for eighth graders, which typically had 20 students. The results indicated that middle and high school students might develop relatively reliable mental models of the states

of matter through guided investigations of computational models of matter based on molecular dynamics according to considerably higher post-test results than pre-test scores.

Moreover, (Yıldırım, 2021) suggested that computer simulations embedded in virtual laboratories affected students' academic performances. The purpose of study of (Yıldırım, 2021) was to determine how using virtual lab applications that were computer simulations in scientific instruction affects students' academic performance and perceptions of these applications. 62 adolescents who were enrolled in the 8th grade at a secondary school in Antalya for the 2019-2020 school year make up the study group. The study used a mixed-methods approach. The control group and the experimental group, who were taught through virtual laboratory programs, were compared in terms of achievement in the study's quantitative dimension. The data collected from the observation forms generated throughout the application process as well as the data collected from the interview forms given to the experimental group students made comprised the study's qualitative component. On the other hand, it has been demonstrated that virtual laboratory applications helped students learn in a meaningful way by enabling the concretization of abstract concepts. Additionally, because these applications were appealing to students, they have been shown to positively support their interest, excitement, and motivation in the science course.

The purpose of the quasi-experimental study of (AlArabi *et al.*, 2022), was to assess the effects of computer simulations (CSs) and conventional face-to-face instruction on students' understanding of Newton's Second Law of Motion (NSLOM) in grade 11. The study took place in two secondary schools in a large city in the United Arab Emirates (UAE). The study's pre- and post-tests were the Newton's Second Law of Motion Achievement Test (NSLMAT), which was utilized to gather data. 90 students in grade 11 between the ages of 16 and 17 took part in the study. Two classes of grade 11 boys (50 students) and two classes of grade 11 girls (40 students) were randomly selected to take part in this study. To examine the data, descriptive and inferential statistics were utilized. Results indicated that CSs helped make connections and draw

attention to the ideas and specifics of NSLOM through visualization. Additionally, CSs produced superior outcomes to those taught in face-to-face instruction. The study advised physics instructors to incorporate CSs into their curriculum and use them as effective resources to raise student learning results.

The aim of study of (Ben Ouahi *et al.*, 2022) was to identify and analyze the opinions of physics-chemistry (Ph-Ch), life and earth sciences (LES) teachers regarding the use and efficiency of interactive PhET simulations in student teaching and learning. In this study, a survey research technique was employed. At middle and high schools, 114 Moroccan science teachers (67 Ph-Ch; 47 LES) were polled. In order to provide light on who utilizes PhET simulations, why they use them, and how they are used, a quantitative analysis was carried out. Despite the existence of a number of barriers that prevented the use of classroom simulations, the findings showed that the use of interactive simulations in investigative science teaching and learning was very effective for both teachers and students. This study suggested that interactive simulations could improve learning activities and aid students' comprehension of scientific ideas in Moroccan science instruction.

In summary, computer simulations are beneficial for both students and teachers. One of their best properties is enabling users to experiment with changing variables easily. In science education, even though the experiments are not assumed as hazardous, computer simulations make laboratory environments safer. Besides computer simulations' practical reasons for usage, research studies showed that students' learning processes are affected positively by using them (AlArabi *et al.*, 2022; Correia *et al.*, 2019; Khan, 2011; Pallant and Tinker, 2004; Pinto *et al.*, 2014; Ruwiyah *et al.*, 2021). Moreover, computer simulations are also beneficial in terms of concepts that invisible to the naked eye such as atoms and molecules (Yıldırım, 2021). The results of reviewed literature supported in terms of investigating pre-service science teachers' experiences of using computer simulations.

2.2.2. Virtual Reality

Virtual reality (VR) can be a simulated experience that is similar to or different from the real world. There are many uses for virtual reality, such as business, education, and entertainment. There are two types of virtual reality: non-immersive and immersive (Psotka, 1995). The latter takes the concept even further by giving the impression of being physically present in the non-physical world. The former is a computer-based environment that can imitate places in the actual or imagined worlds (Freina and Ott, 2015). Nowadays, both types of virtual reality frameworks utilize virtual reality headsets or multi-projected environments to create realistic pictures, sounds, and other sensations that simulate a user's physical presence in a virtual environment. Looking around the artificial world, moving around in it, and interacting with virtual features or items can be done by using virtual reality equipment. Head-mounted displays with a small screen in front of the eyes consist of virtual reality, but specially designed rooms can also create effects with multiple large screens (Freina and Ott, 2015). An example of virtual reality equipment that used in this study can be seen in Figure 2.1. Virtual reality regularly consolidates sound-related and video feedback but may permit other tangible and constrain input through haptic technology.



Figure 2.1. An example of a virtual reality headset used in the study.

Studies showed that student's motivation and engagement towards science lessons increased by using virtual reality (Dalgarno *et al.*, 2016; Makransky *et al.*, 2019; Liu *et al.*, 2020; Makransky *et al.*, 2020; Parong and Mayer, 2018), students have positive attitudes towards virtual reality (Lee and Shea, 2020), science learning performance of students might increase (Chen *et al.*, 2020), and their creative designing skills improve (Chang *et al.*, 2020). However, (Parong and Mayer, 2020) indicated that although virtual reality has many benefits, it also increases cognitive load.

In the study of (Jones *et al.*, 2015), middle school teachers and students' perceptions of virtual reality were investigated after learning science. They researched whether the present assessment was valid and reliable for youth (students) and adults (teachers). Students and teachers separately experienced in virtual reality simulation about heart and electrical circuits. Each group (students and teachers) had four sessions of virtual reality. A presence survey was completed after finishing the sessions by participants. There was only one significant result after analyzing the data: The results showed that students find virtual reality more realistic than the teachers (Jones *et al.*, 2015).

Dalgarno *et al.*, (2016) investigated virtual reality's effects on practicing teaching and presentation skills. The participants of this study were pre-service teachers and were divided into four groups. There were two phases of this study. The results of this study showed that pre-service teachers perceived virtual reality positively. Even though some responses were "confusing" and "boring", pre-service teachers generally responded positively. Moreover, according to the results, the participants' presentation skills increased.

Parong and Mayer, (2018) investigated the instructional effectiveness of immersive virtual reality (IVR) and a desktop slideshow as media for teaching science were compared. Additionally, in this study efficacy of adding a learning strategy to a VR lesson was investigated. The researchers sampled 55 university students in the psychology department for the first purpose. Twenty-seven participants were randomly

assigned to the groups of VR-using and PC-using. Each group was distributed the same topic of biology: the human body. The VR group showed more interest and higher motivation than the PC group. However, the PC group had better performance than the VR group. For the second purpose of this study, the researchers divided the VR group into halves. One-half were asked to summarize what they learned from the VR sessions, whereas the other half were not. The results showed that students who summarized the VR sessions had better learning performance than students who did not. Moreover, researchers found that students who summarized the VR sessions had the same learning performance as the PC group who did not summarize the session.

The consequences of adding immersive virtual reality (IVR) to learning simulations were investigated in another study. The researchers also examined if the principles of multimedia learning are generalizable to IVR. An electroencephalogram (EGG) was used to understand and achieve their goals. The participants were 52 university students in this study which was an experimental study. The participants were divided into the groups PC-using environments and VR-using environments. Moreover, each group received simulations containing on-screen only or on-screen text with narration. In text versions, the VR-using group reported being more engaged than the PC-using group. Yet they learned less than the PC-using group. Moreover, when the EGG was measured, students who used VR had a higher cognitive load than the PC-using group. The researchers concluded that VR could be motivating while learning; however, learning science in VR might cause cognitive overload and distract the learner. Therefore, VR students might have less opportunity to build learning outcomes than the PC group (Makransky *et al.*, 2019).

Moreover, the effects of virtual reality were investigated in terms of students' learning processes. Chen *et al.*, (2020) investigated the effects of virtual reality on developing a hands-on activity in the field of physics (electricity, hydromechanics, kinematics, energy, and energy conservation) to help students learn by doing. The participants were 162 tenth-grade students divided into two groups. Each group was asked to develop a hands-on activity; however, only the experimental group could use virtual

reality to achieve this goal. This study showed that all the students' learning performances increased. The group that used virtual reality achieved significantly better learning performances and hands-on abilities. Thus, this result indicated that virtual reality could be a helpful tool to increase students' learning performances. Students could build mental models on given tasks by using virtual reality. Another purpose of this study was to investigate cyclical learning patterns. The students who used virtual reality formed a cyclical learning pattern. They started with group discussion, then moved on to solving problems, developing a product, and then they chose to go back to another group discussion. However, students who did not use virtual reality showed a linear learning pattern which meant they did not go back to another group discussion.

Another study by (Liu *et al.*, 2020) investigated the influences of using immersive virtual reality (IVR) in science lessons in sixth grade. 90 students were the sample of this study. IVR-based science lessons in the subject of animals and plants were developed for middle-school students. These lessons' effects were examined in terms of learning performance. Head-mounted displays were used in the experimental group, whereas traditional educational methods were used in the control group. The traditional teaching methods included PowerPoint presentations only. The results of this study showed that the experimental group's academic and engagement scores, according to the engagement scale were higher than the control group. Furthermore, the experimental group was more motivated toward IV technology than the control group.

Another research study done by (Chang *et al.*, 2020) suggested that virtual reality affected students creative design performances. Chang *et al.*, (2020) investigated the effects of teaching via virtual reality (VR) on creative design performance and experiential learning processes in physics. The participants were 138 seventh-grade students and they were asked to develop a car model. The participants were divided into two groups in this study: experimental and control groups. The students who were in the experimental group used virtual reality to design their project on car modeling, whereas the control group used only paper and pencil. The results of this study showed that students were positively affected by VR, such as designing creatively, test-

ing, and revising the stages of their projects. Moreover, the analyses showed that VR significantly positively affected creative design outcomes.

The study by Makransky, (Petersen and Klingenberg, 2020) investigated the value of using immersive virtual reality (IVR) science laboratory simulations. The researchers conducted two studies. For the first study, participants were sampled among eight grade students, and there are 99 participants in total. The participants were introduced to IVR by laboratory safety simulations. The results of this study showed that students' interest in science and self-efficacy increased after using IVR. Moreover, according to interviews, female students stated an increase in science career aspirations. For the second study, participants were sampled among high school students, and there were 131 participants. They used a DNA analysis IVR simulation to compare the value of using an IVR simulation or a video of the same simulation. Similarly, the IVR-based group's interest in science was higher than the video group's. The self-efficacy of both groups improved.

The study by (Lee and Shea, 2020) investigated pre-service elementary teachers' attitudes toward using virtual reality (VR) in science lessons in elementary school. There were 38 pre-service teachers as participants in this study which had two stages quantitative and qualitative. For the quantitative part of a pre-test and post-test subject design, pre-service teachers criticized and evaluated VR classroom applications. The results showed that participants felt ready to use VR as an instructional tool. For the qualitative part, the researchers collected answers from open-ended questions. The qualitative study's results also supported quantitative results; participants had positive attitudes toward using VR and thought VR apps could be supportive.

The purpose of study by (Lamb and Etopio, 2020) was to analyze, contrast, and define interactive VR-based clinical teaching environments for pre-service science teachers and those found in real teaching situations. VR-based and real-life teaching environments were compared. The participants of this study were preservice science teachers and they were randomly assigned to real-life and VR conditions. The compos-

ite neuroimaging, psychological, and engagement surveys were not statistically significant. Therefore, the results showed that VR helped preservice science teachers prepare their lessons before implementing them in real-life conditions.

The study of (Kurul *et al.*, 2020) investigated how undergraduate physical therapy students' training in anatomy was affected by immersive, 3D, interactive virtual reality (VR). The study involved a total of 72 students. According to the Purdue Spatial Visualization Test Rotations (PSVT-R), sex, and Kolb Learning Style Inventory, the students were randomly assigned to the control (n= 36) and VR (n= 36) groups. A test with 15 multiple-choice questions was given to each student before and after the intervention. Both the VR group and the control group's post-test scores were significantly higher than their pre-test scores in both cases. It was discovered that the VR group's advantage in the difference between the pre-test and post-test outcomes was significantly greater. This study discovered that teaching in anatomy using a 3D immersive VR system was advantageous. These findings imply that VR systems can be utilized by health students as an alternative to traditional anatomy training methods.

The mixed-method study by (Artun *et al.*, 2020) investigated how virtual reality-enhanced laboratory activities affected pre-service science teachers' science process skills in Turkey. The quasi-experimental pretest-posttest control group intervention involved 54 participants third-grade science teachers who were enrolled at a state institution in Eastern Anatolia, Turkey. There were 30 participants in the control group and 24 in the experimental group. Both groups received the science process skills assessment both before and after the six-week intervention. Six members of the experimental group were also the subjects of semi-structured interviews after the intervention process. Despite the fact that the groups did not differ at the conclusion of the intervention, it was determined that the experimental group's improvement in test scores overall was statistically significant.

Even though there are many positive aspects of using virtual reality in education, there are also drawbacks. In another study by (Parong and Mayer, 2020), students'

cognitive and affective processes were investigated by using immersive virtual reality (IVR). In this study, students were divided into two groups: one uses IVR in a biology lesson, whereas the other uses a slideshow on a desktop. The results showed that the IVR group performed worse than the PC group. IVR group reported higher emotional arousal and extraneous cognitive load. Interestingly, the IVR group showed less engagement than the PC group. IVR group is divided into two halves, and the researchers conducted practice questions after the IVR session to one group, whereas the other group did not receive any inquiries. However, the PC group performed better on biology than both IVR groups, with or without practice questions. Extraneous cognitive load and emotional arousal were the reasons for the low-performance scores of the IVR group. These results support that IVR creates a mental distraction which causes lower learning outcomes.

The problems could be mentioned with using head-mounted-display (HMD) virtual reality equipment were cybersickness, motion sickness, nausea, pallor, sweating, and headaches (Di Lanzo *et al.*, 2020) suggested that such problems may make it less likely that virtual reality will be widely used to improve and develop specific skill-based learning outcomes in engineering education, opening the door for future study focus.

In summary, there are debates on the benefits of using virtual reality in classrooms. Many studies that have been mentioned earlier showed that virtual reality can be beneficial in terms of increasing students' motivations and engagement in science lessons (Dalgarno *et al.*, 2016; Makransky *et al.*, 2019; Liu *et al.*, 2020; Makransky *et al.*, 2020; Parong and Mayer, 2018).

Moreover, the study by (Lee and Shea, 2020) showed that students have positive attitudes toward using virtual reality in lessons. Additionally, the science learning performance of students may increase (Chen *et al.*, 2020), and their creative designing skills improve (Chang *et al.*, 2020) by using virtual reality. The results of reviewed studies supported this study in terms of understanding the experiences of the users. Besides virtual reality's benefits, there are also negative aspects of using it (Parong and

Mayer, 2020) indicated that learning science with VR could cause cognitive overload and divert the learner, leaving less room to achieve learning objectives.

2.3. Representational Competence

Representational competence is the capacity to create and apply precise descriptive representations of a situation or issue in a competent and linked manner (Patwardhan and Murthy, 2017). Representational competence skills include the ability to transition between several kinds of representation and communicate about underlying, weakly seen physical elements and processes (Cooper *et al.*, 2010). The representational competence skills framework is significantly used in the field of chemistry education and science education (Popova and Jones, 2021). It is a general framework in the field of chemistry due to the abstract nature of the subject. In the field of chemistry, some characteristics of matter, such as odor, changing colors, and evaporation, can be seen; however, atoms which constitute matter are not easily observable.

2.3.1. Importance of Representational Competence for Science Education

A thorough comprehension of scientific experiments, facts, and concepts depends critically on various mental representations and how they interact. Representations and visualizations are overutilized in the field of science education. Indeed, the application of various representations as problem-solving tools is widely recognized in science education. Each sort of representation requires a particular style of thinking and has advantages and disadvantages; as a result, it is believed that a skillful synthesis of many representations will be advantageous for the learning process (Scheid, 2018). Learning can improve using images, visualizations, and representations (Mayer and Moreno, 1998).

Representations and models are used primarily in abstract fields such as chemistry. As (Kozma and Russell, 1997) stated, chemistry requires a grasp of the impenetrable and unseen more than other sciences. Even though there are media and

representations, students' understanding of the media can differ. Moreover, (Cooper *et al.*, 2010) found that representing molecules in a 3D (3-dimensional) format enhanced representational competence skills rather than representing molecules in a 2D (2-dimensional) format. 3D formats can be virtual reality applications, while 2D can be computer simulations.

Kozma *et al.*, (2000) underlined the need to include the growth of representational competence in the chemistry curriculum. According to (Kozma and Russell, 1997), chemists possess a particular set of representational abilities or competencies essential to their knowledge of chemistry and conduct their profession. With these abilities, they can perform transition quickly between several representational forms and combine them to effectively communicate their thoughts and comprehend their subject matter (Kozma *et al.*, 2000).

In the research of (Farida *et al.*, 2009), they emphasized that due to their incapacity to describe and explain submicroscopic structures and processes accurately, students often struggle with chemistry. The three levels of chemical representations can be integrated into multimedia for the best development of this skill (Farida *et al.*, 2009). Moreover, in their study, (Stieff *et al.*, 2016) claimed that disciplinary-based interventions to improve representational competence in chemistry might raise students' overall success and reduce failure rates.

Nitz *et al.*, (2014) evaluated students' representational competence, subject-matter knowledge, and development over one instructional unit. Nine hundred thirty-one secondary school students from 51 different classes participated in this study. The findings showed that representational competence relates to subject-matter (content) knowledge. Content knowledge positively predicted representational competence. As a result, representational competence was found to be highly important in science education, especially chemistry education since visualizations and representations are highly used to construct knowledge.

2.3.2. Improving Representational Competence

Stieff *et al.*, (2016) study aimed to enhance representational competence to increase student performance in organic chemistry. They focused on representational competence because they believed that strengthening this group of abilities would result in a broader improvement in course assessments. To do this, two modeling workshops were included in the regular course curriculum. These workshops entailed building real-world molecular models and matching them spatially with diagrams typically used in organic chemistry. Findings showed that students who used concrete models could better communicate between different chemical representations than those who did not. However, they also found that students seldom use accurate models to improve their understanding or problem-solving despite the need to acquire model kits for the course. Although students think models are typically helpful for supporting the presentation of spatial information in discipline diagrams, many think creating models takes too much effort to justify their usage.

The study of (Padalkar and Hegarty, 2015) set out to develop and evaluate treatments that would enhance students' representational and meta-representational skills in organic chemistry. They specifically addressed that many students cannot maintain critical spatial linkages while converting between diagrams after taking an introductory course in organic chemistry. Seventy-five undergraduate students from a research institution were the participants. Each participant had finished at least one organic chemistry course. The results showed that the students utilized the models more frequently and correctly than the control group after the intervention. Moreover, drawing made students commit to the relative spatial positions of diagram components while simultaneously making them aware that the components can take on different positions. This alone might be enough to highlight knowledge gaps in students and help them develop the ability to preserve spatial relations correctly.

Stieff, *et al.*, (2014) conducted an experimental analysis of spatial thinking in the STEM field of organic chemistry to examine the link between spatial ability and repre-

sentational competence. Students' performances were evaluated on three examinations that varied by representational format to explore the association between spatial ability and representational competence. Designs included only three-dimensional models (3D-Model) that highlighted spatial relationships using shading and perspectival cues, only two-dimensional diagrams (2D-Diagram) that hinted at spatial relationships through disciplinary formalisms, and mixed formats that incorporate various molecular structure representations (2D-3D Mixed). The participants were 28 undergraduate chemistry students. The results of this study showed that when comparing representations with similar formats (2D, 3D), students would do better and more quickly than those with mixed designs. Moreover, it is found that mental rotation and representational competence are required to solve mixed-format objects.

2.3.3. Improving Representational Competence with Technology

The study of (Stieff, 2011) aimed to determine how the Connected Chemistry Curriculum affected students' topic understanding and representational skills. The findings showed that compared to other students, those who successfully finished the Connected Chemistry - which is a computer simulation program - unit demonstrated better accomplishment and more frequent usage of submicroscopic chemical representations that demonstrated dynamism. Moreover, it was found that the quality of the student replies in the Connected Chemistry classes suggested that the technology-infused curriculum could improve secondary student success levels and representational competence in chemistry.

Patwardhan and Murthy, (2017) aimed to evaluate the impact of reciprocatively dynamic linking on students' growth in representational competency. Learning about the semantics of each representation, the portions of the domain that are represented, how learners link representations to one another, and how they translated between representations were all considered when evaluating the development of representational competence. Participants were second-year engineering students from three different institutions connected to the University of Mumbai. The following two conditions were

applied to participants at random: (a) Simulation (SIM group) and (b) Interactive Simulation with Reciprocative Dynamic Linking (SIM-RDL). The results showed that the SIM-RDL group outperformed the SIM group in test scores.

Stieff and DeSutter (2021) assessed how activities that required students to create drawings of disciplinary representations in a science classroom increased representational competence and conceptual change. A set of curriculum materials were developed that used disciplinary representations embedded in a simulated microworld. These materials were developed in order to cover a variety of core concepts from the general chemistry classroom and to assess the effectiveness of sustained drawing activities for enhancing RC and learning in the science classroom. A research-intensive institution with 505 students enrolled in one of four general chemistry courses lasting 15 weeks in the first semester took part in this study. During the regular teaching course, 92 students successfully finished a period that included ongoing drawing interventions. A class with the same subject that did not contain drawing exercises was completed by 413 students. The results showed that students who were engaged in free drawing exercises while using the simulations performed better on a test of conceptual chemistry comprehension. However, the performance of students who participated in more drawing activities was not superior to that of students who participated in fewer drawing activities. Instead, students who generated high-quality sketches that more precisely reflected the intended learning objectives of a course and represented a theoretically accurate chemical system had higher results than students who produced low-quality drawings.

McCollum *et al.*, (2014) concentrated on assessing students' matching (e.g., representational transformation) and construction (e.g., representational construction) abilities while utilizing either manipulable 2D projections of 3D molecular images on an iPad or 2D printed representations of molecules. The participants of this study were 102 undergraduate students. Participants were randomly allocated to either the paper-based or iPad-based learning group. The results demonstrated that touch-screen technology positively impacted how students' visual cognitive skills were developed. Moreover, the

ability to convert a structural formula into a physical model of one's design was another indicator of superior building abilities among those who used the iPad during previous activities, even though the iPad was not utilized during the construction exercise.

Due to the strong relationship between science and technology, various methods have been used to implement technology to improve representational competence skills (McCollum *et al.*, 2014; Stieff and DeSutter, 2021; Patwardhan and Murthy, 2017; Stieff, 2011).

3. METHODOLOGY

In this chapter, the methodology used to provide an analysis of the combined effects of computer simulations and virtual reality applications on pre-service science teachers' representational competence skills will be presented. The chapter will start with the sample (3.1), procedure (3.2), digital tools (3.3), data collection instruments (3.4), data analysis (3.5), and ethical considerations (3.7) will be explored respectively.

3.1. Sample

The sample of this study involved five pre-service science teachers who were studying their third year and five pre-service science teachers who were studying their fourth year at the Department of Science Education at Boğaziçi University. In order to determine the pre-service science teachers, a participant application form was distributed. People with epilepsy were not included in the study.

The participants were sampled purposively. The criterion of this study was sampling pre-service science teachers who have completed first- and second-year general chemistry, general biology, general physics and educational sciences courses. The researcher visited the classes of the participants and distributed a brochure that explains the study and the researcher and asks for volunteer participants to attend the study.

3.2. Procedure

The qualitative case study design was implemented to analyze the combined effects of using simulation and virtual reality application on pre-service science teachers' representational competence skills. This case study focused on pre-service science teachers' representational competence skills after they attended to a workshop on computer simulations and virtual reality applications.

For this study, the focus is on the bounded system, the students who were studying at the Department of Science Education at a university in Istanbul, Turkey. According to (Yin, 2014), "A case study is an empirical inquiry that investigates a contemporary phenomenon (the 'case') within its real-life context, especially when the boundaries between phenomenon and context may not be clearly evident" (p.16). At this point, it was important for this study to analyze the particular unit of study utilizing a qualitative case study method.

According to the problem and purpose of the study, interviews that were semi-structured and open-ended tests were used as data collection instruments. Ethical approval was obtained from the Institutional Review Board to enlighten the research procedures that were suitable with ethical issues. And each participant was provided with an informed consent form. In order to sample participants, an invitation brochure was distributed to third grade and fourth grade undergraduate students of the Department of Science Education (Appendix C). The brochure included a QR code to direct volunteer participants to a Google Form named Participant Invitation Form. This form consisted of the participant's demographic information and prior experience in using computer simulations and virtual reality (Appendix D).

Table 3.1. The procedure of the study.

Participants	**Sessions**	**Type of the Sessions**	**Instruments**	**Treatments**	**Instruments**
Preservice Science Teachers (PsST) N= 10	1	Individual	Pre-Test 1+ Interview 1		
	2	Group		PhET Simulations	Post-Test 1
	3	Individual	Interview 2+ Pre-Test 2+ Interview 3	Virtual Reality Tutorial + Virtual Reality Application (Nanome)	Post-Test 2 + Interview 4

After the sampling procedure, the participants were invited to a workshop that continued for three sessions. In the first session, which lasted 50 minutes, the partic-

ipants filled Pre-Test 1 at the beginning of the session. After filling out the Pre-Test 1, each participant was interviewed individually about their experience on computer simulation. During the interviews, each participant was asked whether they would give consent to audio record or not. After the consent was obtained by the participants, the interview was audio-recorded. Interviews lasted approximately 20 minutes to 30 minutes and were conducted face-to-face.

In the second session of the workshop, which lasted 50 minutes and held as a group, the participants were informed about computer simulations and virtual reality applications. Groups were decided according to whether the participants schedule and availability for the study. A computer simulation was used in the second session. Then the participants were asked to build an atom model and a molecule model by using a computer simulation. After each participant completed their task, Post-Test 1 was distributed.

The third session of the workshop lasted 120 minutes and was held individually. At the beginning of the session, the participants were interviewed (Interview 2) individually about their representations in Post-Test 1. After the interview which lasted approximately 20 minutes to 30 minutes, the participants were asked to fill out Pre-Test 2. The participants were interviewed (Interview 3) about their representations of atom and molecule models in Pre-Test 2. Then a tutorial about using virtual reality equipment was represented to the participants. After the tutorial, the participants were asked to build an atom model and a molecule model by using the virtual reality application. After using the virtual reality application, Post-Test 2 was distributed. At the end of the workshop, each participant was interviewed (Interview 4) about their experience in virtual reality and their representations of atom and molecule models in Post-Test 2. During the interviews, each participant was asked whether they give consent to audio record or not. During the interviews, each participant was asked whether they would give consent to audio record or not. After the consent was obtained by the participants, the interview was audio-recorded. Interviews lasted approximately 20 minutes to 30 minutes and conducted face-to-face. After interviews completed, the

participants were asked to design a classroom activity which involved virtual reality application.

Before the main study a pilot study was conducted with two pre-service science teachers in the case of there was a need, the follow-up interviews could be conducted with participants. With this pilot study, it was expected to learn about the appropriateness of interview questions, pre and post-tests, and if there was a need for improvement in research design. After the pilot study a clarification added to the interview question: "*How do you use it?*" with the follow up question: "*Can you describe your application method?*" about the participants using of computer simulation and virtual reality applications in their lessons.

3.3. Digital Tools

3.3.1. Computer Simulation

PhET simulations named "Build an Atom" and "Build a Molecule" were used as computer simulations obtained by the participant. In the first simulation (Build an Atom), pre-service science teachers are asked to build atoms of Helium and Oxygen, as can be seen in Figure 3.1. The website link of the first simulation is https://phet. colorado. edu/ en/ simulations/ build- an- atom. The participants were asked to use the periodic table to build firstly a neutral Helium atom, then a neutral Oxygen atom. To achieve this goal, they were expected to use an adequate number of protons, neutrons, and electrons.

In the second PhET simulation (Build a Molecule), the participants were asked to build Fluorine molecule and Hydrogen molecule. The website link of the second simulation is http://phet. colorado. edu/ sims/ html/ build- a- molecule/ latest/ build- a- molecule_en.html. The participants were asked to choose "Playground" mode firstly, then to build Fluorine molecule. They were asked to click the button "3D" and to observe. The same procedure was applied with Hydrogen molecule, as well.

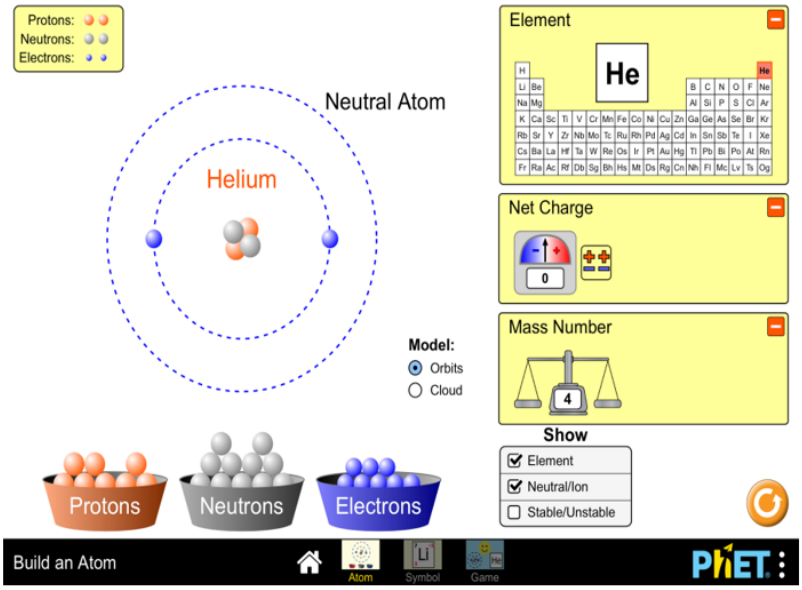


Figure 3.1. Helium atomic structure in PhET simulation (PhET Interactive Simulations, 2023).

3.3.2. Virtual Reality Application

An Oculus application named "Nanome" was used as a virtual reality application. Firstly, the participants were introduced to the tutorial on "Nanome". In this tutorial, they learned to control the virtual reality equipment and understood the buttons in the controllers. In this application, pre-service science teachers were asked to build atoms of Helium and Oxygen. The website of the virtual reality application is https://www.oculus.com/experiences/quest/3077598929010226/.

After they built the atoms, the participants were asked to build molecules of Fluorine and Hydrogen. To achieve this goal, firstly they needed to choose the bonds. Then, they opened the periodic table and choose the Fluorine and Hydrogen atoms.

3.4. Data Collection Instruments

3.4.1. Pre-Tests

Before the workshops on computer simulation and virtual reality application, the participants were asked to answer the questions of Pre-Test 1 and Pre-Test 2. The tests included similar but not identical open-ended questions, which included drawing a storyline of certain atoms and molecules (Appendices E, G). The questions of the Pre-Test 1 and Pre-Test 2 included storyline of atoms which were in the same group of periodic table such as He and Ne, Na and Mg. The molecules that were asked to be formed were either covalent bonded compound or molecular compound. The participants were asked to explain their drawings and details of their atom and molecule drawings.

3.4.2. Post-Tests

After the workshops on computer simulation and virtual reality application, the participants were asked to answer the questions of Post-Test 1 and Post-Test 2 (Appendices F, H). The tests included similar but not identical open-ended questions, which included drawing a storyline of certain atoms and molecules. The participants were asked to explain their drawings and details of their atom and molecule drawings. The storylines of atoms that were in the same group on the periodic table were included in the questions on the Post-Test 1 and Post-Test 2. Either covalently bound or molecular compounds were the types of molecules that had to be generated. Moreover, the tests included six open-ended questions about the participants' explanation of drawings of atoms and molecules, whether any change occurred in their mental model of atoms and molecules, and their thoughts about computer simulation and virtual reality application separately.

3.4.3. Interview Questions

In total, four interviews were conducted before and after each treatment (Appendices I, J, K, L). The semi-structured interview questions were prepared to understand the combined effects of computer simulation and virtual reality application on their representational competence skills. The corresponding instruments that were used to collect data were the semi-structured interviews that were specifically developed to collect data regarding the research questions. The first interview was conducted in the first session of the workshop. The other three interviews were conducted in the third session of the workshop as can be seen in Table 3.2.

3.5. Data Analysis

In the data analysis process, interview recordings were transcribed verbatim. From these transcripts, the researcher applied thematic analysis where similar statements and concepts were examined, and the emergent themes and categories were identified with phrases and patterns of words (Braun and Clarke, 2012). These phrases were defined as codes, "a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data" (Saldaña, 2013). By sorting these categories into meaningful and manageable segments, the researcher used findings to answer the study's research questions.

The data were analyzed step-by-step to determine its meaning. The researcher first studied the data before writing the codes line by line. The researcher identified the main themes and categories of the study by grouping these codes into sensible and manageable portions after reviewing the coding process. Finally, in order to make sense of the data and respond to the study's research questions, themes and categories were used.

3.5.1. Analysis of Pre-Tests and Post-Tests

The drawings of pre-tests and post-tests were analyzed as supporting data sources to interview data. The content analysis method was applied, which was explained as "an unobtrusive technique that allows researchers to analyze relatively unstructured data in view of the meanings, symbolic qualities, and expressive contents they have, and of the communicative roles they play in the lives of the data's sources" (Krippendorff, 2013). The technique for coding and categorizing the data was created by the researcher.

Drawings of pre-tests and post-tests are analyzed by the adaptation of "Atom Representation Evaluation Key" (Yaseen, and Akaygun, 2016), as can be seen in Table **??**. In this manner, Dalton's atomic model referred to a sphere, Bohr's atomic model referred to an elliptical shape included subatomic particles, Modern Atomic Theory referred to have an electron cloud, and Synthetic atomic model referred to a combination two or more atomic models.

Table 3.2. Atom representation evaluation key (Yaseen and Akaygun, 2016).

THEME OF CRITERIA	**PRE-TEST 1**	**POST TEST 1**	**PRE-TEST 2**	**POST TEST 2**
Atomic Model	Dalton: Bohr: Quantum (Modern): Synthetic:	Dalton: Bohr: Quantum (Modern): Synthetic:	Dalton: Bohr: Quantum (Modern): Synthetic:	Dalton: Bohr: Quantum (Modern): Synthetic:
Sub atomical Particles	Proton: Neutron: Electron:	Proton: Neutron: Electron:	Proton: Neutron: Electron:	Proton: Neutron: Electron:
Orbital Representation	Flat Circle: Elliptical: Electron cloud:	Flat Circle: Elliptical: Electron cloud:	Flat Circle: Elliptical: Electron cloud:	Flat Circle: Elliptical: Electron cloud:
Motion Representation	Shown: Not shown:	Shown: Not shown:	Shown: Not shown:	Shown: Not shown:
Atomic Model in Molecules	Dalton: Bohr: Quantum (Modern): Lewis: Synthetic:	Dalton: Bohr: Quantum (Modern): Lewis: Synthetic:	Dalton: Bohr: Quantum (Modern): Lewis: Synthetic:	Dalton: Bohr: Quantum (Modern): Lewis: Synthetic:
Molecular Construction	Shown: Not shown:	Shown: Not shown:	Shown: Not shown:	Shown: Not shown:

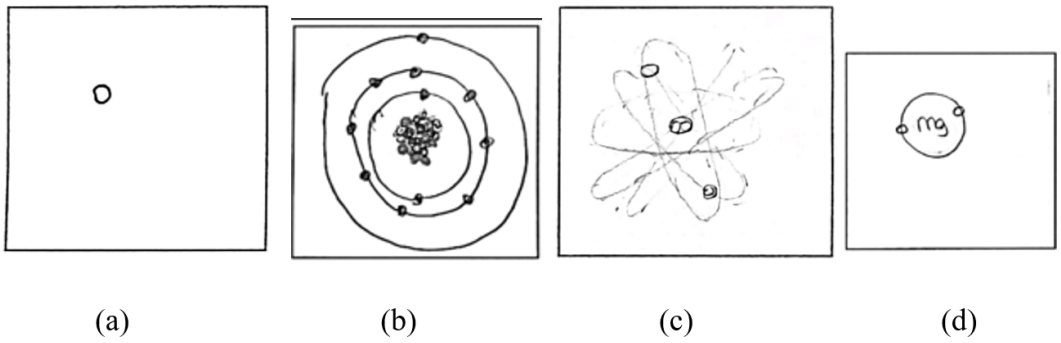


Figure 3.2. The scanned drawings of the participants showing different types of atomic models: (a) Dalton's; (b) Bohr's; (c) Modern; (d) Synthetic.

3.5.2. Analysis of Representational Competence

In order to analyze representational competence skills levels of participants, the answers of Pre-Tests, Post-Tests, and Interviews were analyzed by using (Echeverri Jimenez's, 2022) table of Popova's interpretation of Kozma and Russell's representational competence skills, their descriptions and examples as can be seen in Table 3.3.

Table 3.3. Popova's interpretation of Kozma and Russell's representational competence skills, their descriptions and examples (Echeverri Jimenez, 2022).

Skills	**Description**	**Example**
Interpret	Decode surface features of a representation	Recognize atomic features.
Generate	Produce, draw or build a representation	Link to content knowledge. Follow a convention system to produce a representation.

Skills	Description	Example
Translate	Map features of one representation into another	Draw an atom model by using the features atomic modelling of virtual reality and computer simulation.
Identify affordances	Identify what a given representation shows that other representations cannot	Recognize that some atomic features such as motion, subatomic particles, and 3-dimensional representations are represented in one representation but they are not represented in another one.
Identify limitations	Identify what a given representation does not communicate	Recognize that subatomic particles cannot be seen in the atomic representation of the virtual reality application.
Select	Select the most appropriate representation for a purpose	Utilize the best model of representation to communicate the content.
Use	Use representations to make predictions, draw inferences, and support claims	Use Newman projections to explain the Gauche effect or chair conformations for 1,3-diaxial interactions.
Reflect	Acknowledge that representations correspond to but are distinct from the phenomena that they represent	Recognize the usefulness of a model to explain a result and acknowledge the model's limitations in other cases.

Researchers' first concern while collecting, analyzing, and interpreting study results is credibility. The nature of guaranteeing validity and reliability for quantitative and qualitative investigations is different. According to (Firestone, 1987), "the quantitative study must convince the reader that procedures have been followed faithfully

because the very little concrete description of what anyone does is provided. The qualitative study provides the reader with a depiction in enough detail to show that the author's conclusion makes sense".

There are many ways to increase the credibility of a qualitative study, including triangulation, inter-rater reliability, and adequate participation in data collecting (Shenton, 2004). In this study, triangulation, inter-rater reliability, expert opinion, and the researcher's position strategy were applied to promote reliability and validity. For triangulation, which (Denzin, 1970) explained as "the combination of methodologies in the study of the same phenomenon", pre and post-tests and interviews were used to provide multiple sources of data. For inter-rater reliability, which (Lange, 2011) explained as "the extent to which two or more raters (or observers, coders, examiners) agree" interview transcripts were sent to another researcher who is a PhD student at the Department of Mathematics and Science Education at Boğaziçi University and the percentage of agreement for this study was 93% and Cohen's Kappa (κ) was 0.926 which is defined as almost perfect or perfect agreement.

Expert opinions of five different researchers for interviews, and pre and post-tests questions were taken into account and changes were done according to their feedback. Finally, the researcher discussed her role in the study to clarify how her viewpoint, presumptions, and potential biases may affect how the study was carried out and how it is interpreted (Probst and Berenson, 2014).

3.6. Ethical Considerations

Ethical considerations were taken into account in this investigation. First, the Institutional Review Board granted its ethical approval to confirm that the research protocols are in line with ethical considerations (Appendix A). To safeguard the privacy of the study's human subjects, the names of the participants were kept out of the research. To protect interviewees' identity, each research subject was given a pseudonym (a number).

Informed consent forms were used to seek the participants' consent prior to data collection. In-depth explanations of the study's objectives and participants' rights were provided. After finishing the thesis study, all research data collected throughout the study was told to be erased from the researcher's personal computer and placed there instead in a password-protected folder.

3.7. The Role of the Researcher

The researcher's role in this thesis project was shaped by her educational and career experiences. The researcher was a workshop practitioner and interviewer for this study. The researcher is a master's student in Mathematics and Science Education Department and worked as a science teacher at a private school. Since, pre-service science teachers who were studying at university located in Istanbul, Turkey were selected purposefully, the researcher reached out the population by attending their courses at the university and invited them to the workshop. The participants who were willing to attend the workshop filled out the Participant Information Form and shared their contact information. Therefore, the researcher reached out to the participants and decided to the first session date of the workshop. In the first session, the researcher gave information about the consent form to ensure the participants' confidentiality and anonymity. In this study, pre-tests, pos-tests, and interviews were used as a data collection instrument; protecting the privacy of participants and analyzing the data without personal bias was the responsibility of the researcher. Qualitative research provides a dialectical process that may affect both researcher and participants (Pillow, 2003); at that point, the researcher must think about how to deal with personal interests and feelings and own the effects of conducting the study ethically.

4. FINDINGS

In this chapter, the findings from the study will be presented in relation to each research question. This qualitative case study focused on investigating the effects of using simulations, first and then virtual reality applications and comparing them on preservice science teachers' representational competence skills. With the analysis of interview questions, pre-test 1, post-test 1, pre-test 2, and post-test 2, nine main themes emerged: (1) representation of atom; (2) change in representation of atom; (3) representing process for the atom; (4) representation of molecule; (5) change in representation of molecule; (6) representing process for the molecule; (7) simulation; (8) virtual reality; and (9) representational competence.

In light of the research questions, the data were open-coded and according to codes, categories were determined. Each category was grouped into themes. The first theme, *Representation of the Atom*, involves two categories: type of representation and properties. The second theme is the *Change in Representation* of Atom. The third theme, the Representing *Process for the Atom*, involves obstacles and solutions. Under the *Representation of Molecule* theme, two categories, type of representation and properties, were investigated. The fifth theme *is Change in Representation of* Molecule. The sixth theme, named *Representing Process for the Molecule*, involves obstacles and solutions. The seventh theme, *Simulation*, describes the experience, method of application in a lesson, strengths, weaknesses, subject, and reasoning for using. The same categories with Simulation emerged from data in the eighth theme, *Virtual Reality*. The last theme, *Representational Competence*, included the categories of change in the representation of an atom, change in the representation of a molecule, change in representational competence skills, comparison of representations of computer simulations and virtual reality, effects of simulation and virtual reality on representational competence skills. Table 4.1. describes the themes and categories of the study.

Table 4.1. The categories under the themes emerged from the data.

Themes	**Categories**
Representation of the Atom	- Type of Representation - Properties
Change in Representation of Atom	- Change in Representation of Atom
Representing Process for The Atom	- Obstacles - Solutions
Representation of the Molecule	- Type of Representation - Property
Change in Representation of Molecule	- Change in Representation of Molecule
Representing Process for The Molecule	- Obstacles - Solutions
Simulation	- Experience - Method of Application in a Lesson - Subject - Reasoning for Using - Strengths - Weaknesses
Virtual Reality	- Experience - Method of Application in a Lesson - Subject - Reasoning for Using - Strengths - Weaknesses
Representational Competence	- Comparison of Representations of Computer Simulations and Virtual Reality - Effects of Simulation and Virtual Reality on Representational Competence Skills

4.1. Representation of the Atom

Representation of the atom was investigated regarding the first research question of the study: "*What are the combined effects of using computer simulations and virtual reality applications on pre-service science teachers' representational competence*

skills?". The data collected through Pre-Test 1, Post-Test 1, Pre-Test 2, Post-Test 2, and interviews with the pre-service science teachers revealed three categories: (1) Representation; (2) Properties; (3) Change in Representation of Atom. Data is analyzed within the adaptation of (Yaseen and Akaygun, 2016) evaluation key.

4.1.1. Type of Representation

Representation of the atom has been changed through the study. The participants mainly used atomic theory to explain their drawings. The sixth question of the first interview protocol aimed to understand representation of atom: "*Can you explain how you represented the helium atom? Which atomic model did you use in your representation?*". Nine participants represented the given atom according to Dalton's atomic model, whereas one participant represented according to Modern Atomic Theory, as seen in Table 4.2. Participant 4 represented the given atom according to Dalton's atomic model as can be seen in Figure 4.1 and stated as follows:

> This is a sphere, Dalton; I think I used Dalton. I think I just paid attention to the fact that it is round and the drawing model we use all the time. A circle is drawn. This circle idea or sphere figure was usually taken as the basis when representing molecules. This came to my mind, and I chose to draw it that way (Participant 4, Interview 1).

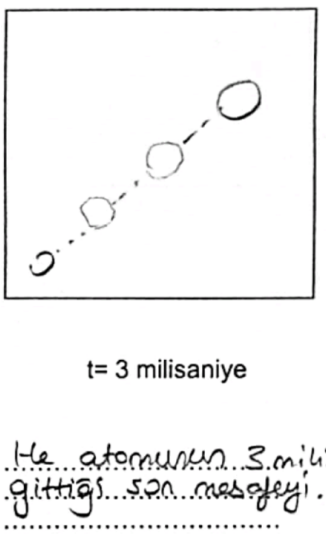


Figure 4.1. Participant 8's drawing of atom in pre-test 1.

Participant 8 represented the given atom according to the Modern atomic model, as can be seen in Figure 4.2, and stated as follows:

> When I draw an atom, I use orbitals in atomic models, but there is also knowledge of electron clouds with modern theory. But since I can't show it exactly, I'm still drawing orbitals. In other words, I imagine it like this, the nucleus stays a little fixed, the electrons around it move very quickly, and there is a non-stop vibration (Participant 8, Interview 1).

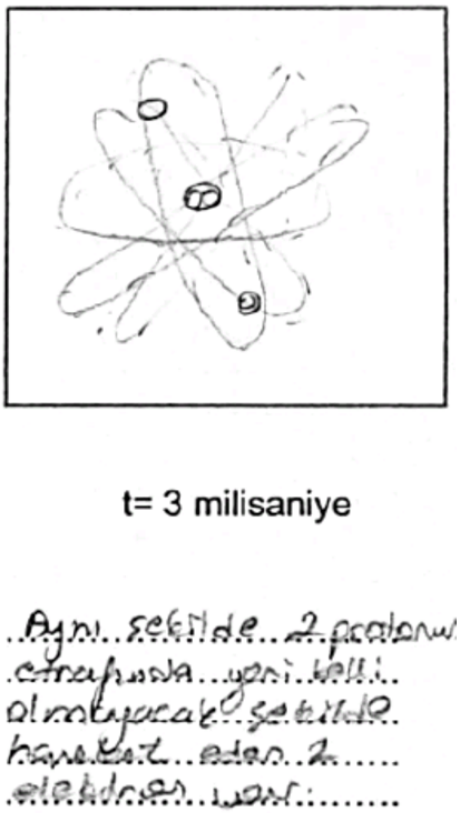


Figure 4.2. Participant 4's drawing of atom in pre-test 1.

Table 4.2. Number of participants who showed a certain type of atomic model.

NUMBER OF PARTICIPANTS				
Theme of Criteria	**PRE-TEST 1**	**POST TEST 1**	**PRE-TEST 2**	**POST TEST 2**
Atomic Model	Dalton: 9	Dalton: 2	Dalton: 1	Dalton: 3
	Bohr: 0	Bohr: 6	Bohr: 7	Bohr: 3
	Quantum (Modern): 1	Quantum (Modern): 1	Quantum (Modern): 0	Quantum (Modern): 0
	Synthetic: 0	Synthetic: 1	Synthetic: 2	Synthetic: 4

However, the third question of the second interview indicates that after the PhET simulation named "Build an Atom", drawings of the participants have been changed: "*Can you explain how you represented the Neon (Ne) atom? What type of atomic model did you use in your representation?*". Before the PhET simulation application, nine participants drew the given atom according to Dalton's atomic model, whereas, after the treatment, two participants represented their atomic model according to Dalton's atomic model, as seen in Table 4.2. Six participants represented atoms in Bohr atomic model; moreover, each participant showed a given atom according to Modern atomic theory and in a synthetic way in consonance with Post-Test 1.

Participant 4 explained drawings of Post-Test 1 in the interview 2 as can be seen in Figure 4.3, according to Bohr atomic model as follows:

> The neon atom drawing has the nucleus in the middle. Although I couldn't draw all of them, I made a logical note of it. Because it is neutral, it contains as many protons and neutrons as a neon atom. And I represented orbits with dashed lines around them. Then I placed my electrons in these orbits as 2+8 using the electron configuration rule (Participant 4, Interview 2).

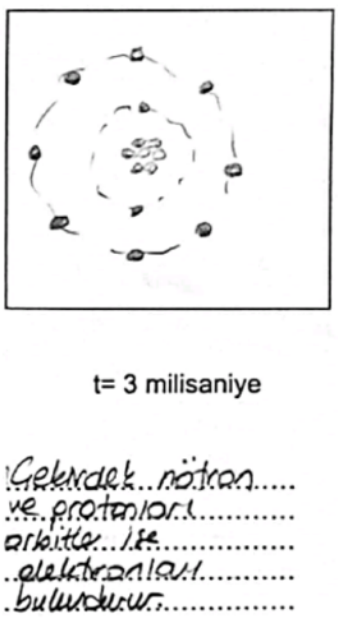
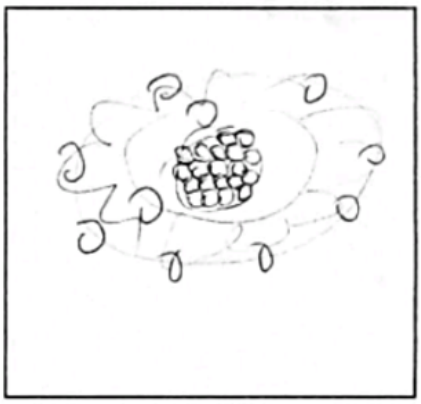


Figure 4.3. Participant 4's drawing of atom in post-test 1.

Participant 8 used a synthetic way (using Bohr and Modern atomic theory) to describe a given atom as can be seen in Figure 4.4. The drawings of Participant 8 are stated as follows:

> After using the simulation, I already drew this thing, so I put an equal number of protons and neutrons in its nucleus. Then I drew two orbitals and distributed the electrons as two + eight. I have drawn an atom with two layers, two orbitals, a proton, and a neutron in its nucleus... By scribbling like a light mist on the back like this, I showed it as if it was moving (Participant 8, Interview 2).



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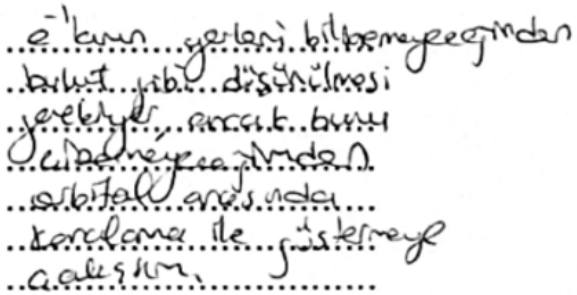


Figure 4.4. Participant 8's drawing of atom in post-test 1.

Before the virtual reality application, the participants completed Pre-Test 2 and were interviewed - the fifth question of the third interview aimed to determine the participants' atomic representation in Pre-Test 2: "*Can you explain how you illustrated the sodium atom? What type of atomic model did you use in your representation?*". Seven participants represented a given atom according to Bohr's atomic model, one used Dalton's atomic model, and two used the synthetic model, as seen in Table 4.2.

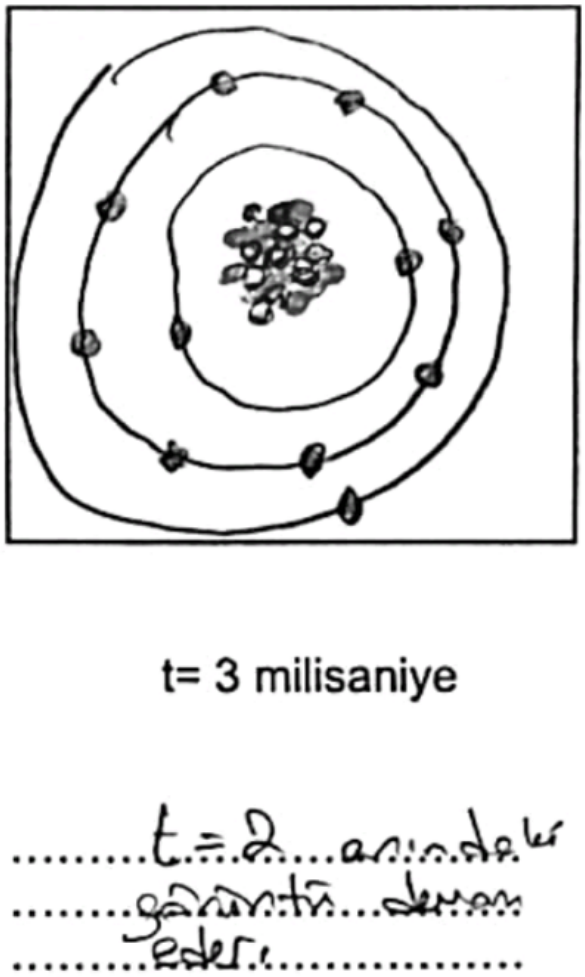
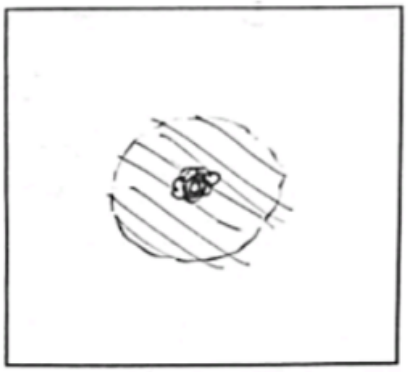


Figure 4.5. Participant 9's drawing of atom in pre-test 2.

Participant 9 showed Bohr the atomic model in her drawings as can be seen in Figure 4.5 and stated, "*I used the orbiting atom model. There are electrons, protons, and neutrons*". Whereas Participant 10 represented the given atom synthetic model, both using Dalton's atomic model and Modern atom theory Figure 4.6, and stated as follows:

> For example, I scanned the inside more vertically like this. I tried to show the thing in it; we call it an electron cloud or layers. You know, they are on the same axis, like a sphere around the center, but I tried to show that they rotate. I did something like that by scanning the inside. Of course, compared to the previous one, I think I've just demonstrated that this sphere is primarily empty; there are protons and neutrons in the middle (Participant 9, Interview 3).



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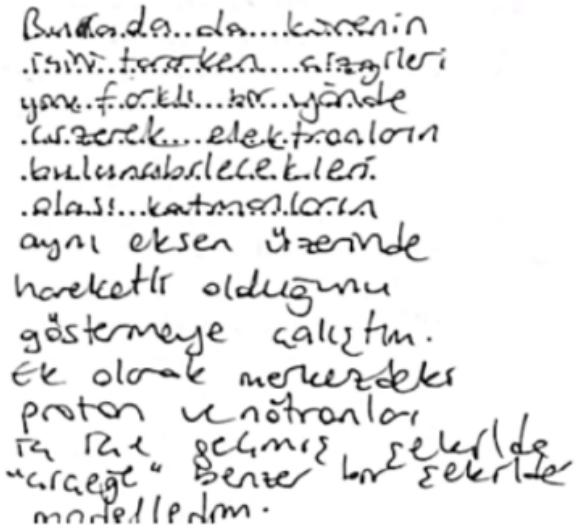

Figure 4.6. Participant 10's drawing of atom in pre-test 2.

Post-Test 2 and Interview 4 were applied following the virtual reality application. The ninth interview question revealed the explanation of atom drawings in Post-Test 2: "*Can you explain how you represented the Magnesium atom? Which atomic model did you use in your representation?*". Table 4.2 shows that three participants used Dalton's atomic model, whereas three showed Bohr's atomic model, and four used a synthetic model.

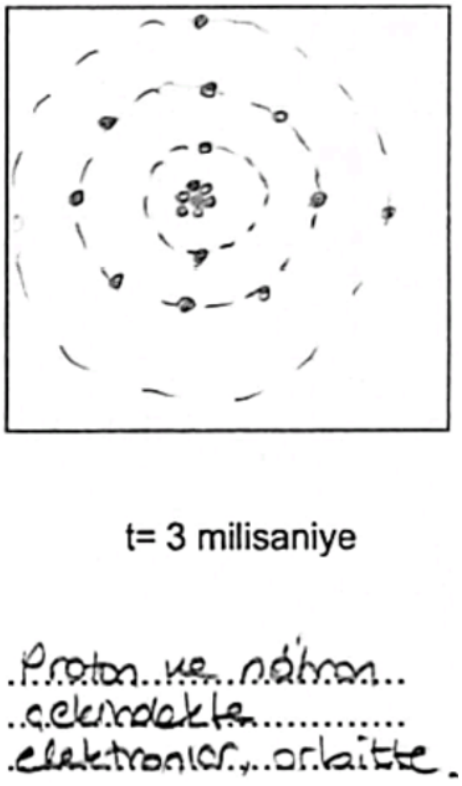

Figure 4.7. Participant 4's drawing of atom in post-test 2.

Participant 4 represented a given atom according to Dalton's atomic model as can be seen in Figure 4.7 and stated in Interview 4, "*Here I have shown the magnesium atom as a sphere, and for 3 milliseconds, they are actually in motion*". Whereas Participant 5 used Bohr atomic model as can be seen in Figure 4.8 and stated as follows:

> First, I drew a core; then, I drew six circles inside. 3 of them represent protons, and 3 of them represent neutrons. To illustrate this, I wrote the letter plus inside the protons and n inside the neutrons. There are two layers outside the core. In the first of these layers, there are two rounds, inside of which there is a minus. I wanted to indicate that they are electrons with a minus sign. In the same way, sorry, in the 3rd layer, there is an electron in the 2nd layer. It also has a minus (Participant 5, Interview 4).

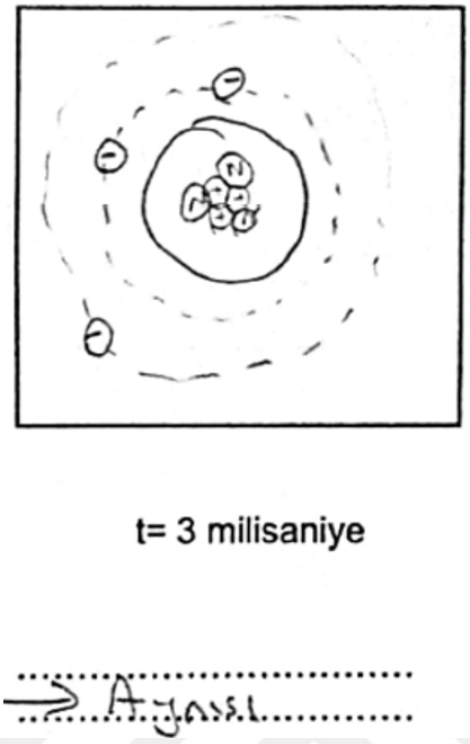

Figure 4.8. Participant 5's drawing of atom in post-test 2.

Participant 7 used a synthetic model, both showing Dalton's and Bohr's atomic models as can be seen in Figure 4.9 and in Interview 4 stated that:



Figure 4.9. The drawings of participant 7 for the same atom in post-test 2.

> I used a round and simple model in the first two frames, as in virtual reality. In the last two, I tried to show the subatomic particles, to show the orbits and so on... For example, magnesium has 2 extra electrons in the last two orbitals (Participant 7, Interview 4).

In summary, pre-service science teachers' representation of atom can be categorized according to atomic theory: Dalton, Bohr, Modern, and synthetic. The representation of atomic models changed during the study.

4.1.2. Properties

When pre-service science teachers were asked to draw given atoms, the properties of atoms were also invited to explain. Describing the properties of the representation of the atom was addressed to the first research question. According to Pre-Test 1, Post-Test 1, Pre-Test 2, Post-Test 2, and interviews, three criteria have been detected as properties of representation of an atom. These three criteria are subatomic particles, orbital and motion representations. The number of participants and theme of criteria is shown in Table 4.3.

Table 4.3. Number of participants who showed each theme of criterial.

NUMBER OF PARTICIPANTS				
Theme of Criteria	**PRE-TEST 1**	**POST TEST 1**	**PRE-TEST 2**	**POST TEST 2**
Subatomic Particles	Proton: 1 Neutron: 1	Proton: 7 Neutron: 7	Proton: 8 Neutron: 8	Proton: 5 Neutron: 5
Shown Orbital	Electron: 1 Flat Circle: 9	Electron: 8 Flat Circle: 2	Electron: 10 Flat Circle: 2	Electron: 7 Flat Circle: 4
Representation	Elliptical: 0 Electron cloud: 1	Elliptical: 6 Electron cloud: 2	Elliptical: 7 Electron cloud: 1	Elliptical: 5 Electron cloud: 1
Motion Representation	Shown: 8 Not shown: 2	Shown: 9 Not shown: 1	Shown: 9 Not shown: 1	Shown: 7 Not shown: 3

4.1.2.1. Subatomic Particles. After Pre-Test 1, Post-Test 1, Pre-Test 2, and Post-Test 2, the participants were asked to explain their atom drawings during interviews. Findings of interview transcripts and drawings of the participants in Pre-Test 1 showed that one of the participants included protons, electrons, and neutrons in her drawings, as can be seen in Table 4.3. The same participant also used Modern Atomic Theory to represent her atom as can be seen in Figure 4.10. At the same time, nine participants did not show any subatomic particles.

Participant 8 stated that:

> I paid attention to the appearance of subatomic particles. Also, I wanted to show that the electron can be found in different places (Participant 8, Interview 1).

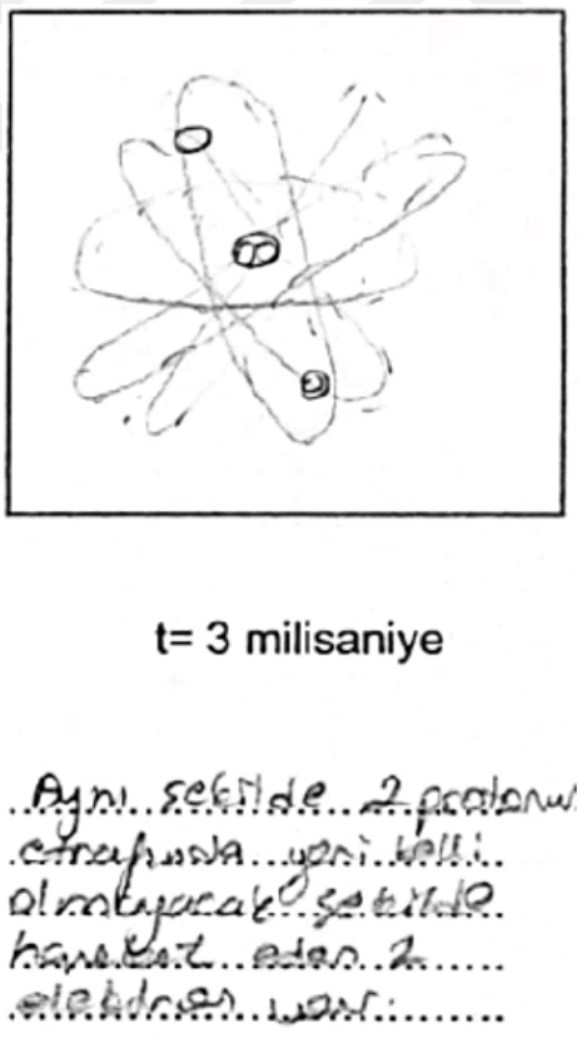

Figure 4.10. Participant 8's drawing of atom in pre-test 1.

However, as shown in Table 4.3, seven participants represented protons and neutrons in their drawings after the PhET simulation in Post-Test 1. Meanwhile, the number of participants increased to eight for the students who showed electrons. These findings were also consistent with the representation of atom, which means that the participants who represented given atoms according to Bohr, Modern, and synthetic atomic models also included subatomic particles in their drawings. Yet, one participant included electrons while not including the protons and neutrons as can be seen in Figure 4.11. For instance, Participant 1 stated as follows:

> The nucleus is not so important; after all, we draw neutral atoms, not in the form of ions. So, I thought it would be important to draw electrons. I drew the electrons (Participant 1, Interview 2).

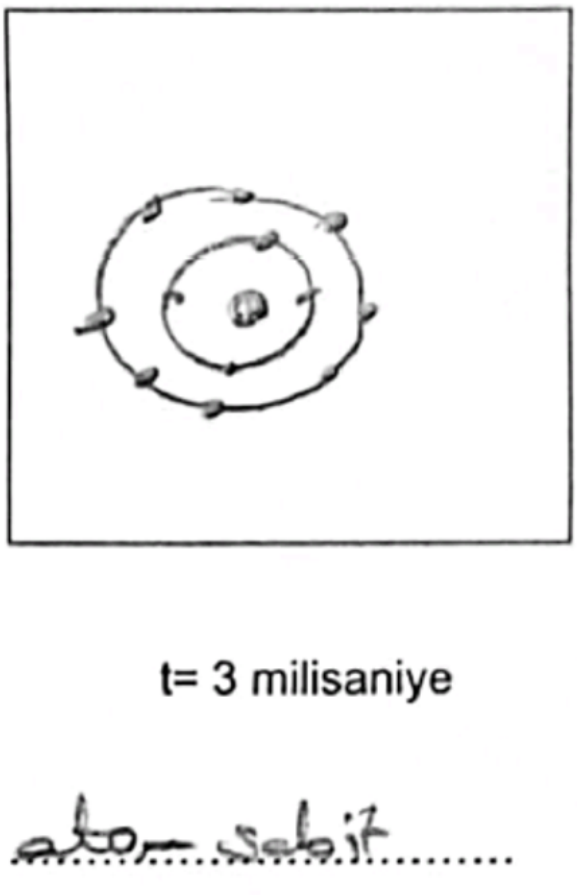

Figure 4.11. Participant 1' drawing of atom in post-test 1.

During Pre-Test 2, all the participants included electrons in their drawings; however, eight of them included protons and neutrons in their drawings, as seen in Table

4.3. Although, Participant 7 stated that "*Na (Sodium) has an excess of one electron*", she also drew the atom according to Dalton's atomic model as can be seen in Figure 4.12.

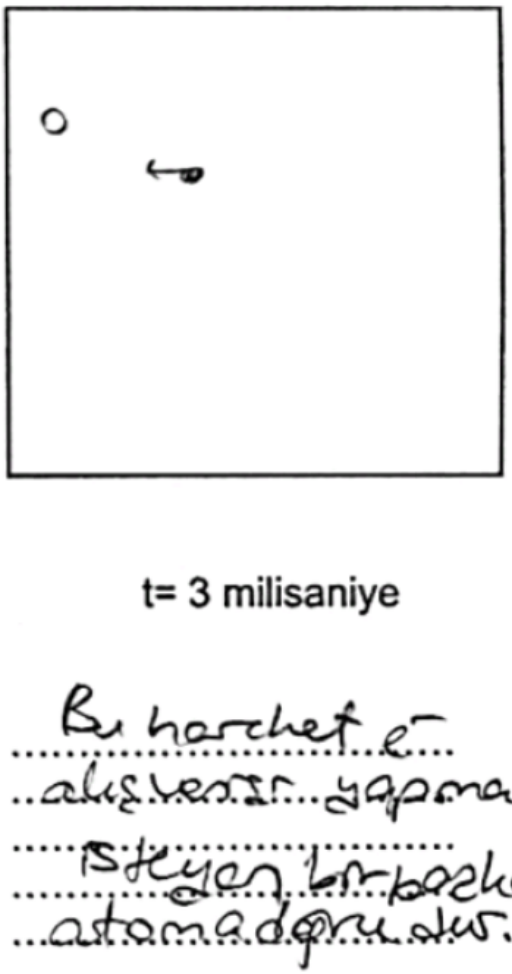

Figure 4.12. Participant 7' drawing of atom in pre-test 1.

Findings from Post-Test 2 and interviews revealed that five participants represented protons and neutrons in their drawings after the virtual reality application, whereas 7 included electrons, as seen in Table 4.3. Because three participants used Dalton's atomic model in their drawings, they did not include subatomic particles as can be seen in Figure 4.13.

Participant 10 stated as follows:

> When I did it (draw the atom) before, I showed subatomic particles. I didn't show it now (Participant 10, Interview 4).

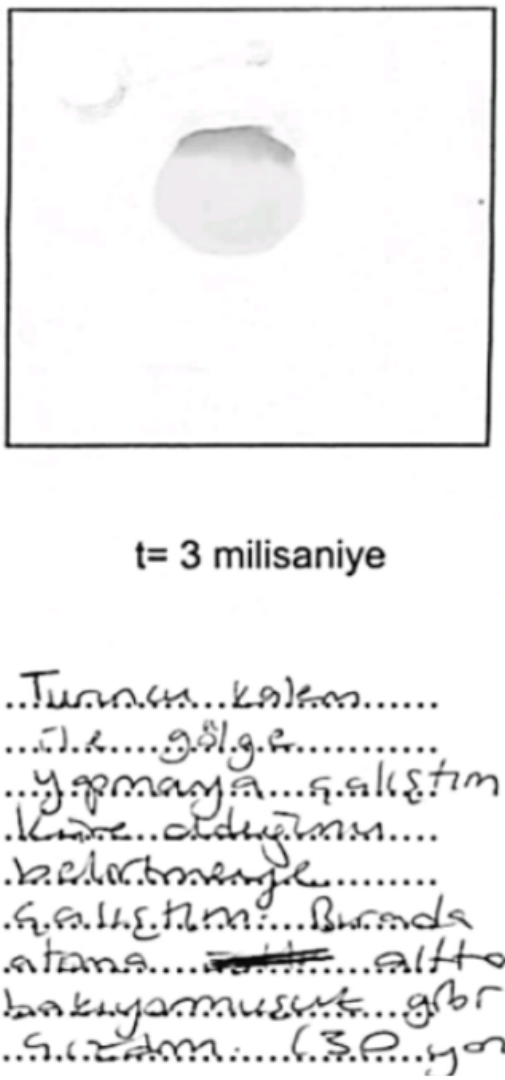

Figure 4.13. Participant 10' drawing of atom in post-test 2.

4.1.2.2. Orbital Representation. When the participants represented the given atom, they used flat circles, elliptical, and electron clouds to represent orbitals. Consistent with the atom representation, findings from Pre-Test 1, Post-Test 1, Pre-Test 2, Post-Test 2, and interviews showed that the participants' choices of orbital representations varied. In Pre-Test 1, nine participants used flat circles (Figure 4.14a) to represent

orbitals, whereas one used electron clouds (Figure 4.14c), as seen in Table 4.3. However, after the PhET simulation, in Post Test 1, two participants illustrated flat circles (Figure 4.14a) and electron clouds (Figure 4.14c). Meanwhile, six of them used elliptical orbitals (Figure 4.14b).

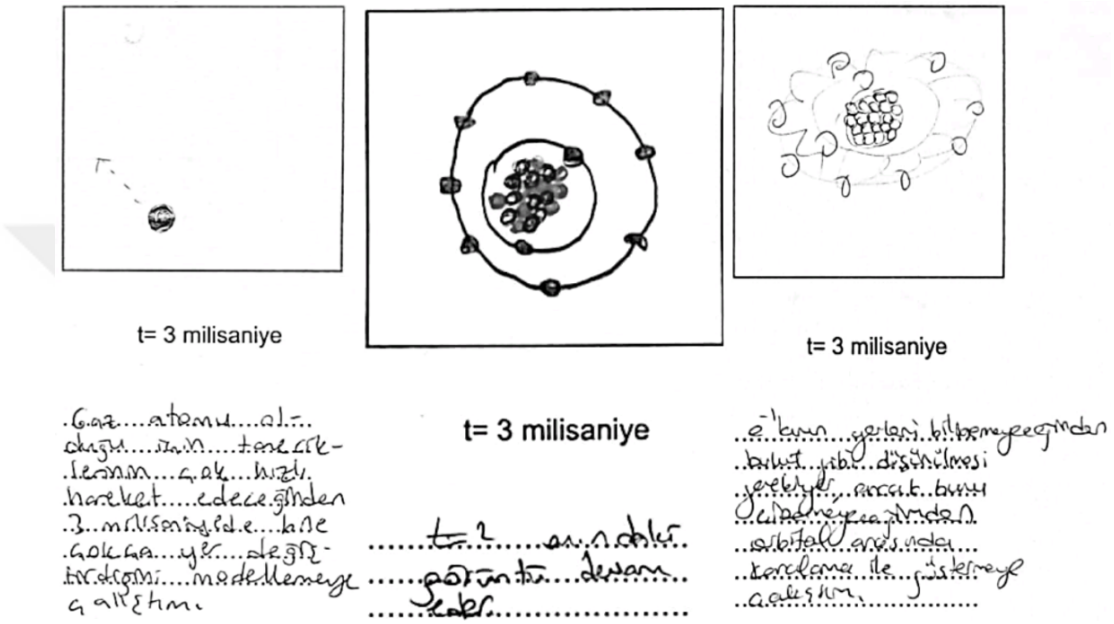

Figure 4.14. Examples of the orbitals: (a) flat circle, (b) elliptical, (c) electron cloud.

Before the deployment of virtual reality, two of the participants displayed a flat circle (Figure 4.14a), one utilized an electron cloud (Figure 4.14c), and seven others employed elliptical orbitals (Figure 4.14b), as can be seen in Table 4.3. However, in Post-Test 2, five participants employed elliptical orbitals (Figure 4.14b), one used an electron cloud (Figure 4.14c), and four used a flat circle (Figure 4.14a).

4.1.2.3. Motion Representation. The representation of motion regarding atom emerged by the analysis of drawings provided for Pre-Test 1, Post-Test 1, Pre-Test 2, and Post-Test 2 or from the participants' explanations given in the interviews. Findings from Pre-Test 1 revealed that eight participants displayed the motion of the atom (Figure 4.15), whereas two did not, as seen in Table 4.3.

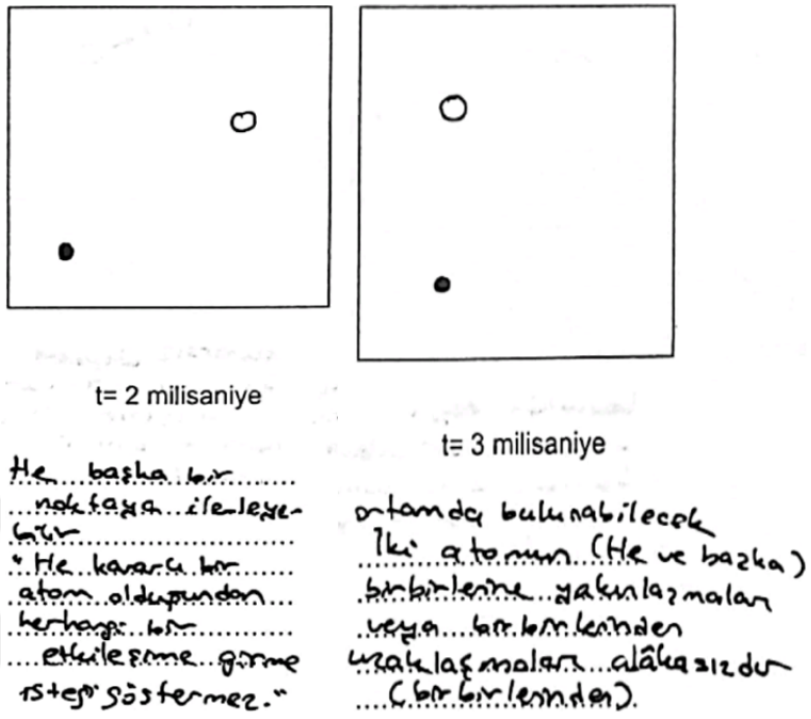

Figure 4.15. An example of motion representation of atom in pre-test 1.

Nine participants demonstrated the motion of atom following the PhET simulation as can be seen in Figure 4.16, while one did not. These findings did not change in Pre-Test 2; however, in Post-Test 2, seven participants illustrated the atom's motion (Figure 4.17), whereas three did not.

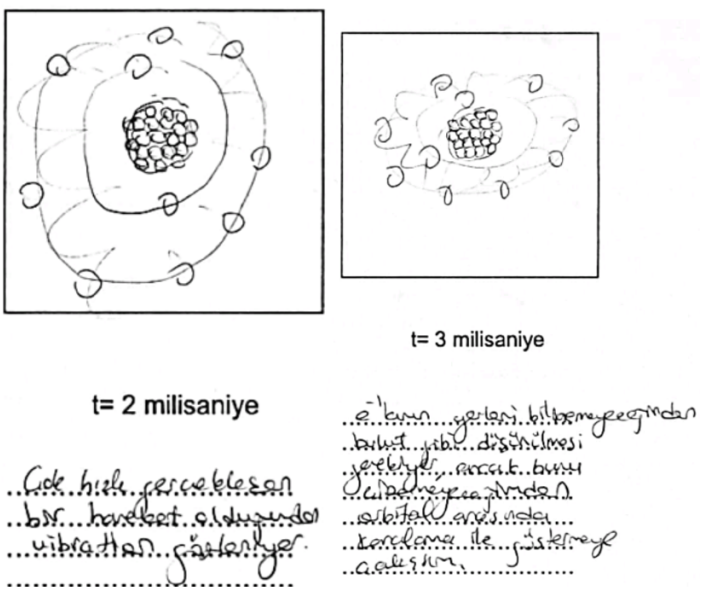

Figure 4.16. An example of motion representation of atom in post-test 1.



Figure 4.17. An example of motion representation of atom in post-test 2.

In summary, the properties of atoms can be investigated under the criteria of subatomic particles, orbital representation, and motion representation. These criteria were consistent with the participants' representation of atoms, which meant that the type of atomic theory used resonated with the atom's properties.

4.2. Change in Representation of Atom

The first questions of Pre-Test 1, Post-Test 1, Pre-Test 2, and Post-Test 2 aimed to investigate the representations of the atom model of the participant. The first question of the second interview protocol aimed to understand the change in the representation of the atomic model between the PhET simulation and the drawings in Pre-Test 1: "*How do you compare the atomic model you created in the PhET simulation with the atomic model you drew in Pre-Test 1? What are the similarities? What are the differences?*".

Participant 8 stated the similarities and the differences between her representation in Pre-Test 1 and the PhET simulation:

> When I first drew, the orbitals in my own head weren't much more obvious to me. But everything looked much more obvious in the PhET simulation. In the

> PhET simulation, I paid more attention to the fact that I personally took the number of protons and neutrons in the nucleus and gave me a direct message, whether it was stable or not, that the number of neutrons and protons must be the same. And there (in PhET), the electron's locations were more specific. In that respect, it's different from my first drawing. The location of the neutron and electron are different (Participant 8, Interview 2).

Participant 2 stated the similarities and the differences between her representation in Pre-Test 1 and the PhET simulation:

> In this first drawing, I drew it in the form of a flat circle in the Pre-Test (1). That's raisin cake. That's how I drew it. There were no electrons, no protons, and nothing in it. So, I drew it straight like this (Participant 2, Interview 2).

Moreover, the third question of the second interview protocol aimed to understand the change in the representation of the atom: "*Have you made any changes to your Neon atom (Ne) model representation relative to your initial atomic model?*".

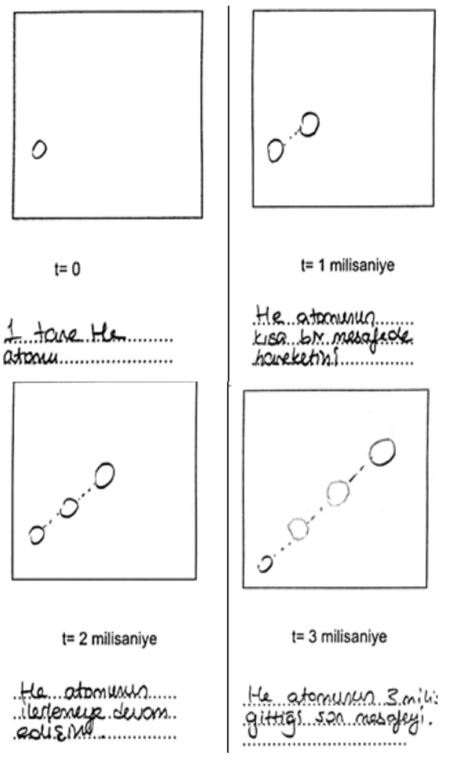

Figure 4.18. Participant 4's atomic representation (dalton's) and explanation from pre-test 1.

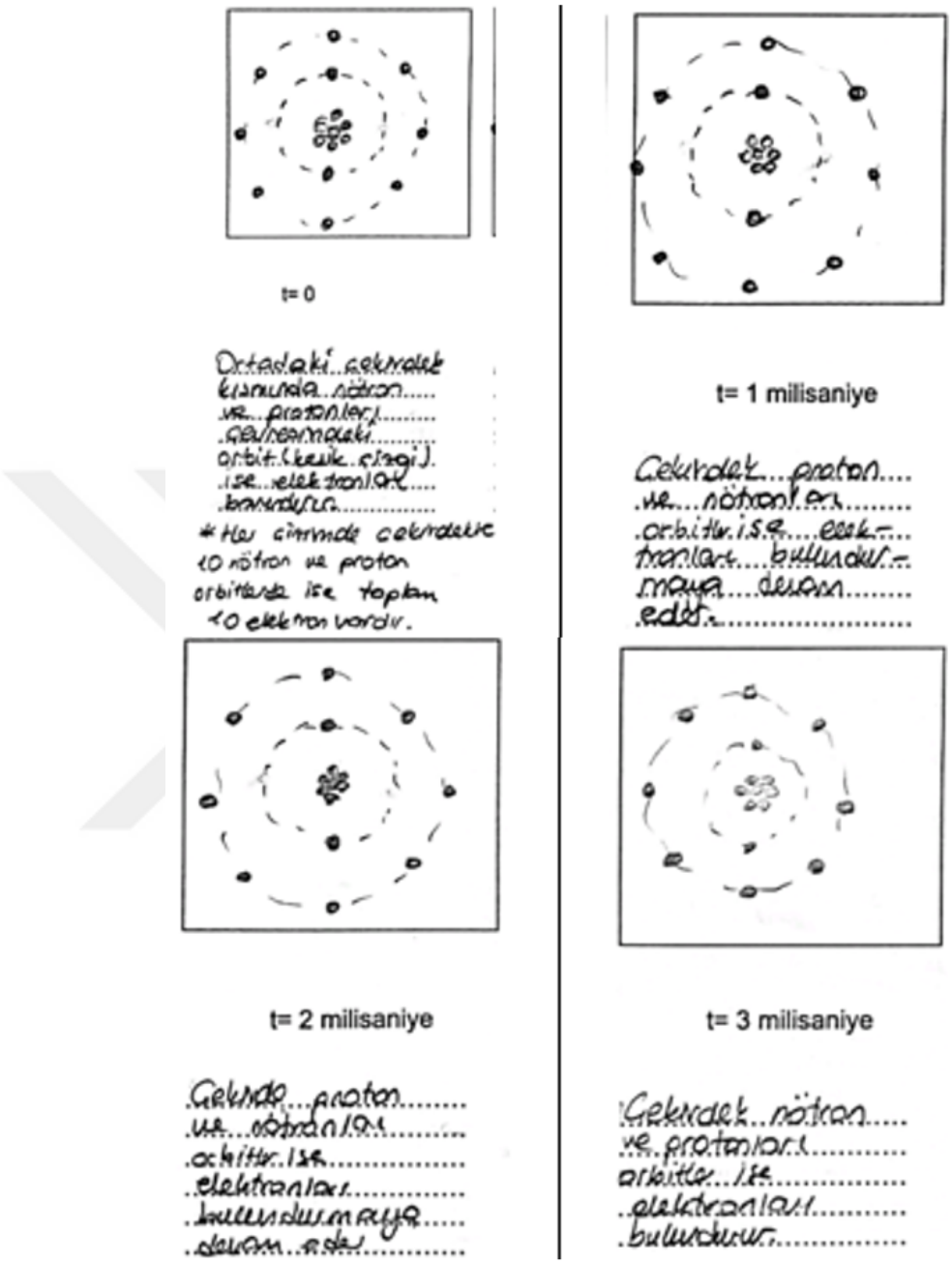

Figure 4.19. Participant 4's atomic representation (bohr's) and explanation from Post-test 1.

The representation change Dalton's to Bohr's from Pre-Test 1 and Post-Test 1 of Participant 4 can be seen in Figure 4.18 and Figure 4.19. In Figure 4.18, Participant 4 represented the given atom according to Dalton's atomic model; however, the same participant drew the atom using Bohr's atomic model after computer simulation treatment, as can be seen in Figure 4.19.

Participant 4 stated that she changed her representation of the atom model:

> I've obviously made some big changes. Because in my first model of the atom (Pre-Test 1) I directly tried to represent the atom as a circle. Of course, this sphere turned into a circle because it is two-dimensional. But after the simulation ok, even though it was 2 dimensional, I was able to detail it. Then I asked myself, why don't I use these circles to represent electrons, protons, and neutrons? I also have no limits in the drawing. Then I added orbitals as well with dashed lines, I thought. I realized that I could transfer it in more detail, even if it was two-dimensional in simulation, and I reflected this in my drawing (Participant 4, Interview 2).

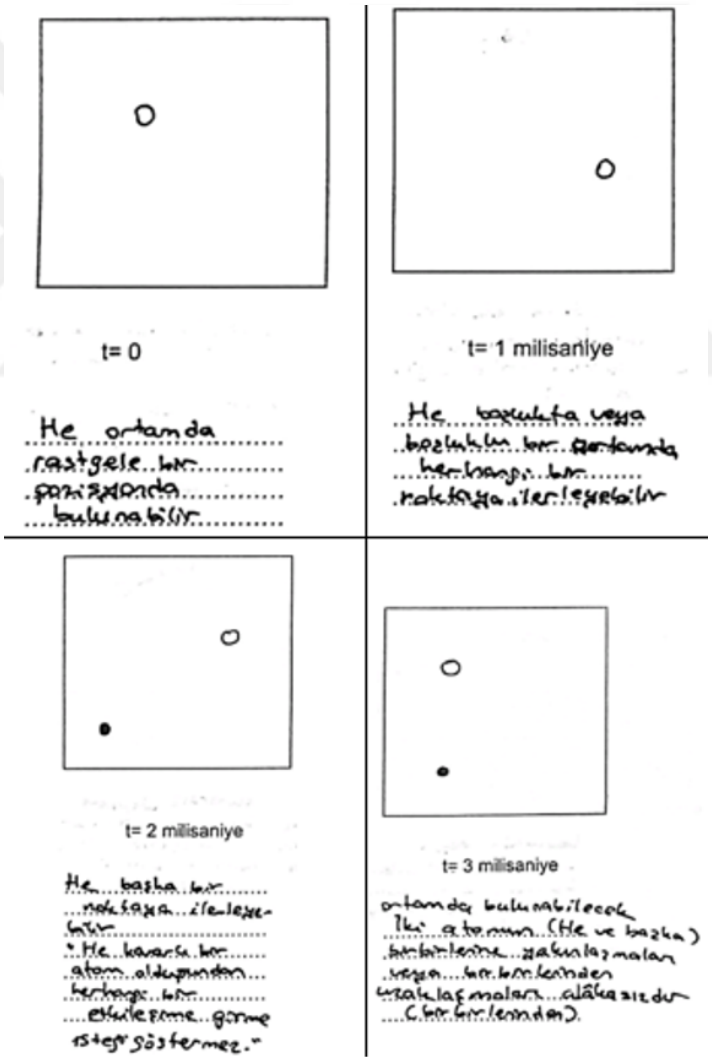

Figure 4.20. Participant 7's atomic representation (dalton's) and explanation from pre-test 1.

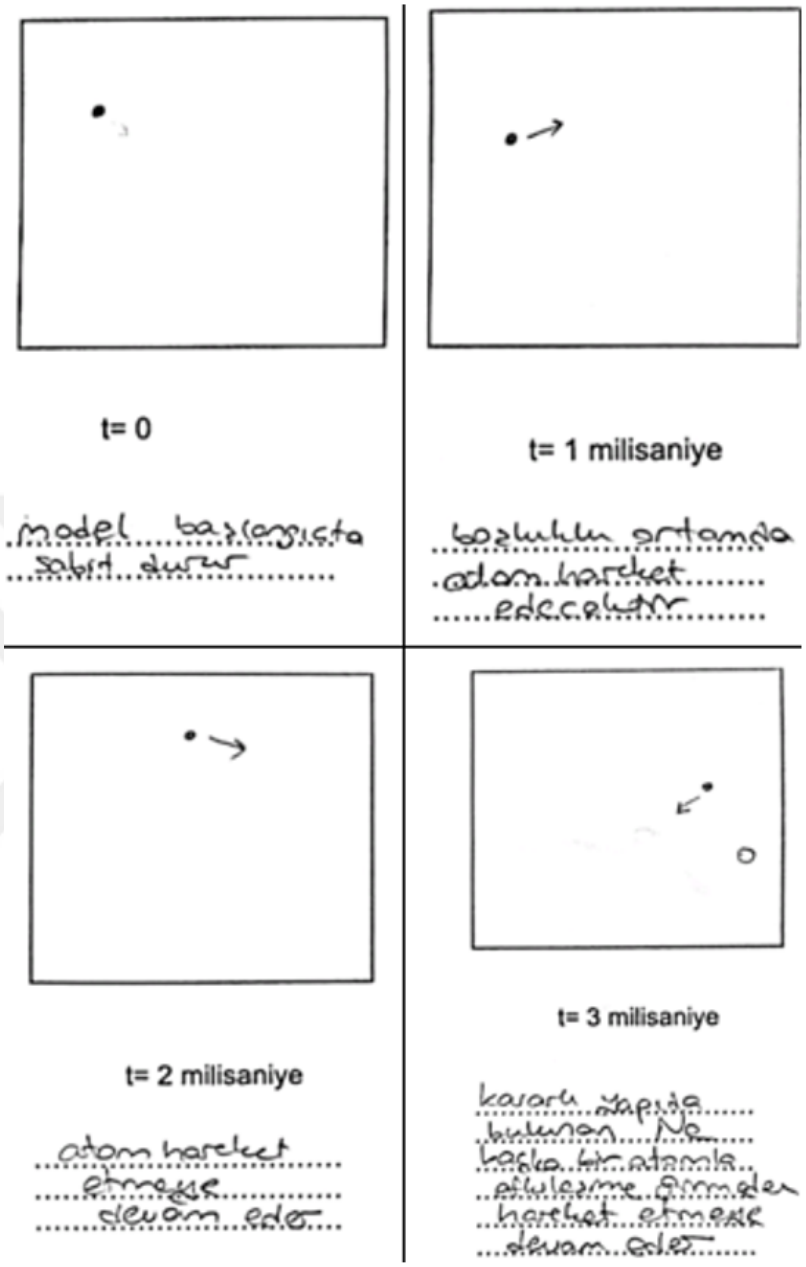

Figure 4.21. Participant 7's atomic representation (dalton's) and explanation from post-test 1.

The atomic models of Figure 4.20 and Figure 4.21 showed that Participant 7 used Dalton's atomic model while representing the given atom meaning that the type of atomic model did not change. Participant 7 interpreted the drawings in Pre-Test 1 as follows:

> Like dot. I drew a filled circle, and I showed you that it is constantly moving (Participant 7, Interview 1).

Participant 7 also stated that she did not change her atomic model in Post-Test 1:

> I did not make a change (to the atomic model) (It is) exactly the same (Participant 7, Interview 2).

Although Participant 8 used Modern Atomic Theory to represent the given atom in Pre-Test 1, she used a synthetic model, meaning the combination of two different atomic models in her representation in Post-Test 1. The atomic model changed Modern to Synthetic as can be seen in Figure 4.22 and Figure 4.23 Participant 8 stated that the differences in her drawings are sharper orbitals and representation of neutrons in Post-Test 1, "*There are neutrons in the nucleus. And there are much sharper orbitals*".



Figure 4.22. Participant 8's atomic representation (modern) and explanation from pre-test 1.

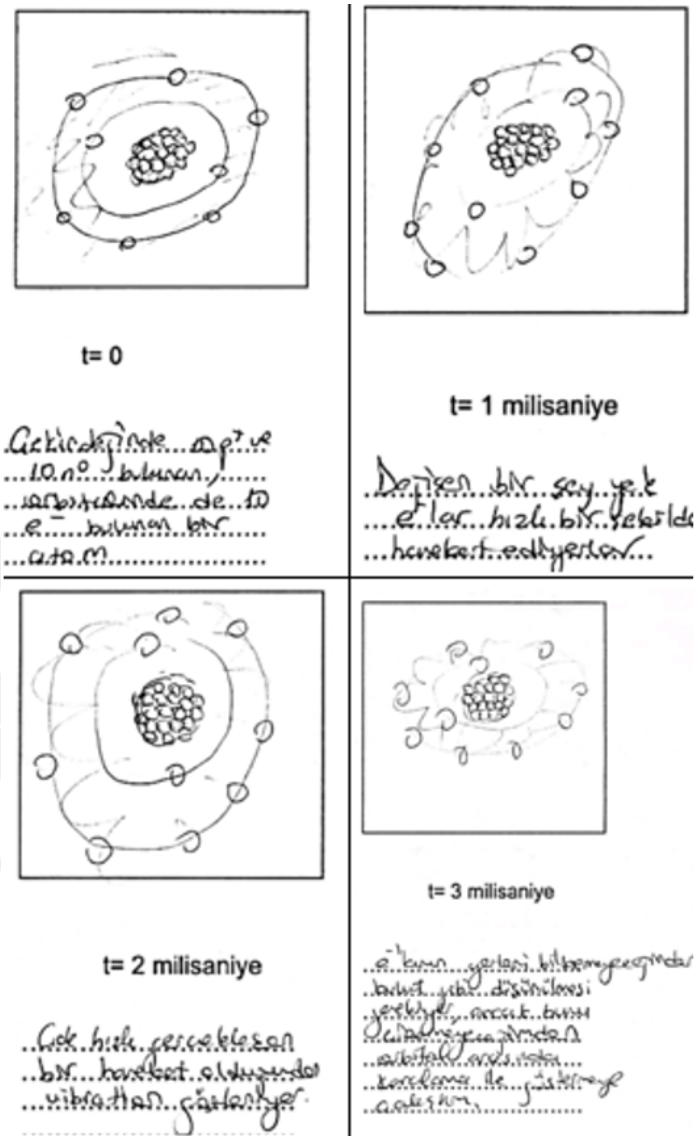

Figure 4.23. Participant 8's atomic representation (synthetic) and explanation from post-test 1.

Even though the atomic model of Participant 5 is according to Dalton's atomic model, as can be seen in Figure 4.24, he used Modern atomic theory in Post-Test 1, as shown in Figure 4.25. Participant 5 stated the atomic model in Post-Test 1, "*First I drew a circle, I thought of it as the core. I drew small dots of protons inside. I drew a more like an electron cloud structure like this around it*". The change in representing atomic model was Dalton's to Modern.

In the second interview, Participant 5 made changes in drawing atom models and stated as follows:

I would say almost completely different. The first time I just drew a small circle, and it was going in one direction throughout time in a regular way. It was just a global model. There were no electrons in it, no protons, no neutrons anyway. In this (Post-Test 1), I focused a little more on the inner, subatomic particles of the atom, for example, I drew the protons, I drew the electrons. Of course, there are no neutrons. I didn't mention it here (Participant 5, Interview 2).

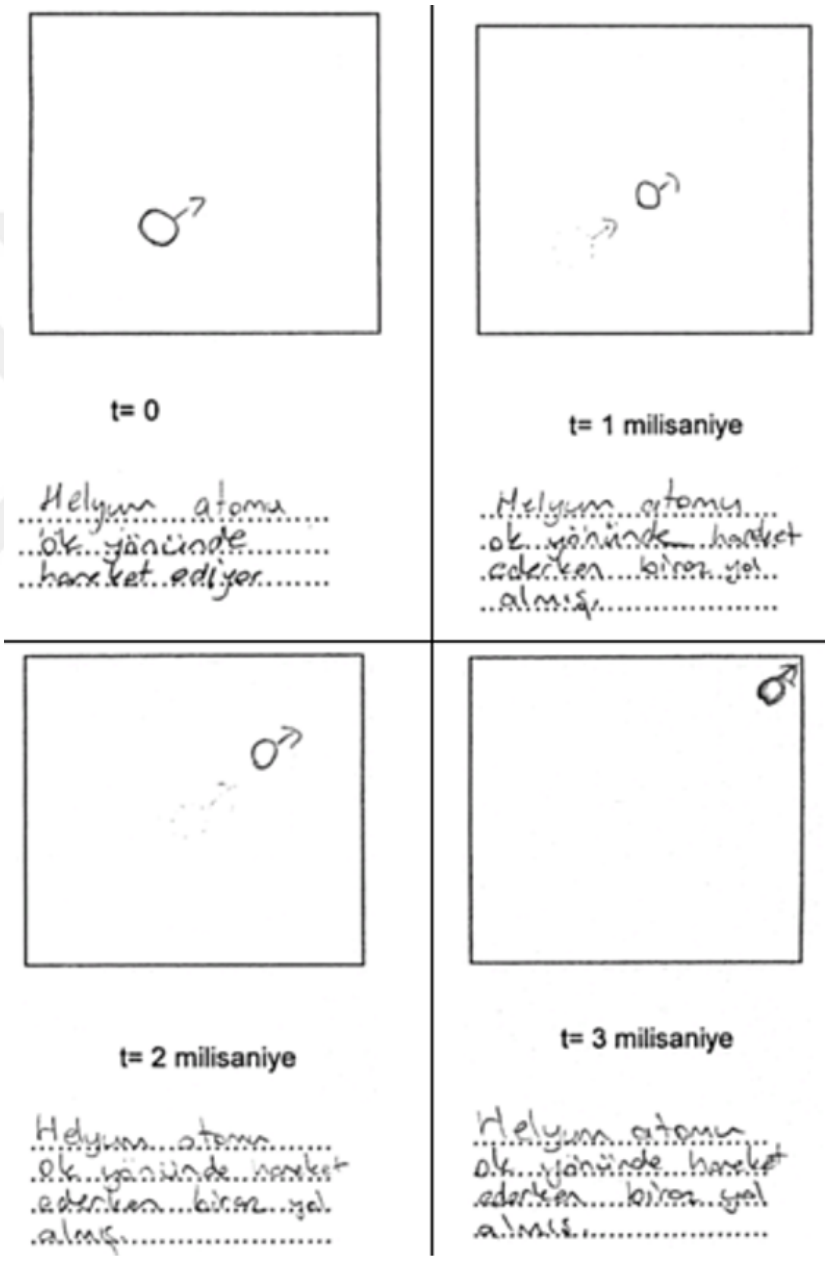

Figure 4.24. Participant 5's atomic representation (dalton's) and explanation from pre-test 1.

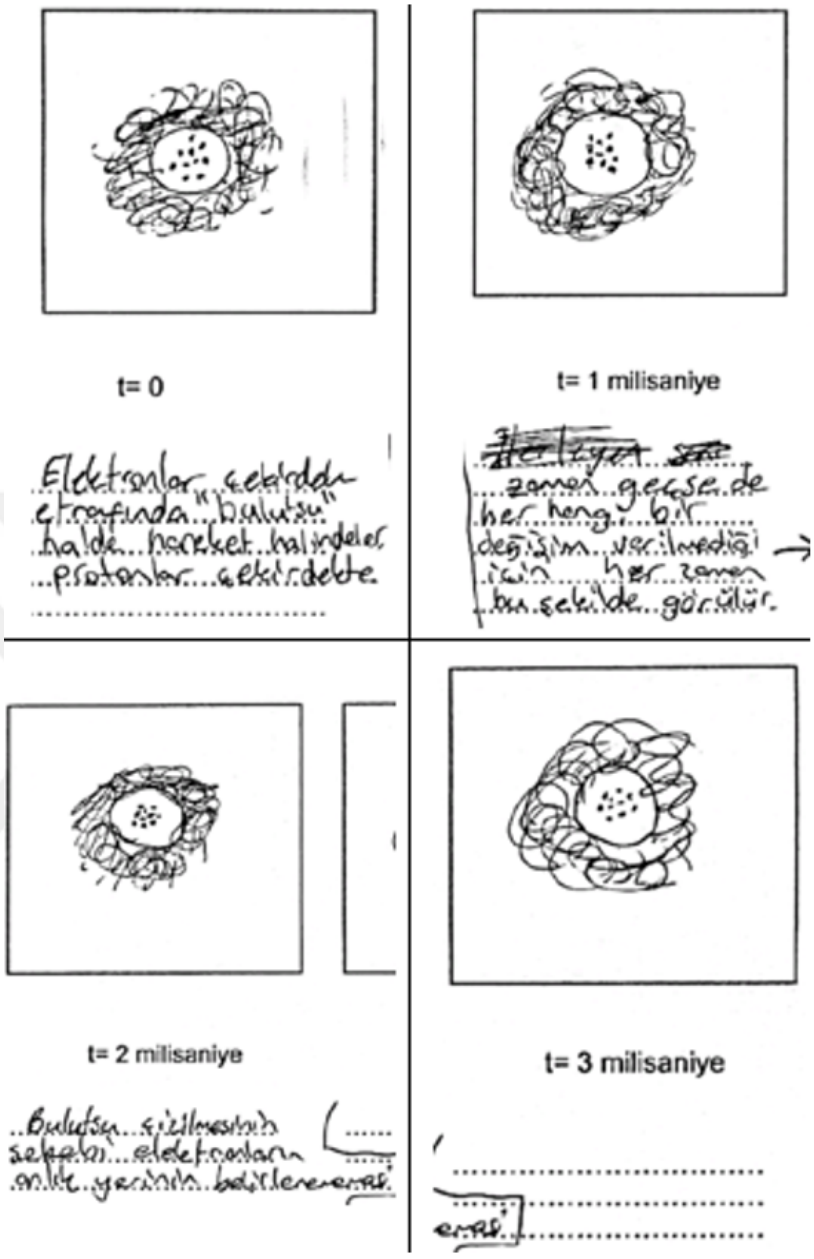

Figure 4.25. Participant 5's atomic representation (modern) and explanation from post-test 1.

Moreover, the second question of the fourth interview protocol aimed to understand the change in the representation of the atomic model between the virtual reality application and the drawings in Pre-Test 2: "*Can you compare the atomic model you created in the virtual reality application with the atomic model you drew in Pre-Test 2? What are the similarities? What are their differences?*".

Participant 7 stated the similarities and the differences between her representation in Pre-Test 2 as can be seen in Figure 4.26 and the virtual reality application:

> The atom models in this virtual reality were the same that we always see, the round simple atom model that I drew at the beginning. Later I made the atomic model more detailed, orbiting, in the second picture (Pre-Test 2). But that thing (the atom in the virtual reality application) basically it looks like round. It looks like the first model I drew (in Pre-Test 1) (Participant 7, Interview 4).

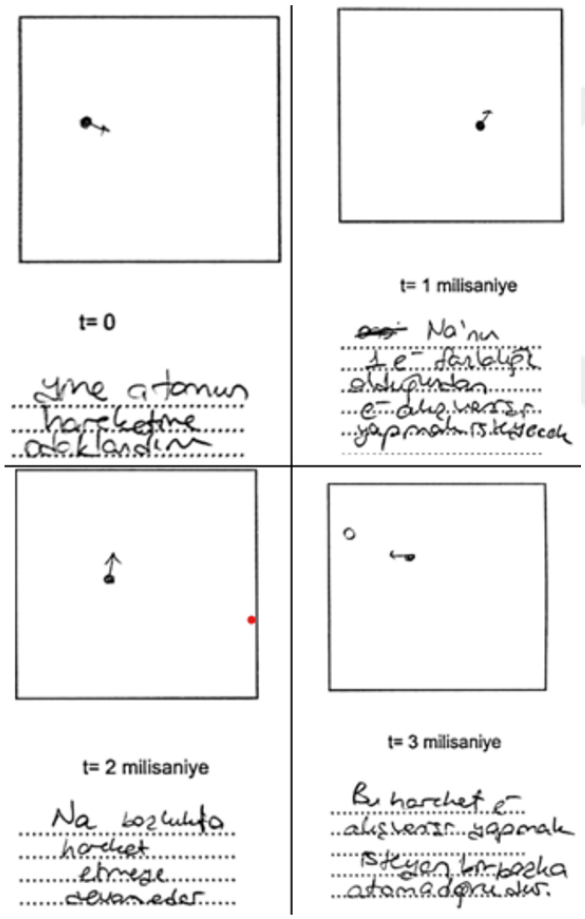

Figure 4.26. Participant 7's atomic representation (dalton's) and explanation from pre-test 2.

Participant 4 stated the similarities and the differences between her representation in Pre-Test 2 as can be seen in Figure 4.44 and the virtual reality application:

> Actually it's (the atomic model in PhET simulation) different from it (the representation in Pre-Test 2) because I drew my atomic model by analogy with the Bohr' atomic model with subatomic particles. We could see electrons, protons, neutrons likewise orbitals, but in the virtual reality application there was

the sphere shape that I mentioned at the beginning (Pre-Test 1) (Participant 4, Interview 4).

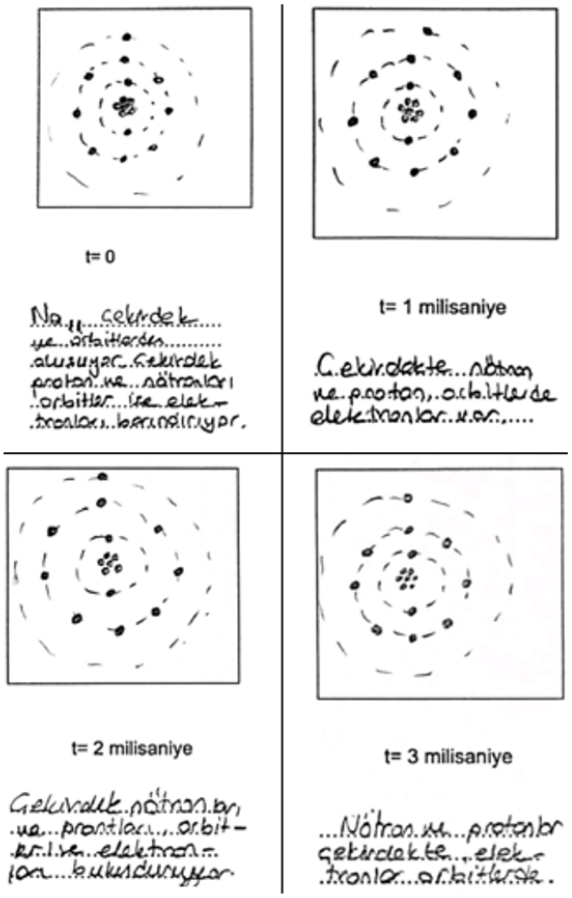

Figure 4.27. Participant 4's atomic representation (bohr's) and explanation from pre-test 2.

Moreover, the eighth question of the fourth interview protocol aimed to understand the change in the representation of the atom after using the virtual reality application: "*Have you made any changes in your Magnesium atom (Mg) model representation from your previous atomic model?*".

The representations from Pre-Test 2 and Post-Test 2 of Participant 6 can be seen in Figure 4.28 and Figure 4.29. In Figure 4.28, Participant 6 represented the given atom according to Bohr's atomic model; however, the same participant drew the atom using a synthetic model (both Dalton's and Bohr's atomic models) after virtual reality treatment, as can be seen in Figure 4.29. The change in representing atomic model

was Bohr's to synthetic.

Participant 6 explained her representation of the atom model as follows:

> Yes, I did (make a change). I just included the last layer and I only focused on the electron. I did not mention protons, neutrons, subatomic particles, nothing else. I tried to show it from different perspectives in both of them (drawings of Pre-Test 2 and Post-Test 2). I also tried to show the motion of the atom in the first drawing (Pre-Test 2) but I did not do it in the second (Post-Test 2). Maybe in terms of showing a feature, you know, it (Mg) has two electrons, it will want to bond, it wanders like this, it's like that. I guess I needed to show... When I looked at it from every angle, yes, it is round, I felt like I needed to add another feature. But of course, I had shown much more before (in Pre-Test 2. For a moment it seemed as if it (electrons) was unnecessary redundancy. That's why I made a simpler, more understandable drawing (Participant 6, Interview 4).

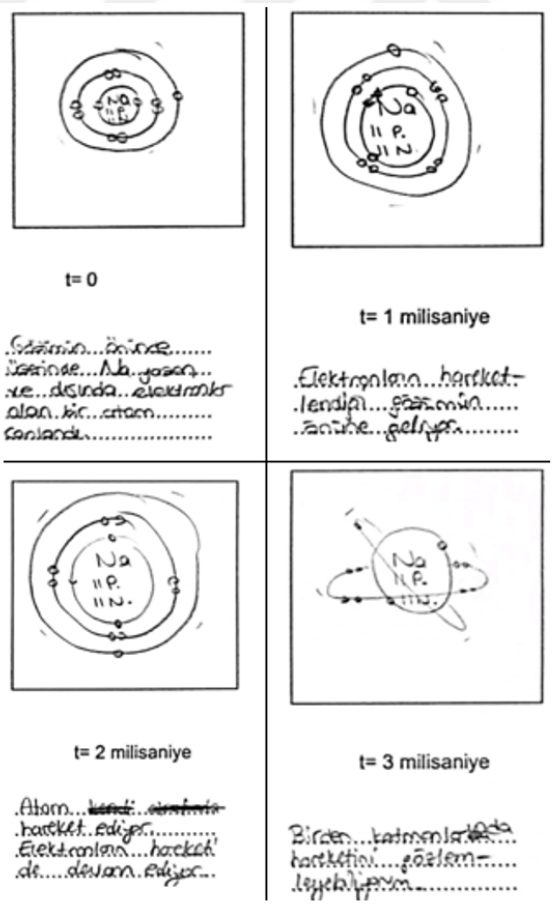

Figure 4.28. Participant 6's atomic representation (bohr's) and explanation from pre-test 2.

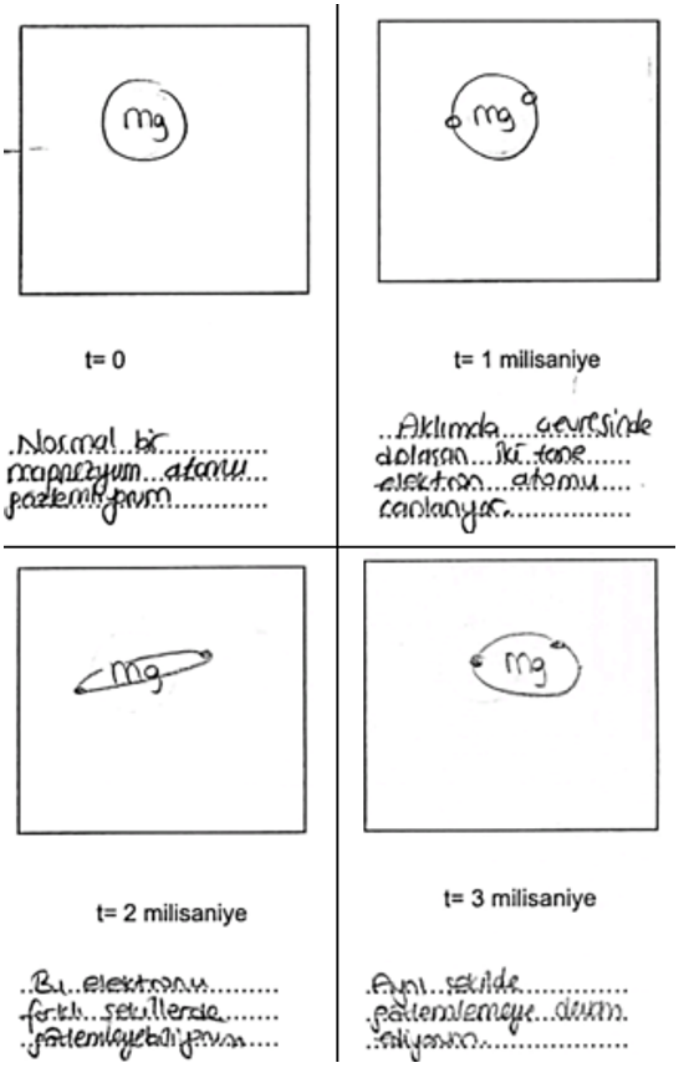

Figure 4.29. Participant 6's atomic representation (synthetic) and explanation from post-test 2.

The representations from Pre-Test 2 and Post-Test 2 of Participant 3 can be seen in Figure 4.30 and Figure 4.31. In Figure 4.30, Participant 3 represented the given atom according to Bohr's atomic model; however, the same participant drew the atom using Dalton's atomic model after virtual reality treatment, as can be seen in Figure 4.31. The change in representing atomic model was Bohr's to Dalton's.

Participant 3 explained the change in the representation of the atomic model as follows:

> Yes, I did (make a change). I drew subatomic particles in the previous one (Pre-Test 2), but I didn't want to focus on that in this (Post-Test 2). I drew

it (the atom) as a sphere because I wanted to focus directly on a form. In my last observation (in the virtual reality application), I had not observed subatomic particles in the workshop. And the last thing (representation) on my mind that I want to show is that magnesium is basically in the form of a sphere. can move etc. was (Participant 3, Interview 4).

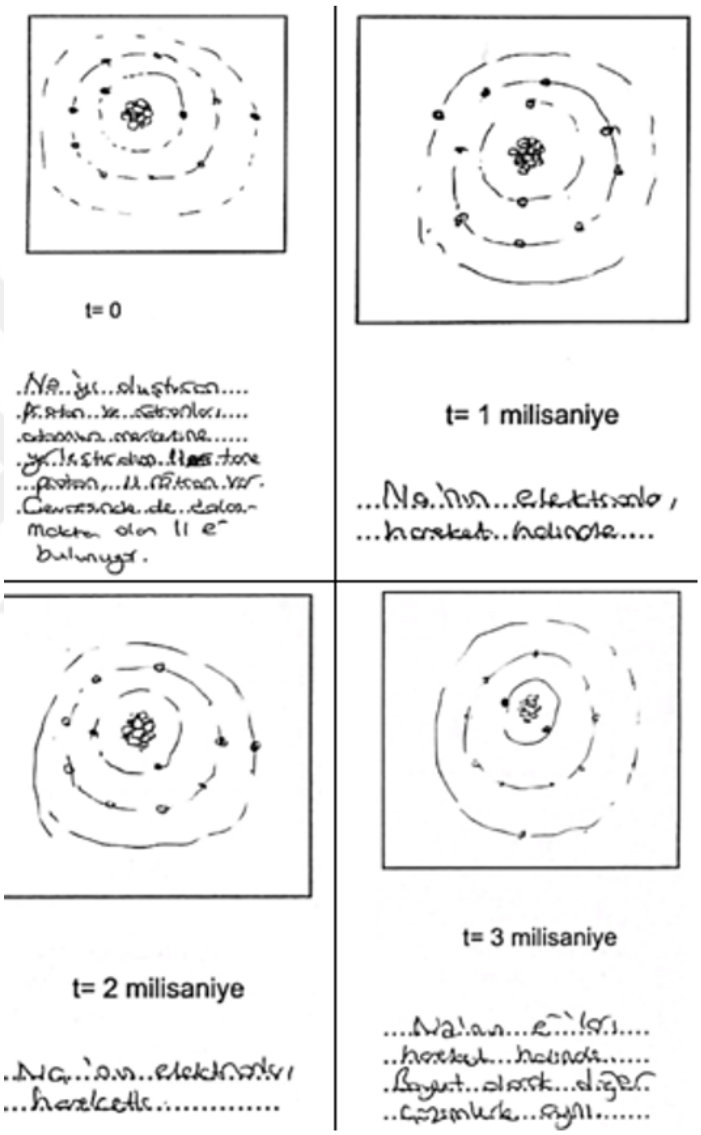

Figure 4.30. Participant 3's atomic representation (bohr's) and explanation from pre-test 2.



Figure 4.31. Participant 3's atomic representation (dalton's) and explanation from post-test 2.

Even though the atomic model of Participant 10 is a synthetic atomic model (both used Dalton's and Modern atomic models), as can be seen in Figure 4.32, he used Dalton's atomic model in Post-Test 2, as shown in Figure 4.33. The change in representing atomic model was synthetic to Dalton's. Participant 10 explained the change in the representation of the atomic model in the fourth interview as follows:

> The model I made after this virtual reality application was as if it resembled the colored sphere I made in previous sessions. For example, when I did it before (in Pre-Test 2), I showed subatomic particles. You know, I didn't draw electrons, but I showed their layers. I also showed the proton and neutrons in the center. But after this application, I modeled this atom in the same way as what I observed in the simulation (Participant 10, Interview 4).

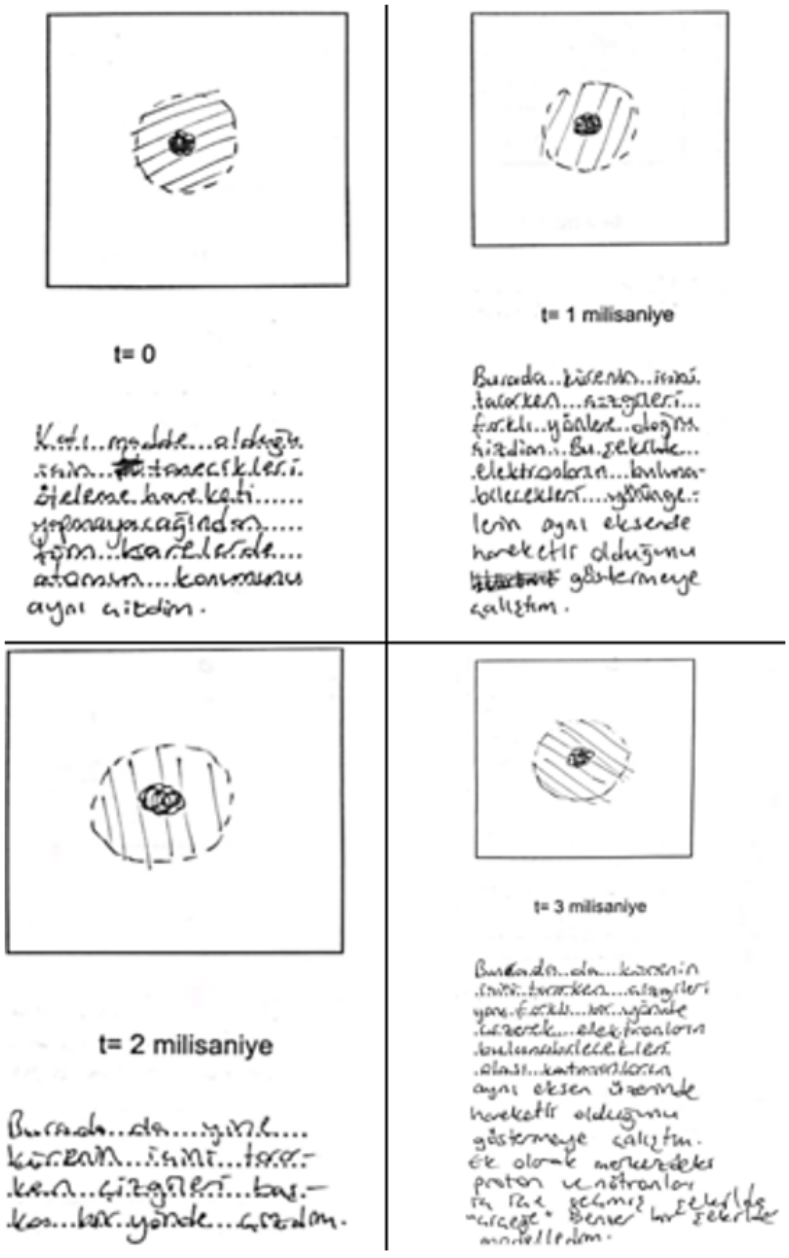

Figure 4.32. Participant 10's atomic representation (synthetic) and explanation from pre-test 2.

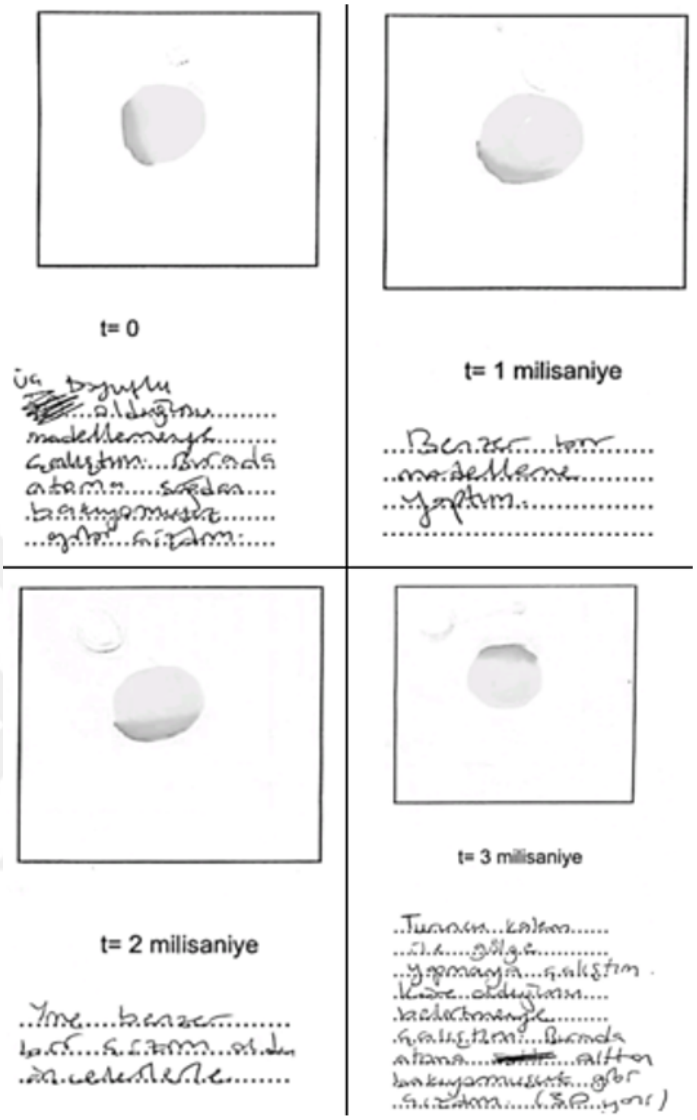

Figure 4.33. Participant 10's atomic representation (dalton's) and explanation from post-test 2.

However, Participant 1 did not make a change in her representation of the atomic model, as can be seen in Figure 4.34 and Figure 4.35. The atomic model that used by the participant was Bohr's to Bohr's. The only change was that electrons were represented as a circle in Pre-Test 2, whereas they were represented as lines in Post-Test 2. Participant 1 explained her representation as follows:

> There is a nucleus; there are orbitals and electrons. This time I showed the electrons in the form of lines. Because I was too lazy to draw 12 balls. Otherwise, there is no other reason. There are 12 electrons and there is the core. I drew the atom in exactly the same way (Participant 1, Interview 4).

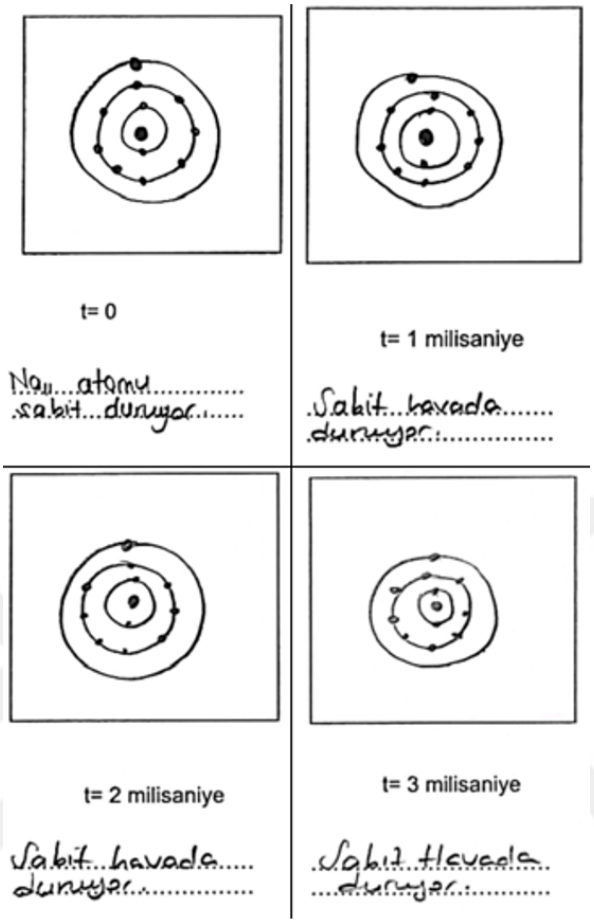

Figure 4.34. Participant 1's atomic representation (bohr's) and explanation from pre-test 2.

In summary, the participants were asked to represent the given atom throughout the study. Atomic theories were used by the participants to represent certain atoms. The findings showed that even though there were changes in the representation of the atomic models of participants, some of them did not make any changes.

4.3. Representing Process for the Atom

The participants were asked in the interviews to explain whether they had any obstacles while drawing the given atom in the Pre-Test 1, Post-Test 1, Pre-Test 2, and Post-Test 2. Obstacles and solutions emerged from the answers given in the interviews.

4.3.1. Obstacles

The sixth question of the first interview asked to investigate the obstacles they faced while drawing the given atom: "*Was there anything in your drawing that you wanted to represent but couldn't? What did you have trouble representing?*".

Table 4.4. Number of participants who stated each codes in the interviews for obtacles of drawing atoms.

NUMBER OF PARTICIPANTS				
Codes for Obstacles of Drawing Atoms	**INTER-VIEW 1**	**INTER-VIEW 2**	**INTER-VIEW 3**	**INTER-VIEW 4**
adding orbitals around the atom	1	0	0	0
drawing the atom in 2D	2	2	4	3
showing motion	2	3	3	2
showing electron cloud	1	0	0	0
showing subatomic particles	1	0	1	1
drawing a sphere	0	0	0	1
drawing the atom from every angle	0	0	1	1
not having any obstacle	6	5	5	4

The obstacles were determined as adding orbitals around the atom, drawing the atom in 2D, showing motion, showing electron cloud, and showing subatomic particles as can be seen in Table 4.4. Six participants stated that they did not have any obstacle during drawing the given atom.

Participant 6 stated as follows:

> Because it's 2 dimensional. To show. Of course, I couldn't show this vibration or anything. For example, it was a challenge not being able to show movement and being in 3D, of course, in 3D (Participant 6, Interview 1).

Codes of the obstacles determined from the second interview were drawing atoms in 2D, and showing motion as can be seen in Table 4.4. Five participants stated that they did not have any obstacle during drawing the given atom. Participant 5 stated that:

> I mean, if I had drawn much better, maybe I would have drawn it more in 3D. Or I was afraid that it would be incomprehensible if I drew the protons closer together this time. That's why I left more space. But so, I'm guessing the protons are much closer in the nucleus (Participant 5, Interview 2).

Investigating obstacles in drawing the specified atom is the subject of the third interview same question as in Interview 2. The obstacles were determined as showing motion, drawing the atom from every angle, drawing the atom in 2D, and showing subatomic particles as can be seen in Table 4.4. Five participants stated that they did not have any obstacle during drawing the given atom. Participant 3 stated as follows:

> Again, I had difficulty showing them in 3D. Then I had a hard time drawing the same as, I couldn't copy and replicate the dimensions of each other in 3 seconds, in 4 different images. Then I did it in different positions because I couldn't show the movement of the electrons instantaneously, but I also looked at it to see if it really seemed to be moving (Participant 3, Interview 3).

The sixth question in the fourth interview focuses on obstacles with the same question asked to draw the specified atom: Obstacles were revealed as showing motion, drawing the atom from every angle, drawing the atom in 2D, drawing a sphere, and showing subatomic particles as can be seen in Table 4.4. Four participants stated that they did not have any obstacle during drawing the given atom. Participant 4 stated:

> Movements again. Secondly, as I said, I can't claim the exact position of these rings or the exact position of the orbits (Participant 4, Interview 4).

4.3.2. Solutions

When the participants mentioned obstacles while drawing the given atom, the solutions they found during the drawing process were asked in the interviews: "*What did you do to overcome this challenge?*". In the first interview, the codes emerged as drawing lines next to the atom for motion, drawing different orbitals for the electron cloud, and adding vibration are the solutions that participants found.

Participant 8 stated:

> I drew different orbitals in others, but I wanted to show vibration at the end, that's why (Participant 8, Interview 1).

In the second interview, the solutions the participants found were trying to show the motion by drawing the fog and drawing the protons closer together Participant 8 stated:

> By scribbling like a light fog on the back like this, I showed it as if it was actually moving (Participant 8, Interview 2).

Moreover, drawing the orbitals at an angle of 45 degrees, trying to show the movement by drawing a fog, and expressing the movement by explaining the bottom were the solutions of the third interview.

Participant 6 stated as follows:

> I drew the layers in a 45-degree, maybe trapezoid, and I drew them differently. I drew a straight and tried to draw an oblique. I wanted to show that it can be observed from different angles by moving the layers this way. I also tried to add movement. They're all actually moving right before my eyes (Participant 6, Interview 3).

In the fourth interview, the participants' solutions were revealed as drawing a trapezoid as can be seen in Figure 4.35 to show it from different angles and writing it

as a description below that the atom is 3D.

Participant 3 stated:

> In order to overcome this obstacle, I expressed in writing below what I was trying to do (Participant 3, Interview 4).

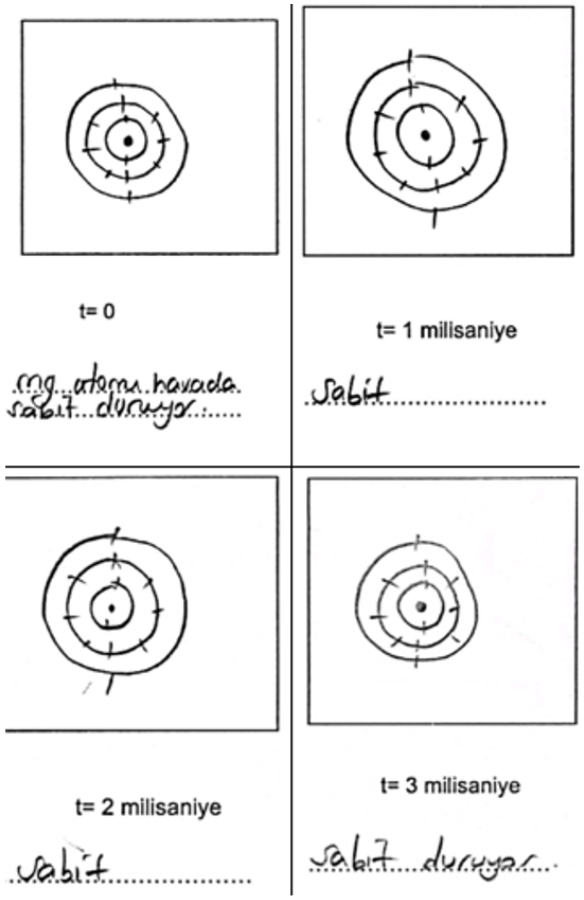

Figure 4.35. The trapezoid representation of atom.

In summary, the theme *representing the process for the atom* had two categories: obstacles and solutions. The participants encountered obstacles in drawing the given atom during the study. These obstacles were mainly unable to show motion, draw the atom in 2D, and unable to show electron clouds and subatomic particles. But they also found solutions to these obstacles while drawing the given atom, as mentioned.

4.4. Representation of the Molecule

Representation of molecules was investigated regarding the first research question of the study: *What are the combined effects of using computer simulations and virtual reality applications on pre-service science teachers' representational competence skills?* The data collected through Pre-Test 1, Post-Test 1, Pre-Test 2, Post-Test 2, and interviews with the pre-service science teachers revealed three categories; (1) Type of Representation; (2) Property; (3) Change in Representation of Molecule. Data were analyzed within the adaptation of (Yaseen and Akaygun, 2016) evaluation key.

4.4.1. Type of Representation

Representation of molecules shown by the participants has been changed through the study. The participants mainly used atomic theory to explain their drawings of molecule. The seventh question of the first interview protocol aimed to understand representation of molecules: "*Can you explain how you represented the formation process of the oxygen molecule with a drawing?*". One participant each used Bohr, Modern, and Lewis atomic models in their representation of molecules in the Pre-Test. In contrast, seven participants used Dalton's atomic model, as can be seen in Table 4.5. Participant 2 represented the given molecule by using Dalton's atomic model and stated as follows:

> I tried to draw the oxygen molecule first as a flat round and larger than Helium. Then, when I came to the last second, I thought of drawing in three dimensions. I did more things that it was 3D and had a back, that is, the back, like a marble ball; I thought that way and did something. I actually tried to make a 3D representation of it. In the last second, they try to form a molecule by slowly forming a bond between 2 oxygen atoms. At the end of this, when we split an apple in half, such a combined shape becomes (Participant 2, Interview 1).

Table 4.5. Number of Participants who showed each Theme of Criteria.

NUMBER OF PARTICIPANTS				
THEME OF CRITERIA	**PRE-TEST 1**	**POST TEST 1**	**PRE-TEST 2**	**POST TEST 2**
Atomic Model in Molecules	Dalton: 7	Dalton: 5	Dalton: 3	Dalton: 7
	Bohr: 1	Bohr: 4	Bohr: 2	Bohr: 0
	Quantum (Modern): 1	Quantum (Modern): 0	Quantum (Modern): 0	Quantum (Modern): 0
	Lewis: 1	Lewis: 0	Lewis:0	Lewis: 0
	Synthetic: 0	Synthetic: 1	Synthetic: 5	Synthetic: 3

Participant 5 used Bohr atomic model as can be seen in Figure 4.36 and stated as follows:

> Here, too, I tried to draw two oxygen atoms further apart at t=0. I have specified electrons in both of these atoms. They both have 8 electrons. There are two layers. According to our middle school knowledge, it consists of two electron layers. There are 2 electrons in the first layer and 6 electrons in the second layer. And these two electrons approach each other throughout the pictures. Now, in the picture t=3 milliseconds later, the second layers are now combined, and they seem to be tangent to each other at a certain point. And in this area, 4 total electrons are used in common, so they are considered to be in the orbit of both. Two of them are for one's electron, two for the other electron. In this drawing, at least, it can be understood that both of them now have 8 electrons in their 2nd orbit (Participant 5, Interview 1).

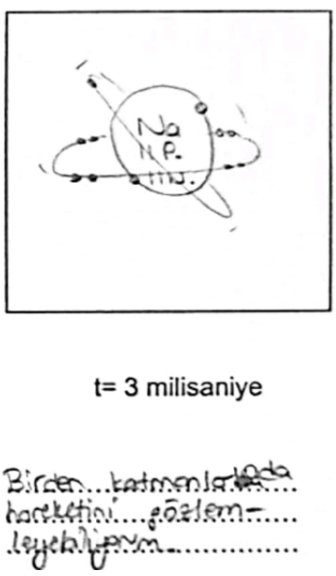

Figure 4.36. Participant 5's molecule representation in pre-test 1.

Participant 8 used Modern Atomic Theory to represent molecules as can be seen in Figure 4.37 and stated as follows:

> It's actually the same thing as the helium I just showed you. But since there are more electrons in this, I couldn't draw many more orbitals. You know, I couldn't create that cloud image directly; only the core is clear. Since it is a molecule formation process, I first drew them separately in a way that would not allow the formation of molecules. I don't know precisely that distance, but I drew it at a distance that would not allow it to be. After that, I zoomed in. And then I showed that it will stay that way stably. Because a stable compound was formed, so, yes, because electrons move, there must be movement, but here, for example, I don't draw a straight line, I show the orbital in a more muffled way (Participant 8, Interview 1).



Figure 4.37. Participant 8's molecule representation in pre-test 1.

Participant 6 used Lewis structure to represent molecules as can be seen in Figure 4.38 and stated as follows:

> Maybe it would be effective if I showed the particles in their layers as if they could show how they bond and unite. In 3 seconds, there is slow motion; they stop, then they get closer, the bonds between them come together with more

gravitational force, and then they unite. I showed the number of electrons in the work in its layers in the form of dots (Participant 6, Interview 1).



Figure 4.38. Participant 6's molecule representation in pre-test 1.

After the PhET simulation workshop given as treatment, the participants were asked to draw molecules in the Post-Test 1. The fourth question of the second interview investigated the representation of molecules in Post-Test 1 with the same question as in Interview 1. Table 4.5 shows that five participants used Dalton's atomic model, four used Bohr's atomic model, and one used a synthetic model to represent the given molecule.



Figure 4.39. Participant 1's molecule representation in post-test 1.

Participant 1 used Dalton's atomic model as can be seen in Figure 4.39 and stated as follows:

> I drew two fluorine atoms first. And I went from the distances in between to explain my formation. So, for drawing. I drew the distance from 3d to 2d, then to d, and then to zero, forming a fluorine molecule. I drew two florets. Then I showed the distance in the middle. I wrote the distance between them in 3d. I wrote F to denote the fluorine atom (Participant 1, Interview 2).

Participant 7 used Bohr atomic model as can be seen in Figure 4.40 and stated as follows:

> I didn't just draw a circle; this time used the newer model type, drawing electrons and orbitals separately. First, I drew 2 electrons in the first orbit and then 7

electrons around them, brought them closer together, and showed them how they were clamped together and how they shared electrons one by one. I drew the nucleus of two different atoms, then the second, the first electron layer, placed two of their electrons in their places, and then placed the remaining 7 electrons in orbit in the next thing. I've done this twice (Participant 7, Interview 2).



Figure 4.40. Participant 7's molecule representation in post-test 1.

Participant 8 used synthetic model (using Bohr's, Modern Atomic Theory, and Dalton's atomic models) as can be seen in Figure 4.41 and stated as follows:

First, I drew two normal atoms. Here in the figure, again, with the same number of protons and neutrons and the electrons around it, evenly distributed, evenly distributed in their orbitals. Later, I drew these slowly while creating a bond at work. Slowly, the two orbitals approach each other. Because they are not close enough to form a bond beforehand. They then reach a sufficient distance and begin to share an electron. And then I made it look like they continue that way because this is a stable atom. Plus, when I drew two electrons and two atoms, which I remember in the simulation, separately, in a way that does not allow bond formation. In the second, there were two round-shaped atoms, and there was a bond between them with a line because this was what I remembered in the simulation. That's how I showed it. You know, when we look at it from a distance, it is shown like this (Participant 8, Interview 2).

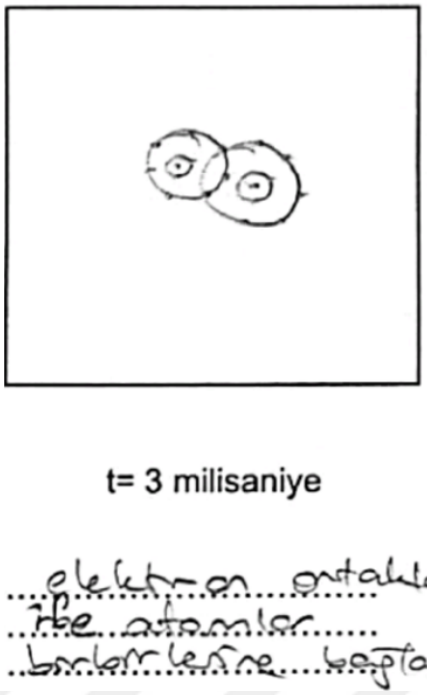

Figure 4.41. Participant 8's molecule representation in post-test 1.

In Pre-Test 2, participants were asked to construct and draw molecules before using the virtual reality application. The third interview's sixth question examines the representation of molecules in Pre-Test 2 with the same question as in previous interviews. As shown in Table 4.5, five individuals utilized a synthetic model to represent the provided molecule, whereas two participants used the Bohr atomic model and three others used Dalton's atomic model.

Participant 6 used a synthetic model both Bohr and Dalton's atomic models are included as can be seen in Figure 4.42, stated as follows:

> This time I did not draw all the layers; I only drew the last layers of the atoms. Because the electrons in their last layer will bond, I know this. Based on this knowledge, I drew it. Again, I drew the motion of atoms. For the first two seconds, I thought it was normal and in a room setting. And they are moving. I drew the lines again. And electrons are also moving in this drawing. In the second and third seconds, I drew lines to show that the electrons will slowly bond between them to be more descriptive. Again, they are moving. In the last drawing, I tried to depict the bond. The electron is now in the form of bonds, and they combine and move (Participant 6, Interview 3).

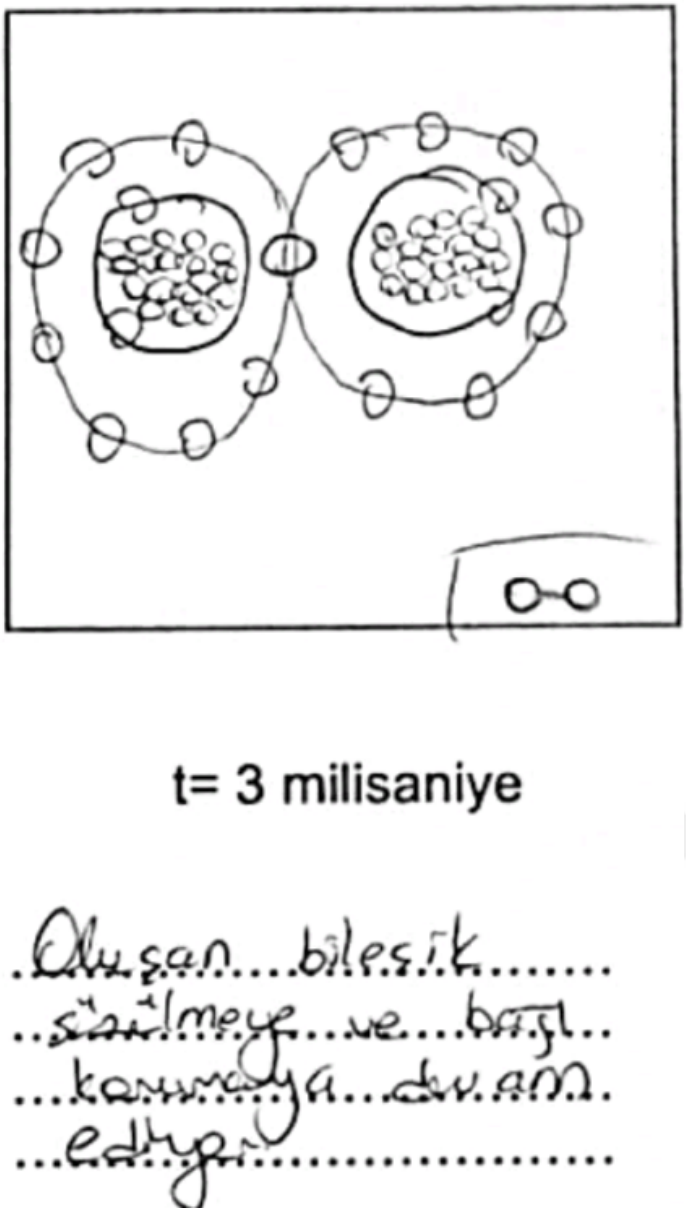

Figure 4.42. Participant 6's molecule representation in pre-test 2.

Participant 4 used Dalton's atomic model to represent molecules as cane be seen in Figure 4.43 and stated as follows:

> Again, we have hydrogen, a chlorine molecule. These are a circle. I show them converging with the dashed lines. And they are getting closer to each other in terms of distance. I put a line between them to show that the bond formation is getting sharper. And they merged again; I made the same integrated drawing as if they were a little bit into each other (Participant 4, Interview 3).



Figure 4.43. Participant 4's molecule representation in pre-test 2.

Participant 9 used Bohr atomic model as can be seen in Figure **??** and stated as follows:

> First, I drew the hydrogen and chlorine separately. I drew the trajectories. I added electrons to it. Then I added the protons and neutrons again. He had not yet bonded in this state. Next, they form bonds by sharing their electrons one at a time. Next, it makes a rotational motion. While I was drawing this, I had something in mind; I wonder if there should be a connection when creating a link. So, I made a bond by drawing two electrons side by side (Participant 9, Interview 3).

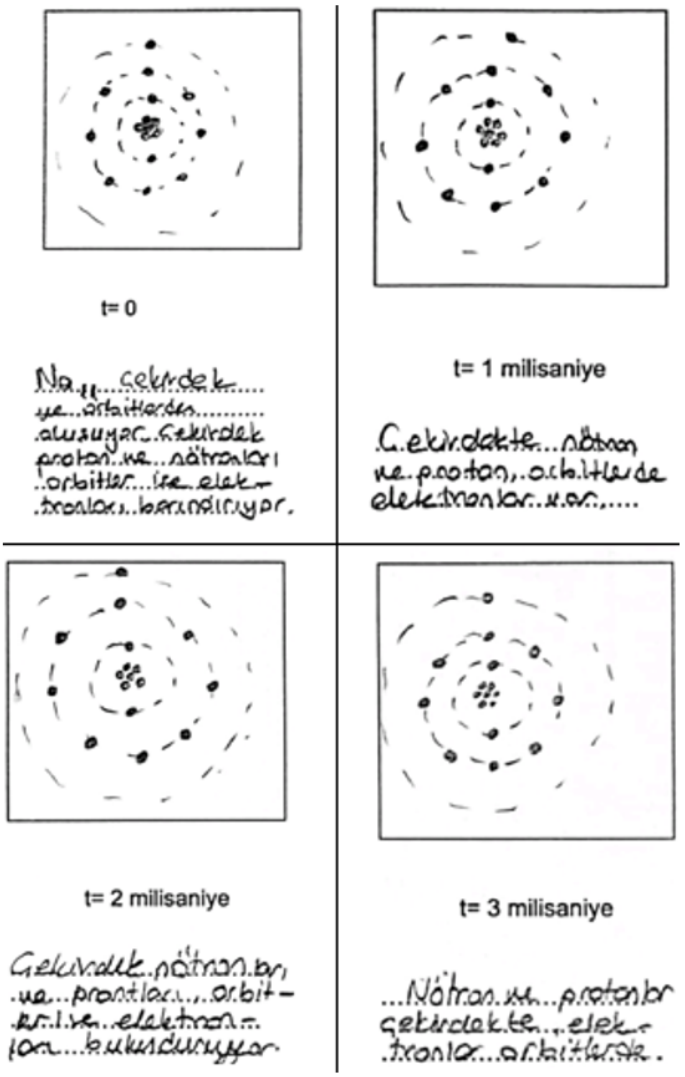

Figure 4.44. Participant 9's molecule representation in pre-test 2.

In Post-Test 2, after experiencing virtual reality, participants again were asked to construct and draw molecules. The tenth question of the fourth interview focuses on how molecules are represented in Post-Test 2 with the same question in previous interviews. Findings showed that three participants utilized a synthetic model, whereas seven employed Dalton's atomic model, as seen in Table 4.5.

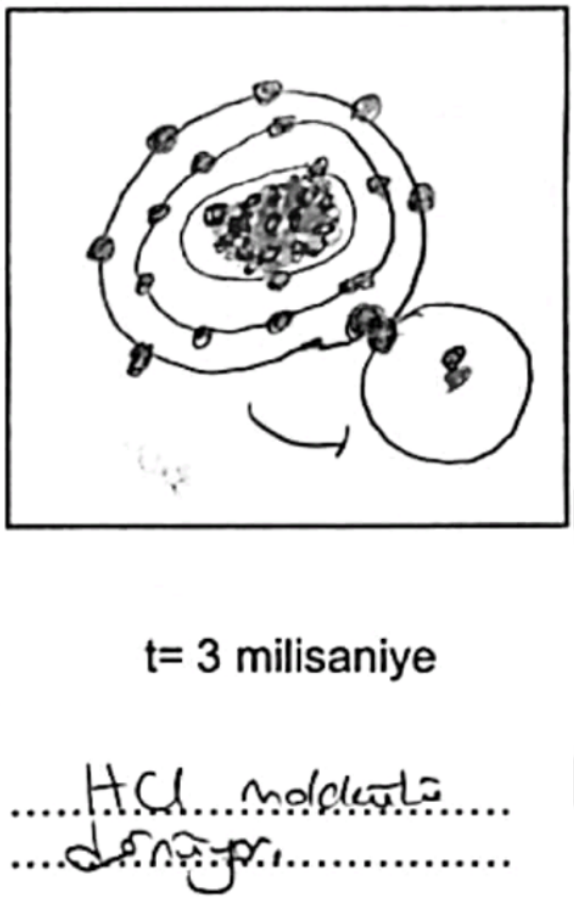

Figure 4.45. Participant 3's molecule representation in post-test 2.

Participant 3 used Dalton's atomic model as can be seen in Figure 4.45 and stated as follows:

> First, hydrogen and fluorine atoms exist in a medium. In the next second, I also added a link to my drawing, as there should be a link between them. But these two have yet to form that bond. In my next drawing, the hydrogen and fluorine atoms joined by a bond to form the molecule. Hydrogen fluoride and the molecule were formed similarly in the 3rd second. I did not include subatomic particles (Participant 3, Interview 4).

Participant 6 used a synthetic model and included Bohr's and Dalton's atomic model features in her drawings as can be seen in Figure 4.46. The participant stated as follows:

> I drew two atoms named hydrogen and fluorine. I drew the layer. I drew your electron again. Then I tried to picture that a bond would form because of their attraction (Participant 6, Interview 4).

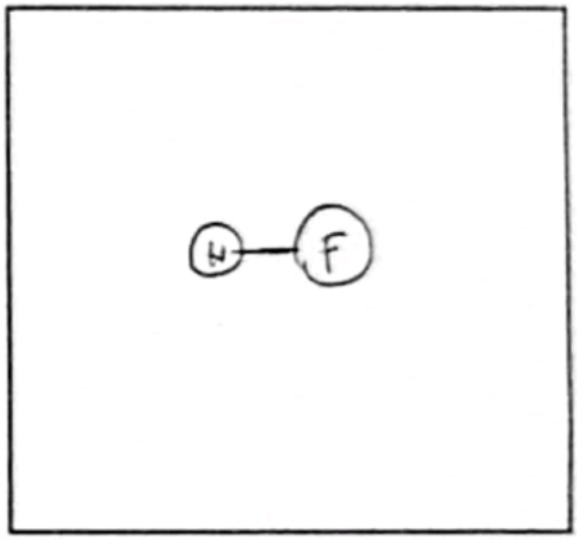

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Figure 4.46. Participant 6's molecule representation in post-test 2.

In conclusion, the depiction of models used by pre-service science teachers can be divided into five main groups: Dalton, Bohr, Modern, Lewis, and Synthetic. Throughout the investigation, numerous molecular representations were used.

4.4.2. Property

Pre-service science teachers were also asked to explain the molecules' properties when depicting specific molecules. The first research question was answered by describing the property of the molecular representation. According to Pre-Test 1, Post-Test 1, Pre-Test 2, Post-Test 2, and interviews, one criterion named molecular construction process has been detected as a property of representation of molecules.

Table 4.6. Number of participants who showed each theme of criteria.

NUMBER OF PARTICIPANTS				
THEME OF CRITERIA	**PRE-TEST 1**	**POST TEST 1**	**PRE-TEST 2**	**POST TEST 2**
Molecular Construction Process	Shown: 9	Shown: 9	Shown: 10	Shown: 8
	Not shown: 1	Not shown: 1	Not shown: 0	Not shown: 2

The molecular construction process was analyzed in both drawings and transcripts of the interviews. As shown in Table 4.6, in Pre-Test 1, nine participants showed molecular construction processes, whereas one did not-the findings from Post-Test 1 mirror those from Pre-Test 1. Before the virtual reality application, 10 participants showed molecular construction processes in Pre-Test 2, whereas, in Post-Test 2, this number decreased to eight. And two participants did not show molecular construction processes in Post-Test 2.

4.5. Change in Representation of Molecule

The second questions of Pre-Test 1, Post-Test 1, Pre-Test 2, and Post-Test 2 aimed to investigate the representations of the molecule model of the participant. The second question of the second interview protocol aimed to understand the change in the representation of the molecule model between the PhET simulation and the drawings in Pre-Test 1: "*How do you compare the molecule model you created in the PhET simulation with the Oxygen (O2) molecule model you drew in PreTest1? What are the similarities? What are the differences?*".

Participant 7 stated the similarities and the differences between her representation in Pre-Test 1 as can be seen in Figure 4.47 and the PhET simulation:

> The same. The same. So, that's the thing (atom) because I drew two things (atoms), flat, round, and empty, and something cylindrical like a bridge in be-

tween. In the simulation, it looked like that when I zoomed in, and when we looked from a distance without zooming in, there was something like two circles stuck together, they turned to 8 (Participant 7, Interview 2).

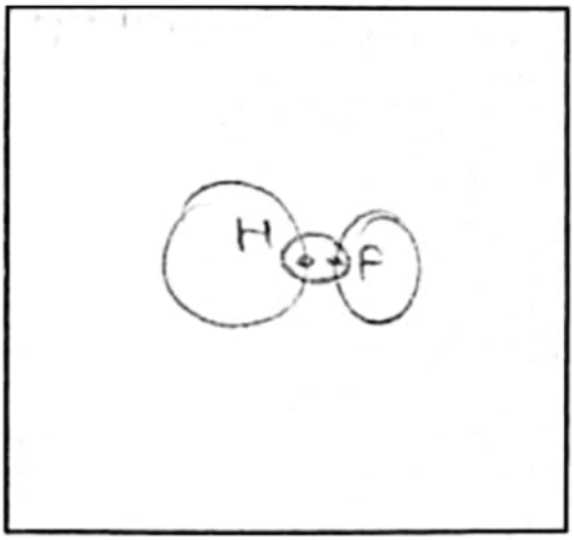

Figure 4.47. Participant 7's molecular representation (dalton's) and explanation from pre-test 1.

Participant 2 stated the similarities and the differences between her representation in Pre-Test 1 as can be seen in Figure 4.48 and the PhET simulation:

Actually, as I originally created this first simulation, it actually came to my mind and I made it the thing in my Pre-Test 1. That's how I tried to draw it in 3D, like a combination of 2 half apples. It actually has a similarity. I can say that there is more similarity in the molecule. Yes, I didn't show the link. There was a long line, or in the simulation, I had not drawn it. I just showed that it was combined. And here he was acting in the simulation. For example, maybe I didn't do that in my drawing. Indicating that he is moving. They were firmly united (Participant 2, Interview 2).



Figure 4.48. Participant 2's molecular representation (dalton's) and explanation from pre-test 1.

Moreover, the fourth question of the second interview protocol aimed to understand the change in the representation of the atom: "*Have you made any changes in your representation of the Fluorine (F2) molecule relative to your previous molecule model?*".

The representations from Pre-Test 1 and Post-Test 1 of Participant 7 can be seen in Figure 4.49 and Figure 4.50. In Figure 4.49, Participant 7 represented the given molecule according to Dalton's atomic model; however, the same participant drew the atom using Bohr's atomic model after the PhET simulation treatment, as can be seen in Figure 4.50. The representation of molecular model changed through Dalton's to Bohr's.

Participant 7 explained her representation as follows:

I did (make a change). I drew a more detailed model. In the first model I drew, I drew only two filled circles. I drew something cylindrical, like a bridge between them. This time (in Post-Test 1), I tried to show electrons and electrons to the layers and to show electron sharing, what is inside that bridge (bond) (Participant 7, Interview 2).

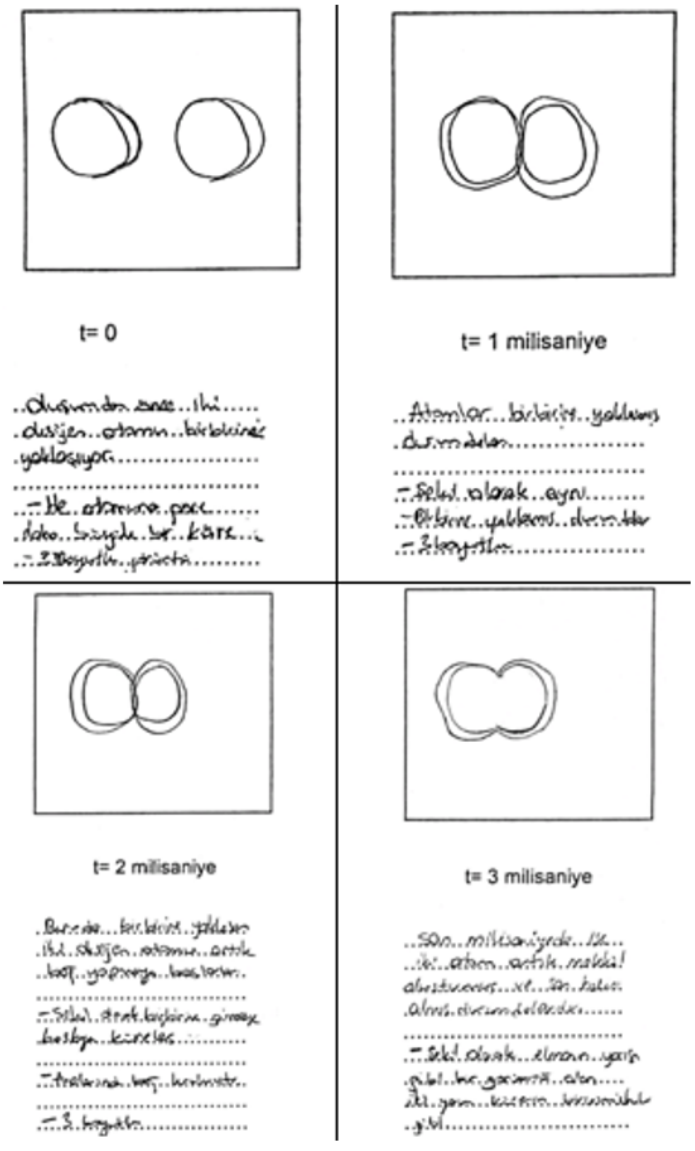

Figure 4.49. Participant 7's molecular representation (dalton's) and explanation from pre-test 2.

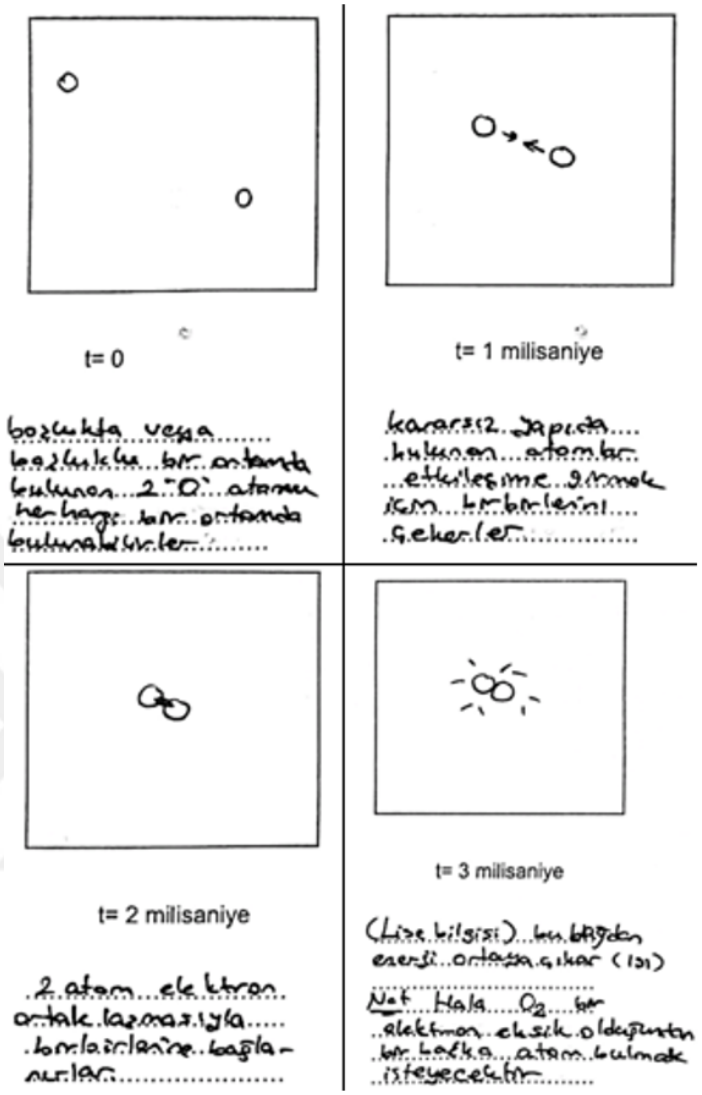

Figure 4.50. Participant 7's molecular representation (bohr's) and explanation from post-test 2.

Even though the molecular model of Participant 8 is represented according to Modern Atomic Theory in Pre-Test 1, as can be seen in Figure 4.51, she used a synthetic model in Post-Test 1, as shown in Figure 4.52. The representation of molecular model changed through Modern to synthetic. Participant 8 explained the change in the representation of the molecular model in the second interview as follows:

> The orbitals are much more regular in my drawing after simulating. Because in the first one (Pre-Test 1), the first layer didn't really go like the second layer, it was like they were moving around, flying around. I can only see it doing so in a certain order, at least here, the first has only two. It seems much more obvious that it is round (in Post-Test 1). It's as if it's a halo around it... But I didn't draw it that way at first (Pre-Test 1). I drew it as if there were things flying

around, electrons flying around. The biggest difference seems to be that. The second is subatomic particles. That is, the number of protons and neutrons in the nucleus has changed. Because I didn't draw neutrons in the first place (Pre-Test 1). Obviously, there can be a change in the number of electrons. Because when I did them after the simulation, I really added electrons, protons, and neutrons with numbers. So, I added the count. That's why it looks more precise. But when I first did it (in Pre-Test 1), I didn't pay attention to the number of electrons or protons. But I drew the nucleus, and there's the proton, but I didn't pay attention to how many. I also drew their view from afar in the corner (in Post-Test 1) (Participant 8, Interview 2).

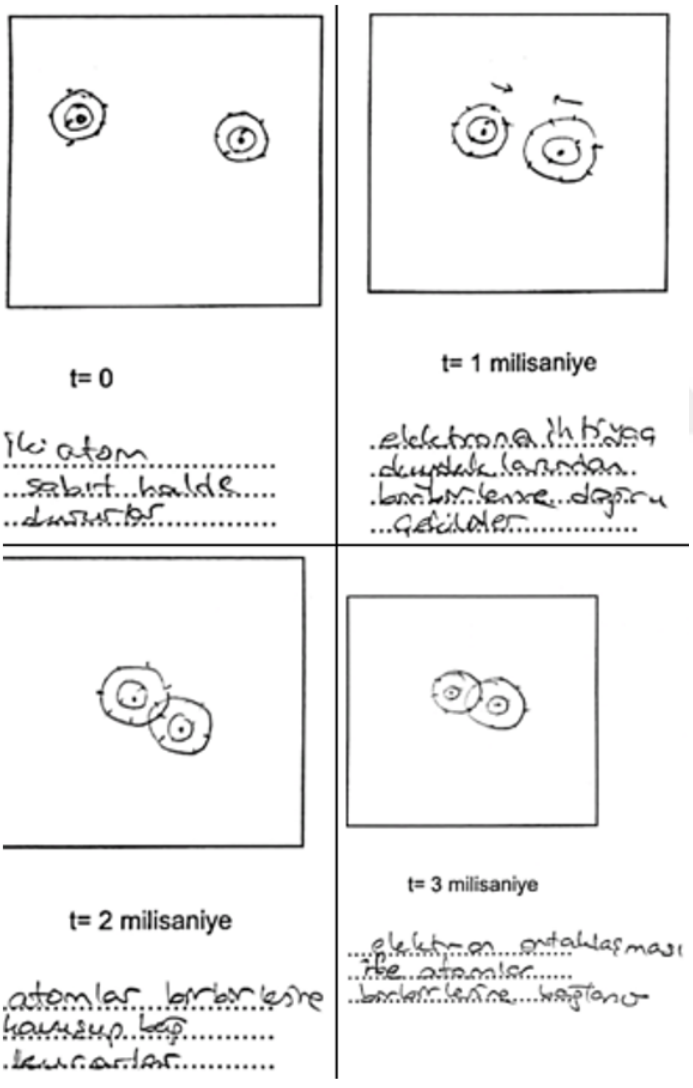

Figure 4.51. Participant 8's molecular representation (modern) and explanation from pre-test 1.



Figure 4.52. Participant 8's molecular representation (synthetic)and explanation from post-test 1.

The representations from Pre-Test 1 and Post-Test 1 of Participant 2 can be seen in Figure 4.53 and Figure 4.54. In Figure 4.53, Participant 2 represented the given molecule according to Dalton's atomic model; however, the same participant drew the molecule using a synthetic model (both used Dalton's and Bohr's atomic models) after PhET simulation treatment, as can be seen in Figure 4.54. The representation of molecular model changed through Dalton's to synthetic.

Participant 2 explained her molecular representation changes as follows:

Yes, I did (a change). In my first drawing (Pre-Test 1), I showed that two separate atoms get closer and closer to form a bond. But here (Post-Test 1), in the first picture, I drew from the moment the bond started to form, and in the 3rd picture, I showed the bond between them. In picture 4, I showed how they combine using subatomic particles (Participant 2, Interview 2).



Figure 4.53. Participant 2's molecular representation (dalton's) and explanation from pre-test 1.

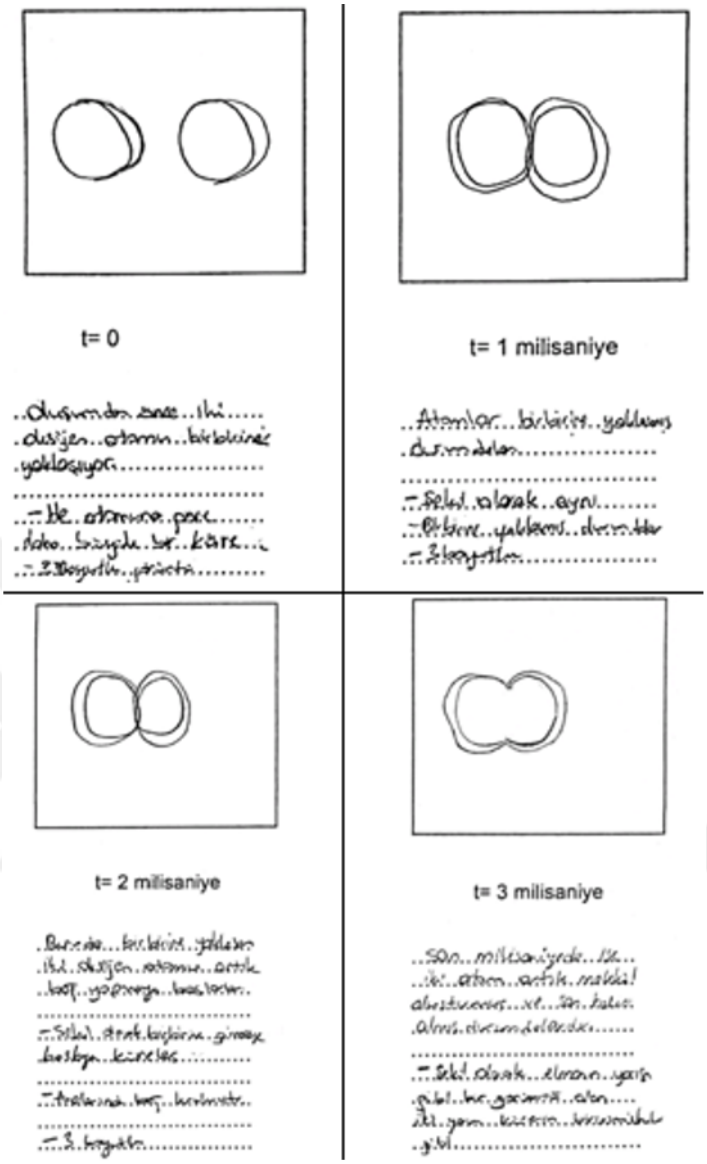

Figure 4.54. Participant 2's molecular representation (synthetic) and explanation from post-test 1.

Although the drawings of Participant 4 did not show a major change, there was a small change in her representation of the molecular model, as can be seen in Figure 4.55 and Figure 4.56. The molecular model was represented Dalton's to Dalton's. The bonding and position of the atoms were changed, and Participant 4 explained her representation as follows:

> I did (make a change). The most obvious change might be showing a little bit of the bond formation patterns and how they stop when they bond at the very end. Because at first (Pre-Test 1), when I was using arrows while approaching, I felt the need to show that the bond was formed directly. And I wanted to show

the strength of the bond with a line. OK, it's done, it's about to happen, and it looks like it's about to end. And when in my first drawing (Pre-Test 1), only two circles stood next to each other, while in my last drawing (Post-Test 1), they stand more closely and densely (Participant 4, Interview 2).

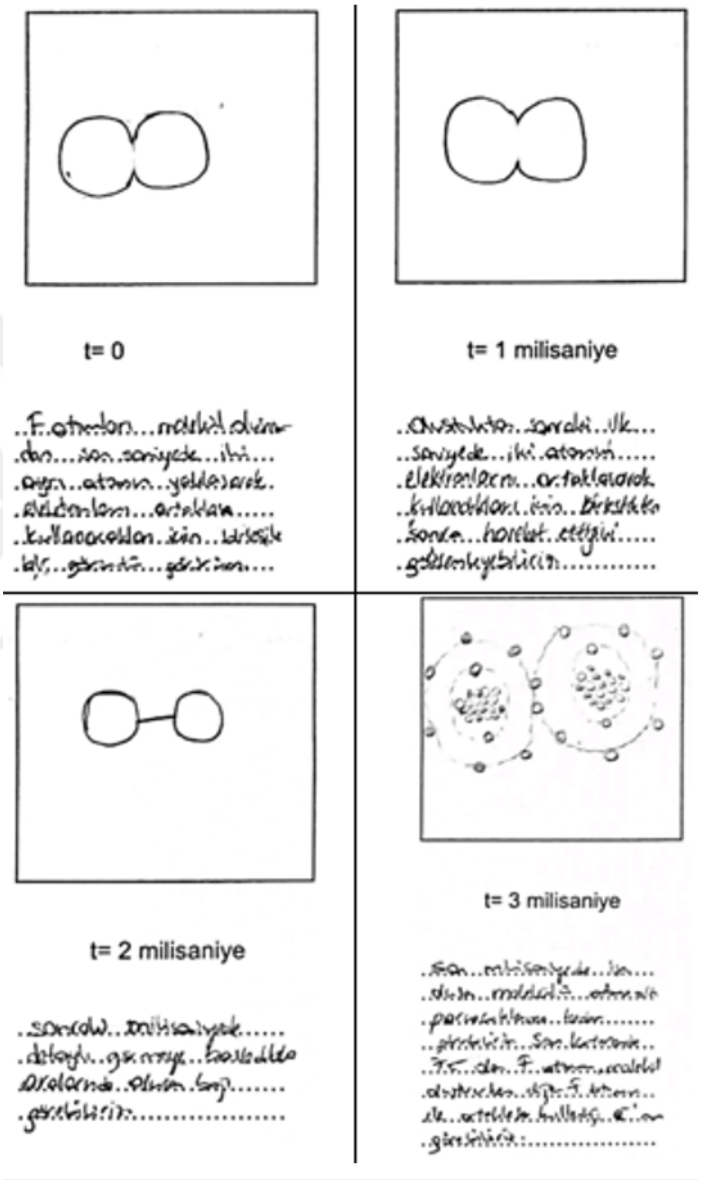

Figure 4.55. Participant 4's molecular representation (dalton's) and explanation from pre-test 1.

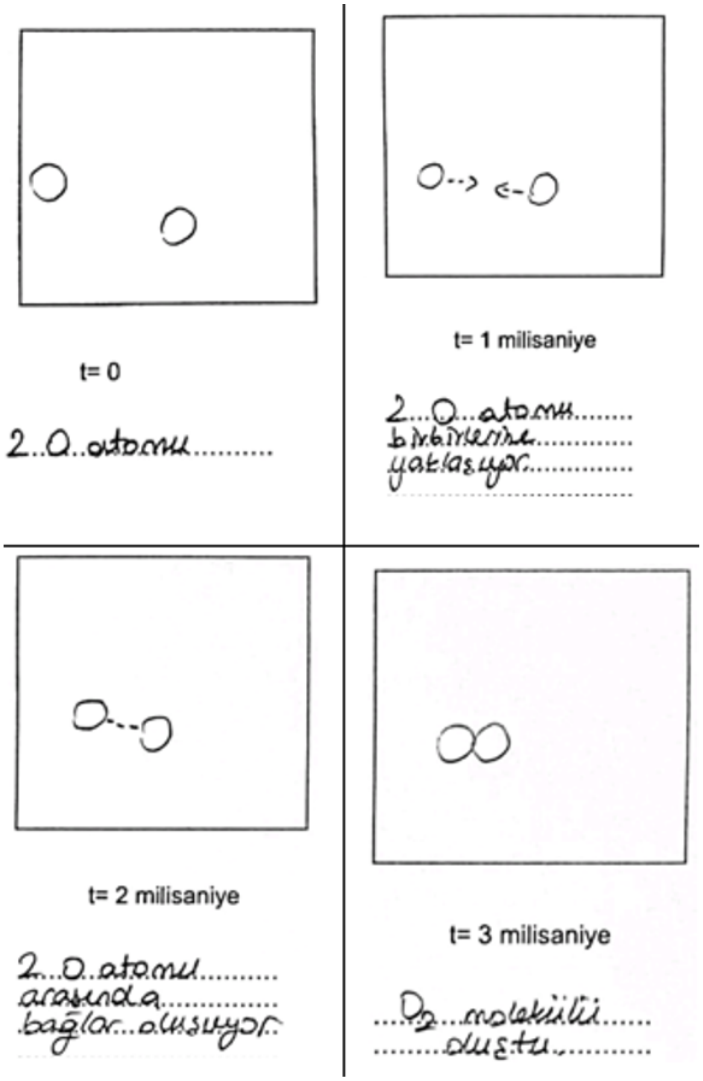

Figure 4.56. Participant 4's molecular representation (dalton's) and explanation from post-test 1.

Moreover, the third question of the fourth interview protocol aimed to understand the change in the representation of the molecule model between the virtual reality application and the drawings in Pre-Test 2: "*How do you compare the atomic model you created in the virtual reality application with the molecular model you drew? What are the similarities? What are the differences?*".

Participant 5 explained the differences and similarities between the representation of the molecule in the virtual reality application and his drawings as can be seen in Figure 4.57:

In the Pre-Test (2), I did something like this; normally, there was hydrogen and chloride at work. Hydrogen and chloride each shared an electron between them. I have drawn two lines here since two electrons will be shared in total. But it actually means a bond. That's why in practice, 1 bond was shown as a single line. It was similar that they were spherical. Here I am, I wrote the letter H on the atom. There, too, hydrogen had its own color, it did not write H on it, but they used color there. Since it's my only pen, I just wrote letters here. He was similar. The atoms were all spherical, but you need something to tell them apart. Here I have shown them letters, they with color. Apart from that, it is a similar event in that they form a bond when the bond between them gets closer to each other (Participant 5, Interview 4).

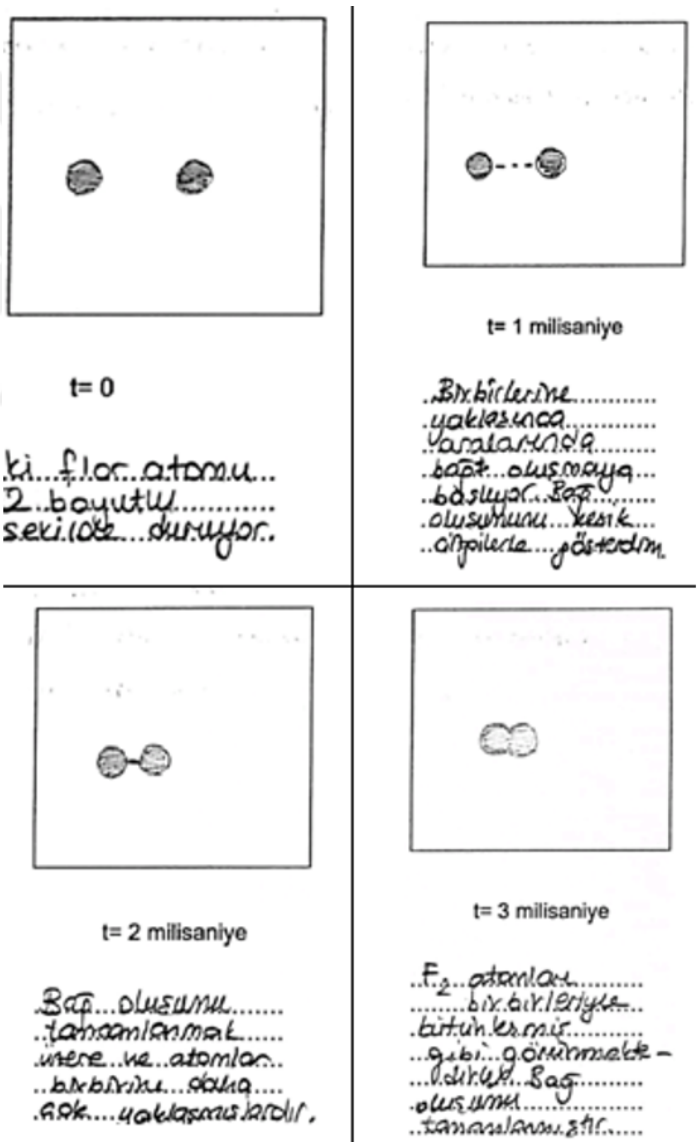

Figure 4.57. Participant 5's molecular representation (dalton's) and explanation in pre-test 2.

Participant 8 explained the differences and similarities between the representation of the molecule in the virtual reality application and her drawings in Figure 4.58:

> As I said in virtual reality, I chose two atoms, or I chose one atom directly. Here they are connected even when a pole is placed next to each other. They even connected when I hit the same key over and over. You know, we just paid attention to the thing, for example, you warned me, draw further away so that they do not tie. Otherwise, when it got closer at work, we could understand from there that they were bonding. Apart from that, for example, even when choosing HCl in the simplest way, one electron is shared in common, we call this bond covalent, we call this bond, what this bond is and what happens when hydrogen and chlorine form a bond, we answer this question in this way. At least on the information thing we collect. And that's how I made my drawing because it was pictured in my head. But in the virtual reality application, obviously, this did not have any importance. So it was straight, obviously nothing else (Participant 8, Interview 4).

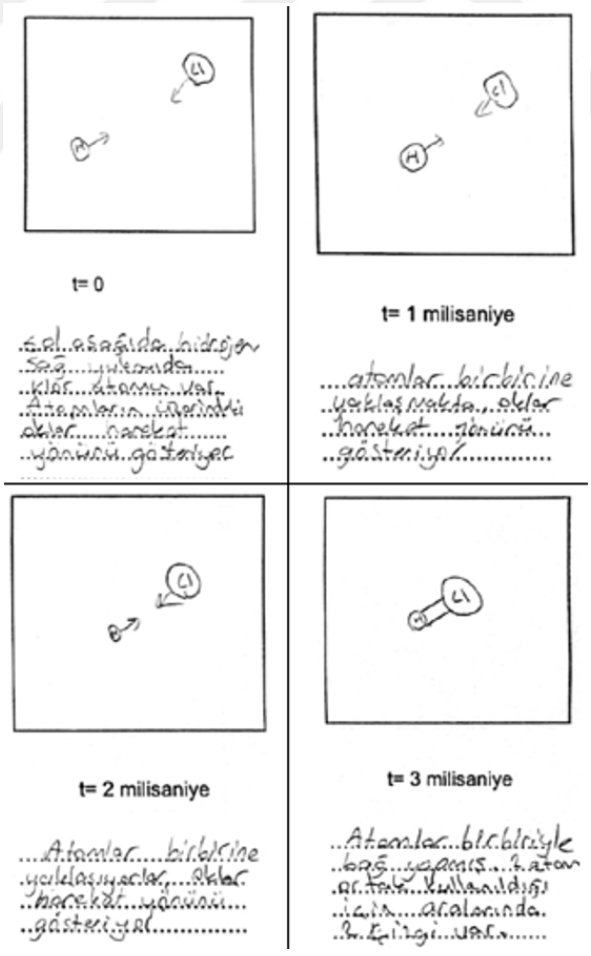

Figure 4.58. Participant 8's molecular representation (synthetic) and explanation in pre-test 2.

Moreover, the tenth question of the fourth interview protocol aimed to understand the change in the representation of the molecule after using the virtual reality application: "*Have you made any changes in your Hydrogen Fluoride (HF) representation relative to your previous molecule model?*".

The representations from Pre-Test 2 and Post-Test 2 of Participant 7 can be seen in Figure 4.59 and Figure 4.60. In Figure 4.59, Participant 7 represented the given molecule in a synthetic model (both used Dalton's and Bohr's atomic models); however, the same participant drew the molecule using Dalton's atomic model after the virtual reality application treatment, as can be seen in Figure 4.60. The representation of molecular model changed through Dalton's to synthetic.

Participant 7 explained her representations as follows:

> I did (make a change). I showed subatomic particles before (in Pre-Test 2), but not this time (in Post-Test 2). I thought I made a mistake in electron sharing when I did it before (in Pre-Test 2), so I didn't find it right. This time, after using VR and looking in more detail, I realized that I could draw something with a simple model, but again more accurately showing the number of bonds in between (Participant 7, Interview 4).

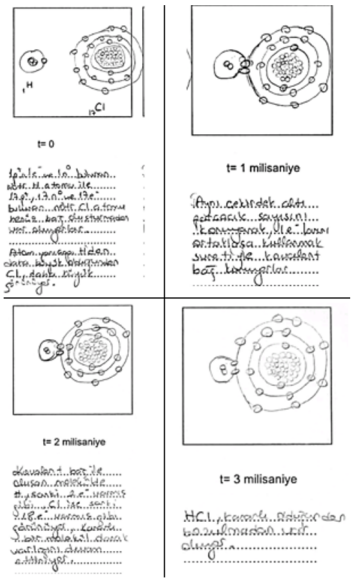

Figure 4.59. Participant 7's molecular representation (synthetic) and explanation from pre-test 2.

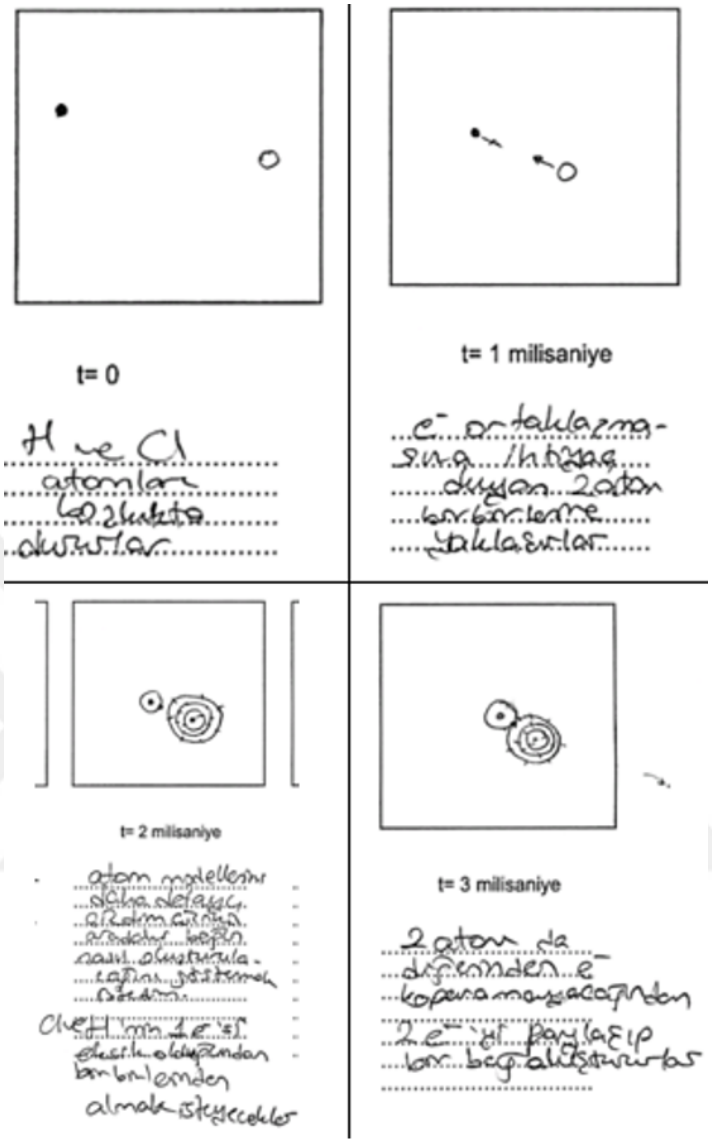

Figure 4.60. Participant 7's molecular representation (dalton's) and explanation from post-test 2.

However, Participant 8 did not make a change in her representation of the molecular model, as can be seen in Figure 4.61 and Figure 4.62. Participant 8 stated, "*No, I did not (make any change) (There are) Just different atoms*".



Figure 4.61. Participant 8's molecular representation and explanation from pre-test 2.

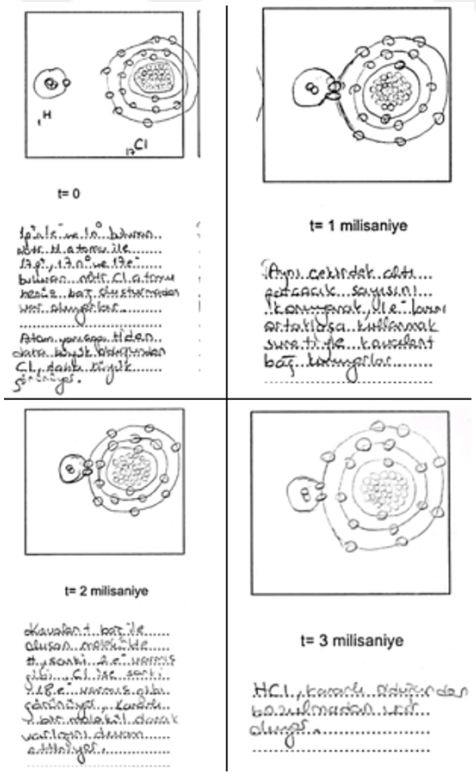

Figure 4.62. Participant 8's molecular representation and explanation from post-test 2.

Although the drawings of Participant 4 did not show a major change, there was a small change in her representation of the molecular model, as can be seen in Figure 4.63 and Figure 4.64. The bonding and position of the atoms are changed, and Participant 4 explained her representation as follows:

> My change was as follows: This time (in Post-Test 2) I did not use arrows or dashed lines while drawing. This time (in Pre-Test 2), I drew close to each other, and finally, I drew normally combined in my molecule in the previous one. It was a bit of a peanut-like thing, intertwined with each other. This time (in Post-Test 2), I wanted to show that there is a direct relationship between the line and the line, to show that there is a connection (Participant 4, Interview 4).

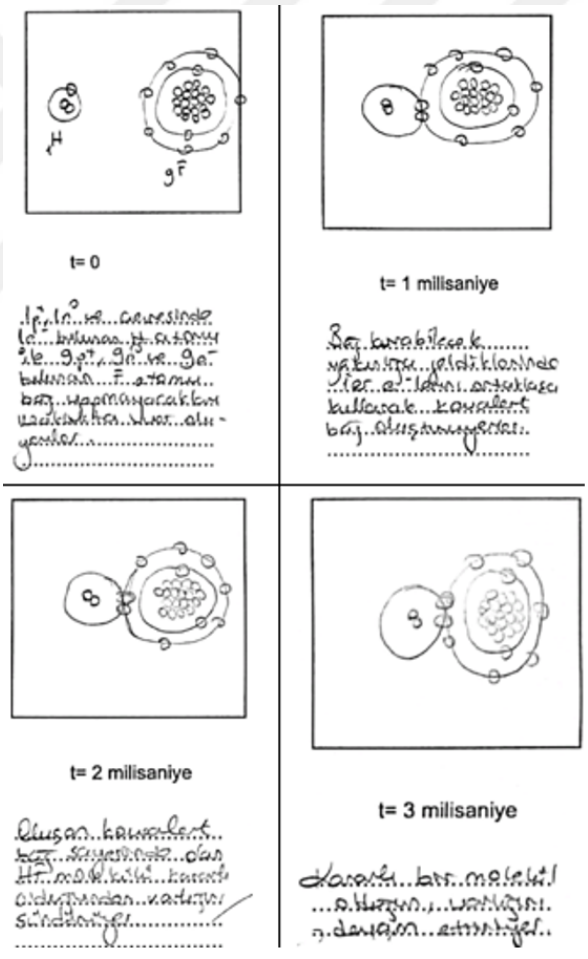

Figure 4.63. Participant 4's molecular representation (dalton's) and explanation from pre-test 2.



Figure 4.64. Participant 4's molecular representation (dalton's) and explanation from post-test 2.

The representations from Pre-Test 2 and Post-Test 2 of Participant 9 can be seen in Figure 4.65 and Figure 4.66. In Figure 4.65, Participant 9 represented the given molecule using Bohr's atomic model; however, the same participant drew the molecule using Dalton's atomic model after the virtual reality application treatment, as can be seen in Figure 4.66. The representation of molecular model changed through Bohr's to Dalton's.

Participant 9 explained her representations as follows:

> Yes (I made a change), again, neutrons, electrons, and protons, I did not include them because I did not observe them (in virtual reality application). Also, it wasn't orbital, so I just drew it as a sphere (Participant 9, Interview 4).

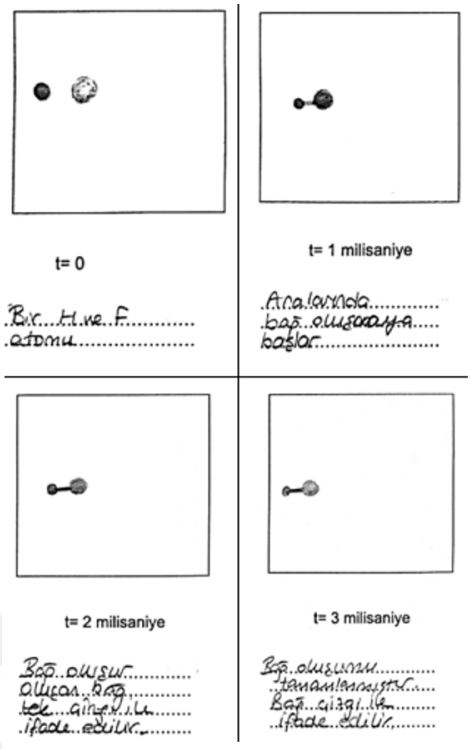

Figure 4.65. Participant 9's molecular representation (bohr's) and explanation from pre-test 2.

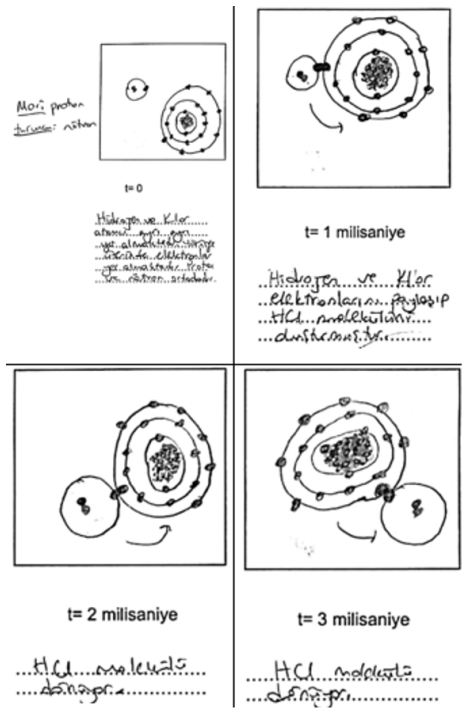

Figure 4.66. Participant 9's molecular representation (dalton's) and explanation from post-test 2.

In summary, the participants were asked to represent the given molecule throughout the study. Atomic theories were used by the participants to represent certain molecules. The findings showed that even though there were changes in the representation of the molecular models of participants, some of them did not make any changes.

4.6. Representing Process for the Molecule

In interviews, the participants were questioned about any difficulties they might have had while sketching the provided molecules in the Pre-Test 1, Post-Test 1, Pre-Test 2, and Post-Test 2. The responses to the interviews revealed the categories of obstacles and solutions.

4.6.1. Obstacles

The seventh question of the first interview investigates whether the participants encounter any obstacles in drawing the given molecules: "*Is there anything in your drawing that you wanted to represent but couldn't? What did you have trouble representing?*". The obstacles as emerged codes from data were found drawing the molecule in 2D, showing motion, showing subatomic particles, and drawing bonds as can be seen in Table 4.7. Six participants stated that they did not have any obstacles during drawing molecules.

Participant 4 stated as follows:

> Actually, I know that these bonds are formed by electrons, but I couldn't think of how to express this in the drawing, so I just put a bond phrase and a symbol and passed. For example, I could not show the formation of bonds between electrons (Participant 4, Interview 1).

Table 4.7. Number of Participants who stated each codes in the interviews for obstacles of drawing molecules.

NUMBER OF PARTICIPANTS				
Codes for Obstacles of Drawing Molecules	**INTER-VIEW 1**	**INTER-VIEW 2**	**INTER-VIEW 3**	**INTER-VIEW 4**
drawing the molecule in 2D	1	2	1	1
showing motion	1	6	3	2
showing subatomic particles	1	2	2	0
drawing bonds	2	3	3	1
drawing the atom from every angle	0	0	0	1
draw the atomic radii realistically	0	0	1	0
not having any obstacle	6	0	1	6

Moreover, the fourth question in the second interview asks about any obstacles the participants may have drawn the provided molecules with the same question as in previous interview. The obstacles were stated as drawing the molecule in 2D, showing motion, showing subatomic particles, and drawing bonds as can be seen in Table 4.7. Participant 6 stated as follows:

> So, I drew a trapezoid between the second and third. this one was to show you who is active. I thought that I rotated it in 3d form in front of my eyes. You know, maybe I could show the movement of this better again, I could add little lines to the sides like I did in my first drawing. So again, the drawing is 2d, so how much can I draw? How can I show? (Participant 6, Interview 2).

The third interview's sixth question inquired about any obstacles the participants may have encountered when drawing the supplied molecules with the same question as in previous interview. The obstacles as codes that were revealed from the interview answers were drawing the molecule in 2D, showing motion, showing subatomic particles, drawing bonds, and drawing the atomic radii realistically as can be seen in Table 4.7. One participant stated as not having any obstacles during drawing. Participant 7 stated:

> Again, I couldn't do something properly; I couldn't show how molecules combine and bond. It was electron sharing, etc (Participant 7, Interview 3).

Participant 8 stated as follows:

> So, I'm sure that's not exactly the size difference between them. So yes, chlorine is bigger than hydrogen. But it looks almost like 1 to 10 among them in my drawing. Atomic radii could perhaps be shown. Or here's what the remaining electrons do. These two have bonded, but what are the rest of them doing? I don't even know this. I hadn't even thought of it before. Maybe it could be shown. But I didn't show it because I didn't know. Because I don't know how to do it (Participant 8, Interview 3).

The tenth question in the fourth interview asks about what obstacles the participants may have faced when drawing the provided molecules with the same question as in previous interview. The obstacles are found as drawing the molecule in 2D, showing motion, drawing bonds, and drawing the atom from every angle as can be seen in Table 4.7. Six participants stated that they did not have any obstacles during drawing molecules. Participant 3 stated as follows:

> Here, we were able to look at my drawing in detail in the workshop, but it remains fixed as I drew it. I can't turn, I can't move. Even though I have it down to milliseconds, it is difficult to accurately transfer such short times to my drawing (Participant 3, Interview 4).

4.6.2. Solutions

In interviews, the participants were questioned about the solutions they found while drawing the supplied molecules when they cited obstacles. The solutions revealed in the first interview were showing the bond as a line, drawing attention to the combination of electrons, and muffled drawing of the orbitals for vibration. Participant 4 stated:

> Usually, if I want to show that something will form a bond, I create lines or something in between (Participant 4, Interview 1).

And Participant 6 said:

> I tried to draw your attention more by drawing the electrons from here, where the dots converge (Participant 6, Interview 1).

In the second interview, the participants found drawing the nucleus as a whole, showing the movement by drawing a mist, and showing the movement by changing the molecule's position as solutions. Participant 8 stated as follows:

> Again, as I did in the previous one, I scribbled the back of it like a mist, you know, the electrons; they use both of them, one of them together, but what are the other electrons doing? You see, they're moving too; I showed it (Participant 8, Interview 2).

Moreover, in the third interview, the participants stated that indicating atoms with symbols, showing motion with lines, and putting symbols next to them are the solutions for obstacles to drawing molecules. Participant 3 said:

> To overcome this obstacle, I made explanations below, but I did not do anything different. I wrote next to them with symbols, here are hydrogen and chlorine (Participant 3, Interview 3).

Participant 6 stated:

> I tried to show that it was moving. Those lines show that (Participant 6, Interview 3).

The last interview revealed that drawing electrons at different angles, explaining under the drawing, and showing atoms with symbols are the participants' solutions. Participant 3 stated:

> I made statements. Besides, I used the letters that symbolize hydrogen and fluorine in my drawing. And I tried to overcome this with what I wrote under it (Participant 3, Interview 4).

Participant 6 stated:

> I tried to draw the electrons on different sides to show the movement (Participant 6, Interview 4).

In conclusion, there are two categories for the molecular representation process: obstacles and solutions. During the investigation, the participants had difficulty drawing the specified molecules. The obstacles were mainly not showing the electrons, inability to show how the bond was formed, and not showing the motion. However, as indicated, the participants overcame these obstacles while drawing the assigned molecule.

4.7. Simulation

The effect of computer simulation was investigated regarding the second research question: What are the experiences of pre-service science teachers using computer simulation? The data collected through interviews with the pre-service science teachers revealed six categories: (1) experience, (2) method of application in a lesson, (3) subject, (4) reasoning for using, (5) strengths, and (6) weaknesses.

4.7.1. Experience

The first question of the first interview protocol for the pre-service science teachers aimed to understand their prior experiences: "*First of all, can you talk about your experience with simulations in general?*" and "*Have you used simulation on an extracurricular subject?*". The pre-service science teachers stated that they used computer simulations in contexts of extracurricular experiences, lesson plans, games, educational simulations, and internships. Participant 5 stated that he used computer simulations in his lesson plans and internships:

> I used the simulations a lot, especially when preparing a lesson plan while doing my teaching internship, that is while teaching at the university. Especially in the online period, most of our lesson plans had simulations (Participant 5, Interview 1).

Participant 7 stated she used simulation in the context of extracurricular activities:

> So, I tried driving a lot. After that, I play games anyway, such as a fighting simulation or target shooting, etc. or game. Or food simulations etc. I tried these (Participant 7 Interview 1).

The first and second questions of the second interview protocol aimed to understand pre-service science teachers' experiences while using the PhET simulation: "*Can you explain step by step what you did in the simulation? How did you create the atomic model?*" and "*How did you create the molecular model representation?*". Participant 1 explained her experience in creating the atomic model in PhET simulation and stated as follows:

> First, I put neutrons and protons in the nucleus. When it had already put in enough numbers (of proton and neutron), it was written which atom it was, above. Then I put the electrons in. Since we made neon, I put 10 protons, and 10 neutrons directly. Everything equally (Participant 1, Interview 2).

In summary, pre-service science teachers' experiences before and after using computer simulations were asked. Before using computer simulations, their experiences were in contexts of extracurricular activities and curricular activities. After using computer simulation, they explained their experiences.

4.7.2. Method of Application in a Lesson

The fifth question of the first interview protocol for the pre-service science teachers aimed to understand their experience with the method of computer simulation application in a lesson: "*Do you plan to use simulation in your lessons when you become a teacher? Why is that? How do you use it? Can you describe your application method?*". All the pre-service science teachers said they would apply computer simulations according to the 5E teaching model. The 5E teaching model includes engagement, exploration, explanation, elaboration, and evaluation phases. All the participants expressed that they would use computer simulations in the future and integrate them in the engagement, evaluation, exploration, and elaboration phases. Participant 1 stated that she would integrate computer simulations in the engagement and evaluation parts:

> To attract children's attention, it can be in the engagement section, or at the end. I analyze everything and show it again in the children's engagement section. Evaluation at the end, maybe the children will show me at the last part of the lesson. I mean they use it more (Participant 1, Interview 1).

Participant 10 stated that he would use computer simulations in any part besides the evaluation part:

> I think I would do it mostly in exploration or elaboration, but I think it could be in engagement depending on the subject. Actually, except for evaluation, it could be in all four of them. It may also be in evaluation, but right now, a more competent person thinks like this, and finds it appropriate, and I think it may be in the first four steps since we do it like a question in the evaluation (Participant 10, Interview 1).

Having said this, pre-service science teachers have thoughts about using computer simulations in their lessons. They stated that they would integrate it according to the

5E teaching model, and analysis of interviews showed that the participants would use computer simulations in the engagement, evaluation, exploration, and elaboration phases.

4.7.3. Subject

The participants' selections for integrating computer simulations are determined by the answers to the second, third, fourth, and fifth questions in the first interview protocol: "*When you were a student, what subject did you use computer simulations for?*", "*As a teacher, what subject did you use computer simulations for?*", "*What subject did you use PhET simulations for?*" and "*When you become a teacher, what subjects do you use computer simulations for?*".

The participants' answers were analyzed, and it was found that the subjects would select space and solar system, electricity, force, particulate nature of matter, formation of seasons, the transformation of energy, light, adaptation, natural selection, genetics, pressure, chemical and physical changes, mass and weight, systems in our body, energy conservation, and molecule formation.

Participant 1 stated that she would use computer simulations in subjects of solar system, and energy conservation:

> Space issues, that's it, simulations can be used to show the solar system. Other than that, if I have to show something like this right away, I can do an experiment with kinetic energy, an experiment with potential. But if there is no material to show immediately, I can use simulation, for example (Participant 1, Interview 1).

Participant 2 stated that mass and weight, physical and chemical changes, natural selection, and refraction of light can be the subjects that she would use computer simulations:

> It could be in physics about mass and weight, in chemistry there could be physical and chemical changes that I also use, in biology there was something about natural selection that came to mind anyway. There was something else about

> light like this, it's about whether the light absorbs color or not, it's about what it reflects (Participant 2, Interview 1).

Participant 10 stated that he would use computer simulations in more abstract and difficult-to-observe subjects:

> I think I would use it on more abstract subjects and subjects that are difficult to observe. This time last year, a friend of ours used it for the moon's phases, for example, during microteaching. Even we, for example, understood better in this way (Participant 10, Interview 1).

Having said these, the participants mainly stated that they would integrate computer simulations into many science subjects. They stated that they would use computer simulations in chemical and physical changes, space and solar system, energy conservation, and in more abstract and difficult-to-observe subjects.

4.7.4. Reasoning for Using

The third and fourth questions of the first interview protocol aimed to investigate the reasoning for using computer simulations: "*As a teacher, why did you choose this simulation?*" and "*Why did you choose this PhET simulation?*". The reasons behind this were coded under three categories: practical reasons, visualization, and learning.

4.7.4.1. Practical Reasons. The participants stated that they would integrate computer simulations in terms of practical reasons such as being able to do experiments that cannot be done physically, being able to change variables, lack of materials, time-saving, being easy to use, easier to teach, easier to access, suitable for online lessons, simulation is more practical instead of handwork, difficult to observe changes in physical experiments, harming living things, to be able to repeat more, to be able to do long-term experiments in a short time, to be interesting.

Participant 1 stated that she would use computer simulations because some experiments cannot be done in physical environments:

> Because, of course, we can use physical experiments on the subject of energy, but there are also experiments that we cannot do physically. That's why these simulations are very useful for us (Participant 1, Interview 1).

Participant 4 stated that computer simulations allowed students to change variables:

> Firstly, the simulation I used enables students to manipulate the data. That is, by changing the variables, they could obtain different results by changing them. I liked that, so it also provided data interpretations (Participant 4, Interview 1).

Participant 6 stated that computer simulations were easy to use and beneficial in online teaching:

> They are easy to use. And by using simulation, you can actually go through the questions, after that, I can say that it makes the lecture easier. Also, since this is in the online environment, - if the experiment was in a physical environment, we could observe it together, for example, it would be a car, we would push it at different speeds or change the friction of the ground floors, we could have observed it that way - but I saw that the simulation was more effective because it was online and on Zoom (Participant 6, Interview 1).

4.7.4.2. Visualization. All of the participants claimed that computer simulations were beneficial for visualizing the experiment. Their reasons for using computer simulations were embodying abstract concepts such as particles, facilitating learning, making it more memorable, seeing the internal structure of the molecule enable students to visualize it better in their minds, allowing students with visual intelligence to understand better with simulation, being 3-dimensional, having the opportunity to observe the rotational motion of the molecule, having opportunity to observe abstract subjects, different atoms in different ways, to have the chance to observe in various sizes and to have more realistic visuals.

Participant 8 stated that computer simulations enabled students to visualize the experiment more deeply:

> I used computer simulations on the subject of solid pressure. The reason for this is that when we do it with a normal (physical) experiment, it is not possible to see that effect with the naked eye. Because there is a very small change when we actually do the experiment like sinking into the sand. So, when you look at this image, it is very difficult to measure, but when we show this with simulation, this change can be seen more clearly (Participant 8, Interview 1).

Participant 2 stated that computer simulations enabled students to see the internal structure of the molecule:

> In order to understand the difference between physical and chemical changes, the students had to see the change in the internal structure of the molecule. And they can't visualize them in their minds, I chose to use the simulation for better visualization (Participant 2, Interview 1).

Participant 9 stated that computer simulations could provide the opportunity with students to observe abstract subjects:

> Unfortunately, we cannot observe long-term observable subjects such as adaptation. It remains abstract for students. Computer simulations make it concrete. Also, it is sometimes difficult to create an experimental environment (Participant 9, Interview 1).

4.7.4.3. Learning. Three participants stated that computer simulations enhance the learning experience. The reasons they would select computer simulations were to make learning in more theoretical subjects easier, be able to establish cause-effect relationships, and students could experience it on their own. Participant 6 stated as follows:

> You know, they (students) make observations and draw a conclusion from it, that is, they can establish a cause-effect relationship... It provides opportunities, for example, it shows what happens when the temperature rises adding atoms, and this makes learning easier (Participant 6, Interview 1).

Participant 4 stated that computer simulations enhanced the learning process:

> It provided a concrete visualization of molecular subjects that we cannot see with the naked eye or subjects that were actually a little more abstract to explain, such as chemical bonds. I thought that these would speed up and improve the learning process (Participant 4, Interview 1).

Participant 3 stated that computer simulations enabled students to make sense of the subject. She stated:

> It makes a great contribution to the student's understanding of the lesson. In fact, it enables them to discover more by themselves (Participant 3, Interview 1).

In summary, there were various reasons for using computer simulations in the lessons stated by pre-service science teachers. These reasons were categorized as practical reasons, visualization, and learning. The pre-service science teachers explained their reasoning for applying computer simulations.

4.7.5. Strengths

The pre-service science teachers were asked whether they had prior experiences using PhET simulation. The fourth question of the first interview protocol aimed to achieve this: "*Have you ever used PhET simulations before? Could you tell us about your views on using this simulation for teaching purposes? What are their strengths?*". The pre-service science teachers stated that using computer simulation was very beneficial in terms of internalizing the subject, being able to change the variables in the experiment quickly, embodying an abstract subject, being technological, visualizing, having animation in motion, containing supporting elements such as graphics, reaching more students, making it easier to understand, being able to carry out long-term experiments in a short time, performing experiments that were impossible to observe, having no shortage of material, and students could create their definitions. Participant 9 stated that computer simulation enabled students to perform experiments that are impossible to observe:

> Adaptation, for example, presents an event with a very long process, in a short time. I think this is a very important opportunity because it is impossible to observe (Participant 9, Interview 1).

Participant 2 stated that using computer simulation enabled students with changing conditions and variables:

> Its strength was providing students with data from every aspect, graphically, like columns, shapes, and different things, giving data to children. We could choose the world (in the subject of adaptation), we could change the conditions (Participant 2, Interview 1).

Participant 3 stated that using computer simulation had beneficial in terms of reaching more students and lack of material:

> To enable students to explore by experimenting in a very comfortable way. As much as they want, they wonder what happens if I increase the number of batteries, they can do it. So, one more strength is, for example, we can only have two real batteries, and they can build one circuit. But every student can try it on their own screen (while using computer simulation) when in a group. We can reach more students, one-on-one (Participant 3, Interview 1).

After using PhET simulations, the participants answered the eighth of the second interview. This question aims to understand their point of view about the strengths of using the "Build an Atom" simulation: "*What are the advantages of using PhET simulation to generate an atomic model representation?*". When the interview transcriptions were coded and analyzed, the codes emerged from data as being detailed and instructive, showing whether the atom was stable, using a regular and symmetrical representation increased the retention in mind, the opportunity to observe each atom, being compatible with the subject, saving time, being more practical, easy to use, opportunity to try many times are found as strengths of this specific computer simulation.

Participant 6 stated that PhET simulation allowed students to observe each atom and be compatible with the subject:

> There is an opportunity to examine every atom. You know, in the PhET simulation, there is an opportunity to explore the atom more deeply, the chance to examine electrons, protons, and neutrons. This can help students make more relevant connections at lessons. It is more advantageous for them as they have the opportunity to experience it by applying it themselves in accordance with the subject taught in the classroom (Participant 6, Interview 2).

Participant 8 stated that PhET simulation was convenient, and saved time:

> First of all time. It is an abstract thing because it is as if I am describing the contents of something that is not in the air. Something that they cannot observe for themselves, after all. First of all very easy for the time. Very easy to use, PhET simulation, especially this simulation, I think they did something very friendly for the user. Very easily understood. It gives a direct notification when it does everything. It gives you the opportunity to try, frankly, not like delete it and do it again. You put in and take out and you can see the difference. So, I think it will be very useful for the user Participant 8, Interview 2).

Moreover, the ninth question of second interview protocol aimed to understand the strengths of simulation named "Build a Molecule": "What are the advantages of using PhET simulation to build your representation of a molecule model?". The pre-service science teachers stated that showing bonds, not being able to make some molecules by nature, being three-dimensional, creating molecules on their own, being simple, being able to observe the molecule, seeing the geometric shapes of molecules, and having moving visuals were the strengths of the PhET simulation.

Participant 10 stated that the PhET simulation had strengths of being unable to make some molecules and being three-dimensional:

> Since it contains elements, for example, if two things don't bond, you know, the simulation wouldn't allow it. They were pushing each other directly. I throw in oxygen or fluorine in binary form, maybe when he tries another noble gas, he can observe that it is not bonding. Apart from that, for example, the number of atoms is limited there, but again, a molecule with 5-6-7 atoms can be made there very easily and viewed in 3D (Participant 10, Interview 2).

Participant 2 stated that observing molecules in three-dimensional enabled students to visualize the image, and having motion in simulation was very beneficial for

students:

> There was also a 3D representation there. That's why I think that it can actually be more beneficial for students to visualize. The 3D representation. At the same time, since the drawing is only 2 dimensional, they can only see it as a fixed thing. But in fact, when atoms combine, they move. It's good to see that actually (Participant 2, Interview 2).

In summary, the participants were familiar with PhET simulations before the workshop and had thoughts about computer simulations' strengths. They stated that it saved time and enabled them to perform experiments. Their ideas about the strengths of a computer simulation, after using the computer simulations named "Build an Atom" and "Build a Molecule", were similar to their prior views. The codes emerged from data were similar for categories: Strengths and Reasoning for Using. There was a causal relationship between these categories, since strengths were the reasons for using computer simulations according to the participants. Moreover, they also criticized the simulations and found simulation-specific strengths.

4.7.6. Weaknesses

The pre-service science teachers were asked about their prior experiences using PhET simulation in terms of the limitations of the simulations. The fourth question of the first interview protocol aimed to achieve this: "*Have you ever used PhET simulations before? Could you tell us about your views on using this simulation for teaching purposes? What are their weaknesses?*". The pre-service science teachers stated that computer simulations' weaknesses were distracting, taking a long time, having an artificial appearance, creating confusion, being unable to get out of the fiction, being two-dimensional, getting different results when misused, and having a limited number of molecules.

Participant 3 stated that computer simulations had a fixed fiction that was not allowing the user to get over:

> The weakness may be that there is a fiction constructed there and we cannot go beyond it., Let's say that there is no possibility that cable is cut in the PhET, if it were a normal circuit in the classroom if it was a three-dimensional thing, I could cut it and show it to the students like I can't cut it in simulation, I can't show it (Participant 3, Interview 1).

Participant 5 stated that computer simulations were in two-dimensional, and it could create misconceptions:

> Weaknesses are still on a 2D screen, we are trying to understand something about the 3D world at simulation. It can be a little troublesome because the water container that comes to mind in the student's mind may be different from the water container in my mind. Maybe he's dreaming of something huge. Perhaps because he was imagining that vast thing, it does not apply to this topic, but there may be something wrong with other issues, and misconceptions can occur in his head. Because there is nothing real there, the animation stuff. There are no photos from the real world. So, they may have a little question mark in their minds (Participant 5, Interview 1).

After using the "Build an Atom" simulation, the participants were asked about the simulation-specific weaknesses in the eighth question of the second interview protocol: "*What are the limitations of using PhET simulation to generate an atomic model representation?*". The weaknesses after analyzing the interview transcripts were found as not knowing some concepts beforehand, having a two-dimensional image, not being able to observe higher atomic models, not being able to form some atoms, having a certain number of electrons, protons, neutrons, not being able to see both orbitals and electron cloud at the same time, might cause certain judgments to be formed, affect the imagination, not being able to see the s, p, q orbitals.

Participant 4 stated that a weakness of the simulation had a two-dimensional image:

> I compare it with the second simulation. We were able to move when we clicked on 3d in the second simulation. We were able to move it around 360 degrees. In fact, if we could do this on the PhET, if we could do it in the simulation of creating an atomic model, it would give the impression that it is more 3-dimensional (Participant 4, Interview 2).

Participant 2 stated that the simulation affected her imagination:

> Maybe, how can I say, when we read an image or a written text, we picture it in our minds, and this may be something that depends on our imagination. But after seeing the image of something, it becomes stereotyped in it, so that image remains in my mind. You cannot go beyond that limit yourself. It affected my imagination (Participant 2, Interview 2).

Moreover, the ninth question of second interview protocol aimed to understand the weaknesses of simulation named "*Build a Molecule*". The interviewees' answers revealed that not showing that bonds were based on electrons, not being able to observe subatomic particles, not being able to see real images, not being able to observe other atomic models, showing atoms in certain colors may cause misconception, and having a limited number of atoms were the weaknesses of the simulation.

Participant 8 stated that being unable to see real images was a weakness of the simulation:

> Like it should have been this way, there are so many things in nature, you know. Nothing actually progresses the way we do. It is just one model. It describes this model really well. But I think it would be better to add one more option and show the differences between reality and model because it's really a very strict thing. It really looks like plastic. I don't think it gives the feeling of an atom like this (Participant 8, Interview 2).

Participant 4 stated that the simulation did not show that the bonding process depended on electron sharing:

> Since we learned that this (bonding) depends on electrons, I think it may be insufficient at this point (Participant 4, Interview 2).

In summary, the participants explained the weaknesses of using computer simulation in general. They claimed that computer simulations' weaknesses were distracting, taking a long time, having an artificial appearance, creating confusion, being unable to get out of the fiction, being two-dimensional, getting different results when misused, and having a limited number of molecules. After using "Build an atom" and "Build a

Molecule" simulations, they found weaknesses of these simulations as affecting imagination, having two-dimensional images, being unable to see real images, and being unable to see subatomic particles.

4.8. Virtual Reality

The virtual reality application is investigated regarding the third research question: "*What are the experiences of pre-service science teachers using virtual reality applications?*". The data collected through interviews with the pre-service science teachers revealed six categories: (1) experience, (2) method of application in a lesson, (3) subject, (4) reasoning for using, (5) strengths and (6) weaknesses.

4.8.1. Experience

Before using the virtual reality application, the participants were asked about their prior experiences. The first question of the third interview protocol was prepared to achieve this aim: "*First of all, can you talk about your experiences with virtual reality in general? Have you ever used a virtual reality application in an extracurricular subject?*". Five participants had experiences in virtual reality applications, and these experiences were in contexts of extracurricular activities. Participant 5 explained his experiences in using virtual reality applications and stated as follows:

> We are talking about VR glasses. I had the opportunity to use it for about 10 hours. I used it for gaming purposes only. It was an extracurricular subject. I played games with VR on PlayStation. I played various games. First of all, I think it's pretty fun. I've never played a game like that before. Apart from that, it gives hope at such a point because the games I play for VR at the moment are not such creative games. But when I was in the VR, I was getting the feeling that other things could be done with this VR. These games are the first of their kind, and I was thinking that probably very good things would come out. Other than that, my feelings, that is, I was having fun as if I were playing a game and it was active. That was nice. Also, I was a little dizzy while using it. Seems a little nauseous. I was resting for a while, I was taking it out of my eyes, out of my head. I was resting a little. Then I continued again (Participant 5, Interview 1).

After using the virtual reality application, pre-service science teachers were asked to explain their experiences by the first question of the fourth interview protocol: "*Can you explain step by step what you did in the virtual reality application? Which atomic model, the molecular model did you create*?". Participant 2 explained her experiences with the virtual reality application and stated as follows:

> First, I opened the periodic table. From there I selected the hydrogen atom and held it in midair by long clicking it where my index finger was. I did the same with the oxygen atom. Later, when we create molecules, we first choose the bond, single, double, or triple. Whichever of them we need. It was the only tie we needed. That's why I chose that single bond. After choosing that single bond, there were two gaps. I put the fluorine atom in the two spaces, I placed it like that. But we also made a double bond, now I remember. I made the double bond with the oxygen atom (Participant 2, Interview 4).

Participant 7 explained her experiences with the virtual reality application and stated as follows:

> First there was a table on my left arm. From there, we could switch to the periodic table or select a few of the basic atoms. When I chose and placed one of the atoms, for example, I took the oxygen atom first and placed the oxygen atom in the space. I then placed a random hydrogen atom at work. I didn't see many things, but I couldn't see the link in detail because it was small. Then, to make the carbon molecule, first the triple bond was taken and then two representative atom models were formed on both sides of that triple bond. Then, when I take the carbon atom and put it on those representative atoms, a triple bonded c2 model is formed in my hand (Participant 7, Interview 4).

In summary, the participants stated that they had experience using virtual reality in extracurricular activities. After using the virtual reality application, they explained their experiences with the virtual reality application specifically.

4.8.2. Method of Application in a Lesson

The fourth question of the third interview protocol aimed to understand their experience with the method of virtual reality application in a lesson: "*Do you plan to use virtual reality application in your lessons when you become a teacher? How do*

you use it? Can you describe your application method?". The participants' answers revealed that they planned to use it according to the 5E teaching method. They stated that they would use virtual reality applications in the exploration and elaboration phases of the lesson. Participant 3 stated that she would use virtual reality in the exploration part:

> I can use it in the exploration part of the lesson. And students adapt to the subject by seeing it themselves rather than telling me directly in the lesson. They discover themselves (Participant 3, Interview 3).

Participant 10 stated that virtual reality applications could be adapted near the end of the lesson due to their complexity. But also, he stated that if the class was used to the technology that the teacher applied, then in any stage of the lesson is appropriate for virtual reality applications:

> Let's say I use virtual VR glasses while teaching the subject directly, it seems like it would seem like a game for students and create a disconnection from the subject. I thought it was as if their minds were always there when I then took them out and tried to clear things up. I thought I would use it at the end of the topic or deepen the subject a little more towards the end. I thought if you're not used to virtual reality - but if they got used to it, you know, after we're done with the glasses, we'll go back to the lesson and talk about what we saw -. If they understand this routine, I think it can be at any stage. If they are used to that routine when using virtual reality or other technology, we will do this now and then we will do it. If there is no problem in classroom management in that flow, I think it can be used at every stage. For example, as the first introduction to the lesson, I put the board on our board, then the lesson will actually be very interesting. As I said, if the class is used to it, I think it can be used in any situation (Participant 10, Interview 3).

In summary, all pre-service science teachers explained their application method of virtual reality in a lesson according to the 5E teaching method. The participants said they would integrate virtual reality applications in the exploration or elaboration part.

4.8.3. Subject

The participants' selection of subjects to be applied virtual reality applications in their lessons was investigated with the fourth question of the third interview protocol: "*When you become a teacher, what subject would you use virtual reality applications for?*". The answers to the question revealed that pre-service science teachers selected the subjects of animals, planets, pressure, virtual labs, adaptation, atom, electricity, systems in the human body, matter and heat, cells, and phases of the moon.

Participant 3 stated that she would use virtual reality applications in most of the science subjects:

> I use it to show atom models. Maybe they can see these simulations in a more 3D way. In systems in our body, I would use. Then maybe I can use it to observe climatic events such as high pressure and low pressure. It could be about matter and heat. So, it's actually applicable to most science subjects (Participant 3, Interview 3).

Participant 10 said that he would use virtual reality applications in subjects of atoms, cells, systems in the human body, and moon phases.

> It could be something like an atom or a cell, or for example, there are videos, more like animation, such as digestion, excretion, or circulation. For example, it could start from the mouth or from the blood, from the lungs, and from there to the body. Maybe it would be interesting to observe this in 3D, maybe more for the body. It seems to be very two-dimensional in the model. For example, even the cell remains like a single circle until very late, whereas it is very spherical. You know, if you need something like that in the transition to the 3D part. For example, it would be very nice in space stuff. I think it would be nice for things like moon phases or moon and solar eclipses (Participant 10, Interview 3).

Participant 6 stated that she would use VR applications in subject of adaptation:

> It might be for the adaptation issue, but I don't know. If I think I put them (students) into such an environment in a VR glasses. If I put a different species in a forest environment, maybe they can observe how they develop or evolve (Participant 6, Interview 3).

In summary, the participants stated that they would use virtual reality applications when they become a teacher. They gave examples of the subjects they thought integration of virtual reality applications is suitable for. The subjects are revealed by their answers as animals, planets, pressure, virtual labs, adaptation, atom, electricity, systems in human body, matter and heat, cell, and phases of the moon.

4.8.4. Reasoning for Using

The fourth question of the third interview protocol aimed to investigate the reasoning for using virtual reality applications: "*As a teacher, why did you choose virtual reality for these subjects?*". The reasons behind this are investigated under two categories: practical reasons and visualization.

4.8.4.1. Practical Reasons. The participants stated that they would integrate virtual reality applications in terms of practical reasons, such as to be able to observe situations that cannot be observed in nature and to be able to protect themselves by staying away from chemical substances. Participant 4 stated that she would use virtual reality applications in order to protect students from hazardous chemicals and showed different habitats of nature and the results of an experiment easily:

> In biology, there is no such thing as a complete nature around us, or it can be difficult to bring it to students, even if we do, they may not be able to observe it. The odds of observing a living thing are getting smaller and smaller. In this respect, although it (virtual reality) creates an artificial environment for them, it actually takes them to an environment where they can increase their possibilities and make the observations they want. For physics, maybe if I do it in class, they won't be able to see its effect clearly, or I won't be able to create something that will show that effect clearly with the materials I have. But there, they can clearly see this effect. They can do this; they can play with the variables as they want. For chemistry, it is something that reduces the danger at some point for me. As I said, stay away from chemicals which can be very difficult to control in the classroom environment. They (students) really get hurt even if they try what they want, and what they are doing is actually dangerous, and it is dangerous when they physically do it (Participant 4, Interview 3).

Participant 2 stated that students could observe extinct animals by using virtual reality applications:

> Because actually, for example, the dinosaur that comes to my mind, students, how to say, about science, students can learn to classify by observing animals, they can learn to observe. At the same time, I think that it may be different for them because they cannot live through those ages, you know, because we all cannot (dinosaurs are extinct) (Participant 4, Interview 3).

4.8.4.2. Visualization. The participants claimed that virtual reality applications were beneficial for visualizing the experiment. They said they would use virtual reality applications because it concretized abstract concepts such as particles and visualizing them increased memorability. Participant 8 stated that virtual reality applications increased memorability:

> Because we see the current results of many things, but we only see the result, we have no idea why or how it occurs. Even if we learn, they are not permanent. Because it's not what we see in everyday life. Or, as I said, if we see those similarities that take a long time to form, but the things that we can see the results of while they are forming, for example, can enable us to form a healthier or less forgettable perspective. Because virtual reality can make people feel as if they live inside of the experiment. I think this might be useful (Participant 8, Interview 3).

Participant 9 stated that she would integrate virtual reality applications because it concretized the abstract concepts:

> Because it (atoms) is more abstract than other topics, such as force, motion, or electricity. And it becomes very difficult for students to understand something abstract. When I look at my own student experience, I think it will be helpful because it makes it more concrete (Participant 9, Interview 3).

In summary, there were various reasons for using virtual reality applications in the lessons stated by pre-service science teachers. These reasons were categorized as practical reasons and visualization. The pre-service science teachers explained their reasoning for applying virtual reality applications. These reasons were concretizing an abstract concept, increasing memorability, observing situations that cannot be observed

in nature, and protecting themselves by staying away from chemical substances.

4.8.5. Strengths

The third question of the third interview protocol aimed to understand the participants' general idea about virtual reality: "*What do you think about virtual reality applications in general?*". After analyzing the answers, strengths of the virtual reality are found as a category of virtual reality theme. The participants stated that virtual reality was fun, attracted students' attention, eliminated the dangers that might arise from chemicals, could help to eliminate impossibilities, made it easier to understand the subject, integrating technology into the lesson was nice, embodying an abstract subject.

Participant 6 stated that virtual reality could help eliminate impossibilities:

> I hope it will lead to even better things as its use develops in the future. especially in the field of education. Distance education, education to unreachable villages, and opportunities to meet with students. It can be a tool to break the impossibilities (Participant 6, Interview 3).

Participant 4 stated that virtual reality eliminated the dangers that might arise from chemicals:

> Yes, using certain materials is dangerous. There are explosion risks or such things can happen, but this can also be used for a virtual laboratory since nothing will happen in a virtual environment (Participant 4, Interview 3).

After using the virtual reality named Nanome, the participants were asked about the strengths of the virtual reality application. The fourth question of the fourth interview aimed to understand the strengths of the virtual reality application for building an atom: "*What are the advantages of using virtual reality applications to create an atomic model representation?*". Analysis of the interview transcriptions showed that there were strengths of the Nanome virtual reality application, these were being able to see the size of atoms in VR, being able to see unobservable atoms, having unlimited

atomic options, self-experimentation was more interesting, makes information more permanent, being three-dimensional, embodying an abstract subject.

Participant 10 stated that the strength of the virtual reality application was being three-dimensional:

> I remember that observing the atom with a microscope either gives a very blurry image or does not exist at all. That's why observing in 3D is better than a 2D picture like this, at least it's not round, it's a sphere or something. It is good to understand (Participant 10, Interview 4).

Participant 3 stated that virtual reality made information more permanent:

> It feels like you are in that environment and as if these are not too abstract. That is, we can make an abstract subject more concrete and experience it in front of us. It's hard for them (students) to actually model these barely visible atoms, (but in virtual reality) we walk around them, touch them, etc. Students can likewise explore it. And you know, it takes a more correct place in their minds (Participant 3, Interview 4).

Moreover, the sixth interview question of fourth interview protocol asked about the advantages of the virtual reality application for building a molecule: "*What are the advantages of using virtual reality applications to create a molecular model representation?*". The participants stated that the strengths of using virtual reality for building a molecule were that it was catchier because students could touch the molecule, create molecules by choosing bonds, not allowing each bond to form, being 3 dimensional, able to enlarge or shrink, and warning systems when a wrong step is taken.

Participant 3 stated that creating molecules by choosing bonds, warning systems when a wrong step is taken, and making molecules more concrete were the strengths of the virtual reality application while building a molecule. She stated as follows:

> I can see whether or not any of the atoms I choose can actually bond between them, as a result of my choices, whether those bonds match or not. So, it is more permanent when I make a mistake. Because I chose it myself and I get instant feedback. Just in case this doesn't happen, I try something different from

> practice or learn through this testing. This is an advantage. At the same time, enlarging or shrinking it (molecule) as I want makes it more concrete in study (Participant 3, Interview 4).

Participant 2 stated that creating molecules by choosing bonds was a strength of the virtual reality application. She stated as follows:

> We have to take into account the bond formed between those atoms. This may be overlooked while drawing. But simulation does allow this, that is, virtual reality does not allow it, so first we need to consider how many bonds the atom makes (Participant 3, Interview 4).

In summary, there were strengths of virtual reality according to the pre-service science teachers. These strengths are fun, attracting students' attention, eliminating the dangers that may arise from chemicals, helping to eliminate impossibilities, making it easier to understand the subject, integrating technology into the lesson is nice, and embodying an abstract subject. And after using the virtual reality named Nanome, they stated that it made such an abstract subject concrete because it was three-dimensional. Strengths and Reasons for Using were the two categories where comparable codes emerged from the data. Since the participants cited strengths as the main reasons they used VR applications, there was a causal relationship between these categories.

4.8.6. Weaknesses

The participants also found weaknesses in virtual reality in general. The third question of the third interview revealed that the pre-service science teachers claimed that there were some weaknesses: "*What do you think about virtual reality applications in general?*". The participants who used virtual reality before claimed that virtual reality could be difficult to use in class, and excessive use might cause dizziness. Participant 10 stated that virtual reality could cause dizziness:

> I'm just thinking about the thing, it's like I'm talking about VR glasses, but it seems like long-term use makes the eyes a little tiring. You know, wearing

> those glasses for a few hours and meeting or working was a bit too tiring for me (Participant 5, Interview 3).

Participant 7 stated that it could be difficult to integrate virtual reality into the lessons:

> I guess virtual reality applications do not take more than 10 people, I guess we couldn't do it as a group. It is something that can be done individually. So, let's say there are 20 people in the class, I will put on virtual reality glasses with 20 students individually. It'll be like I'm going to teach 20 different lessons. I don't think I can do it (Participant 7, Interview 3).

After using virtual reality, the participants were asked about the weaknesses of the application for building an atom. The fifth question of the fourth interview protocol aimed to understand these weaknesses: "*What are the limitations of using virtual reality applications to create an atomic model representation?*". The participants stated that being unable to see subatomic particles, not being able to see the movement of atoms, and not being based on any atomic model are the weaknesses of the virtual reality application in terms of building an atom.

Participant 7 stated that the virtual reality application was not based on any atomic model and was not showing subatomic particles:

> When I looked from the bottom and the side, I couldn't see anything, so there is only one ball. It doesn't even show inside. At least if we zoomed in, maybe we could see inside such a design could be made. But there was no mention of subatomic particles, nor was it any different. They just put a prism-like look like this inside it. I've never seen a real atom, I don't know how it looks, but there are certain models that scientists have reached after all. And I think he could have been close to them at least... For example, you can't do anything using it because the person who did it didn't pay attention to it. I can't use it. It doesn't make sense because, if the details I mentioned are added, such as subatomic particles, then it can turn into something very useful and more productive. Because the idea is very nice, you know, a world that you can really touch and adjust and see in three dimensions, it gives you an opportunity. But it also takes away this opportunity because it wasn't designed that way (Participant 7, Interview 4).

Participant 6 stated that being unable to see the movement of atoms was a weakness of the virtual reality application:

> Maybe their (atoms) movements could be observed. You know, because atoms are moving. You know, it's vibrating, making a translational motion, which would be better if it could be observed. This also felt like a limitation. Because when we learn, we learn all its features. Observing all of its features would also be an option, maybe. I think the observation could have been better (in this way) (Participant 6, Interview 4).

The participants were asked about the weaknesses of the virtual reality application for building molecules. The seventh question of the fourth interview protocol aimed to understand the weaknesses of the virtual reality application in terms of molecule representation as previous interview. Analysis of the answers revealed that not being able to see electron sharing and not being able to see subatomic particles were the weaknesses of the virtual reality application.

Participant 4 stated that being unable to see subatomic particles was a weakness of the virtual reality application:

> I was thinking that I couldn't actually represent the electron in my own drawing. And I might want to represent it in virtual reality and to be able to see that electrons form these bonds. I think that's been the limit of virtual reality. Because it actually does everything not externally, but also by the particles inside the atom. Since I can't see this again in virtual reality, I think this is a limit (Participant 4, Interview 4).

Participant 1 stated that being unable to see electron sharing was a weakness of the virtual reality application:

> In the formation of two molecules, for example, if it is a covalent bond, they share their electron. It would be nice to see it. It wasn't shown there, only the connection was visible (Participant 1, Interview 4).

In summary, the participants stated that there were weaknesses in virtual reality applications. The participants who have prior experience with virtual reality claimed

that it can cause dizziness and it could be difficult to apply in the classroom. After using the virtual reality application named Nanome, they found some weaknesses such as being unable to see subatomic particles, not being able to see the movement of atoms, not being based on any atomic model, and being unable to see the movement of atoms.

4.9. Representational Competence

Representational competence was investigated through the first research question: "*What are the combined effects of using computer simulations and virtual reality applications on pre-service science teachers' representational competence skills?*". The data collected through Pre-Test 1, Post-Test 1, Pre-Test 2, Post-Test 2, and interviews with the pre-service science teachers revealed two categories: (1) Comparison of Representation of Computer Simulations and Virtual Reality; (2) Effects of Simulation and Virtual Reality.

4.9.1. Comparison of Representation of Computer Simulations and Virtual Reality

The participants were asked to compare the computer simulations and the virtual reality application. The comparison of the two technological tools (computer simulations and virtual reality application) was investigated to answer the first research question: "*What are the combined effects of using computer simulations and virtual reality applications on pre-service science teachers' representational competence skills?*". The participants evaluated the PhET simulation and Nanome application in terms of the concepts of atoms and molecules. The fourth question of the fourth interview protocol aimed to investigate this comparison: "*How do you compare the PhET simulation with the virtual reality application? What are the similarities? What are the differences?*".

The participants stated the differences and similarities in terms of the representation of an atom. All the participants stated that computer simulation was better

than virtual reality application because subatomic particles could be seen. Since it was important to learn about subatomic particles, computer simulation was more effective than virtual reality application. However, the participant stated that atoms were not in 3D in the computer simulation.

Participant 3 stated the similarities and differences between the computer simulation and the virtual reality application as follows:

> There was a periodic table in the PhET simulation. I remember there was a painting (the periodic table); we could choose what we wanted from there. But as a difference, we could not see in 3D (in PhET simulation). We couldn't get around it, so it didn't feel like an atom or molecule was directly in front of us, next to us. Couldn't get off the screen. I wanted to enlarge or shrink and walk around it (the atom). The similarities are that the atom is basically composed of a sphere, and they can form bonds between them, single, double bonds, etc. They were also involved in the simulation and in the workshop (in virtual reality). By the way, another difference is that in the first PhET simulation, these subatomic particles were also present, but not in this workshop (in virtual reality) (Participant 3, Interview 4).

All the participants stated that the virtual reality application and the computer simulation were parallel in terms of the representation of a molecule.

However, the differences as codes emerged from interviews as being able to see complex molecules in virtual reality, observing molecules is more realistic in VR, being able to control atoms in VR. Participant 6 stated the similarities and differences between the computer simulation and the virtual reality application as follows:

> In the PhET simulation, I could also observe the bonds forming molecules. In VR, I could observe without forming a bond, two atoms standing side by side. I could observe it as a molecule formed in the simulation. But I could observe the bond and the atom in the virtual reality application. I was able to observe in 3D again in both. But in VR applications, of course, it becomes more realistic. You can take it all over me like it's all around me (Participant 6, Interview 4).

In summary, the participants compared the computer simulations and the virtual reality application. The participants evaluated the PhET simulation and Nanome

application in terms of the concepts of atoms and molecules. Findings show that PhET simulation is more effective in representing an atom than Nanome virtual reality application. However, the participants found PhET simulation and Nanome virtual reality application were similar in terms of the concept of molecule.

4.9.2. Effects of Simulation and Virtual Reality on Representational Competence Skills

The effects of computer simulation and virtual reality application on representational competence skills were investigated regarding the first research question: "*What are the combined effects of using computer simulations and virtual reality applications on pre-service science teachers' representational competence skills?*". Data gathered from Pre and Post-Tests and interviews revealed that the pre-service science teachers showed the first level of representational competence skills. However, the number of participants who improved representational competence skills changed during the study. The levels of representational competence skills are adapted from (Kozma and Russell, 2005).

Table 4.8. Participants and their representational competence level by each instruments.

Participant #	PRE-TEST 1	POST-TEST1	Δ (PreTest 1-PostTest 1)	PRE-TEST 2	POST-TEST 2	Δ (PreTest 2-PostTest 2)
1	1	3	2	3	3	0
2	1	4	3	4	5	1
3	1	3	2	3	3	0
4	1	3	2	3	3	0
5	1	4	3	4	4	0
6	1	4	3	4	4	0
7	1	3	2	3	5	2
8	1	3	2	3	3	0
9	1	3	2	3	3	0
10	1	1	0	1	2	1

Table 4.8 shows each participant number and their representational competence level for Pre-Tests, Post-Tests and Interviews. All participants showed first level of representational competence skills at Pre-Test 1 and Interview 1. Six participants showed

third level of representational competence skills at Post-Test 1 and Interview 2, after completion of workshop of the computer simulation. Whereas three participants improved their representational competence skills to fourth level; however, Participant 10 remained in first level as can be seen in Table 4.8 at Post-Test 1 and Interview 2. Change of levels between Pre-Test 1 and Post-Test 1 for each participant was showed in fourth column of Table 4.8. Six participants improved their representational competence two levels, whereas three participants three levels. However, there was no change for Participant 10 as can be seen in Table 4.8. The levels were not changed at Pre-Test 2 and Interview 3. After completion of the session of the virtual reality application, five participants showed third level of representational competence skills, two participants reached fourth level of representational competence skills, and two participants also improved representational skills to fifth level competence. Moreover, Participant 10, improved the representational competence skills to second level competence as can be seen in Table 4.8. The last column of the Table 4.8. showed the change of levels between Pre-Test 2 and Post-Test 2 for each participant. Two participants improved representational competence one level, whereas one participant two levels.

As (Kozma and Russell, 2005) defined these competences as sequential levels, higher levels of representational competence skills included lower levels. For instance, if one participant showed fifth level of representational competence skills, the participant had the skills of lower levels of representational competence meaning fourth, third, second, and first levels.

Table 4.9. Representational competence skills levels and the number of participants.

NUMBER OF PARTICIPANTS				
LEVELS	**PRE-TEST 1+ IINTERVIEW 1**	**POST-TEST 1 + INTERVIEW 2**	**PRE-TEST 2 + INTERVIEW 3**	**POST-TEST 2 + INTERVIEW 4**
The ability to identify and analyze features of a particular representation and patterns of features and use them as evidence to support claims or to explain, draw inferences, and make predictions about relationships among chemical phenomena or concepts.	10	10	10	10
The ability to transform one representation into another, to map features of one onto those of another, and to explain the relationship.	0	9	9	10
The ability to generate or select an appropriate representation or set of representations to explain or warrant claims about relationships among chemical phenomena or concepts.	0	9	9	9
The ability to explain why a particular representation or set of representations is more appropriate for a particular purpose than alternative representations.	0	3	3	4
The ability to describe how different representations might say the same thing in different ways and how one representation might say something that cannot be said with another.	0	0	0	2
The ability to take the epistemological position that representations correspond to but are distinct from the phenomena that are observed.	0	0	0	0
The ability to use representations and their features in social situations as evidence to support claims, draw inferences, and make predictions about observable chemical phenomena.	0	0	0	0

Table 4.9 shows the representational competence skills levels and the number of participants in terms of their representation of the atoms. It can be seen that all

participants in each Pre-Tests, Post-Tests, and Interviews showed the first level of representational competence skills: "*The ability to identify and analyze features of a particular representation and patterns of features and use them as evidence to support claims or to explain, draw inferences, and make predictions about relationships among chemical phenomena or concepts*". However, no participant showed more than the first level of representational competence skills.

The third question of the second interview protocol aimed to understand the effects of the computer simulation on representation of atoms and molecules: "*Did the PhET simulation give you an idea when building your atom and molecule model a second time? How?*".

Participant 7 stated that computer simulation gave her the idea that atom representations can be changed according to the level of the students:

> (Computer simulation) gave a little (idea) so I might need to draw more detail or simpler, depending on the thing, the situation, the level (of the student), or what we're going to do in the lesson. I realized that, depending on what I wanted to tell the student, I could use either the first atomic model or the more modern atomic model. I can do both (Participant 7, Interview 2).

Participant 2 stated that computer simulation affected her representation of the given atom:

> (Computer simulation) Definitely gave (an idea). For example, before doing the simulation, I would think of drawing protons and electrons again, but this time I could forget about the neutron. So, we should not forget the neutron in this respect. It also showed that the nucleus would be in an unstable state. So, I drew both the neutron and the proton in the nucleus (Participant 2, Interview 2).

However, Participant 10 stated that change in representation did not occur immediately:

> It's very, very, very, you know, it's as if a change in thought doesn't happen just because of such a blast. I mean, it seemed to me that it would be better if what

> was a little more similar (with the drawings of Pre-Test 1). Sounds like: "*Oh, we saw this here (in the computer simulation), let me draw what I see, this time, it is like this*". It felt like a very forced change. That's why I stayed like this (the same representation). You know, because I thought about the thing when I was explaining a molecule to a student, I thought as if I had to draw something like this again. That's why I thought I'd stick with it since it's still the first thing that comes to mind in my mind (Participant 10, Interview 2).

After using the PhET simulation named "Build an Atom", nine participants demonstrated second and third representational competence skills levels: "*The ability to transform one representation into another, to map features of one onto those of another, and to explain the relationship*" and "*The ability to generate or select an appropriate representation or set of representations to explain or warrant claims about relationships among chemical phenomena or concepts*".

Three participants showed the fourth level of the representational competence skills in Post-Test 1: "*The ability to explain why a particular representation or set of representations is more appropriate for a particular purpose than alternative representations*", as can be seen in Table 4.9. In addition, similar variables are revealed in Pre-Test 2.

The ninth question of the fourth interview protocol aimed to understand the effects of the virtual reality application on the representation of atoms and molecules: "*Did the virtual reality application give you an idea while creating your atomic model once again? How?*".

Participant 3 stated that the virtual reality application helped her to overcome the boundaries of representing an atom:

> Yes, it (the virtual reality application) gave an idea. I drew a circle similar to this before and before the previous PhET simulation. But I didn't focus on making it bigger or smaller, for example, I just thought it would all be the same size. These drawings are actually my reviews. When I enlarge them in my mind, I can enlarge them in this drawing. I got over it here (in the workshop). Because we were removing these limits in the workshop, I could zoom in and out as much as I wanted. Our investigation knew no bounds (Participant 3, Interview 4).

Participant 6 stated that after using the virtual reality application, she needed to represent the given atom in a clearer way:

> It may be in terms of showing a feature, you know, it has two electrons, it will want to bond, it wanders like this, it is found like this. I guess I felt the need to show it or well, I just drew a circle, when I look at it from every angle, yes, I felt like I needed to add another feature to it. But of course, I had shown more before (in Pre-Test 2). It suddenly came into being, came alive, for a moment it felt as if it were unnecessary redundancy. That's why I made a simpler, more understandable drawing. The simulation was simpler or the simplistic image in the simulation was just as plain to my mind. I can say so. I mean simulation in virtual reality all the time. The last time we did virtual reality, it was a plainer image. That's why it came to life in my head as plain (Participant 6, Interview 4).

Participant 4 stated that the virtual reality application did not affect her representation:

> Frankly, it didn't give (idea) much. Because what I saw there (in the virtual reality application) was a sphere. And after the simulation (computer simulation, PhET), I said: yes, that's right, actually they have subatomic particles, there is no shell outside of it, it (the atom) wasn't just a sphere. It (computer simulation) gave such information. Therefore, I can say that virtual reality did not affect my thinking again (Participant 4, Interview 4).

After using the virtual reality application named "Nanome", findings showed that all participants reached the second level of representational competence skills. Nine participants showed the third level of representational skills. But four participants demonstrated the fourth level of representational competence skills, different from Pre-Test 2, as can be seen in Table 4.9. Moreover, two participants reached fifth level of representational competence skills: "*The ability to describe how different representations might say the same thing in different ways and how one representation might say something that cannot be said with another*".

In summary, the participants were found to have the first level of representational competence skills before the study. According to their description of the representation of the atoms and interview answers PhET simulation named "*Build an Atom*" and the

virtual reality application named "*Nanome*" could improve representational competence skills. However, some participants also stated that the computer simulation or the virtual reality application did not affect their representational competence.

5. DISCUSSION

The purpose of this study was to explore the combined effects of computer simulations and virtual reality applications on pre-service science teachers' representational competence skills. Data were collected through a qualitative research approach with pre-tests, post-tests, and interviews with ten pre-service science teachers. Themes were determined with emergent codes from data analysis. The implications for the study's findings and conclusion will be explored. Limitations and suggestions for additional study and application will be given.

5.1. Discussion and Implications

In this part, the study findings will be discussed under four headings: (1) effects of computer simulations on representational competence skills, (2) combined effects of computer simulations and virtual reality applications on representational competence skills, (3) experiences in using computer simulations, (4) experiences in using virtual reality applications.

5.1.1. Effects of Computer Simulations on Representational Competence Skills

This study utilized the list of representational competence skills, which (Kozma and Russell, 2005) stated as follows:

> The ability to use representations to describe observable chemical phenomena in terms of underlying molecular entities and processes. The ability to generate or select a representation and explain why it is appropriate for a particular purpose.
>
> The ability to use words to identify and analyze features of a particular representation (such as a peak on a coordinate graph) and patterns of features (such as the behavior of molecules in an animation).
>
> The ability to describe how different representations might say the same thing in different ways and explain how one representation might say something different or something that cannot be said with another.
>
> The ability to make connections across different representations, to map fea-

> tures of one type of representation onto those of another (such as mapping a peak of a graph onto a structural diagram), and to explain the relationship between them.
>
> The ability to take the epistemological position that representations correspond to but are distinct from the phenomena that are observed.
>
> The ability to use representations and their features in social situations as evidence to support claims, draw inferences, and make predictions about observable chemical phenomena.

This study found that pre-service science teachers' representational competence skills were improved by using computer simulations like "Build an Atom" and "Build a Molecule" as can be seen in Table 4.9. All of the participants demonstrated first-level representational competence skills before the computer simulation treatment according to Pre-Test 1, identifying and analyzing features of a particular representation. Nine participants reached second-level skills which is transforming one representation into another and explaining the relationship in Post-Test 1 which was applied after the PhET simulation treatment. Moreover, nine participants reached third-level skills which is generating or selecting an appropriate representation or set of representations to explain or warrant claims about relationships among chemical phenomena or concepts. At the same time, three participants reached fourth-level skills explaining why a particular representation or set of representations is more appropriate for a particular purpose than alternative representations.

Due to the strong relationship between science and technology, various methods have been used to implement technology to improve students' representational competence skills (McCollum *et al.*, 2014; Patwardhan and Murthy, 2017; Stieff and DeSutter, 2021; Stieff, 2011). One of the major technological tools that had been used were computer simulations in science education.

The results of study of (Stieff, 2011) support the findings of this study: students who completed the Connected Chemistry (a kind of computer simulation) course successfully outperformed their peers in terms of accomplishment and frequency of use of submicroscopic chemical representations that showed dynamism. Additionally, it was discovered that the responses of the students were of a high enough standard to show

that the technology-infused curriculum can raise secondary students' levels of success and representational competence in chemistry.

Moreover, the results of the study by (Patwardhan and Murthy, 2017) revealed that the group which involved second-year engineering students who worked with Interactive Simulation with Reciprocative Dynamic Linking (SIM-RDL) outperformed the group who worked with the Simulation (SIM) in Representational Competence assessment test scores in electrical engineering course. They aimed to evaluate the impact of reciprocatively dynamic linking on students' growth in representational competency. Reciprocative Dynamic Linking refers to additional interaction in numerous external representations that are dynamically linked to assist learners' cognitive demands. Learning about the semantics of each representation, the portions of the represented domain, how learners link representations to one another, and how they translate between representations were all considered when evaluating the development of representational competence. The results of this study also supported that computer simulations had a positive impact on the representational competence skills of the students.

On the other hand, (Stieff and DeSutter, 2021) found that the performance of students who participated in drawing activities was better. They studied the effectiveness of sustained drawing activities of atoms and molecules in enhancing representational competence and conceptual change in a science classroom. The sample for the study consisted of 505 students who were enrolled in one of four 15-week first-semester general chemistry courses. Students who produced high-quality sketches accurately representing the course objectives and chemical systems had higher results. They developed curriculum materials using disciplinary representations embedded in a simulated microworld. The study found that students who engaged in free drawing exercises while using simulations performed better on conceptual chemistry comprehension tests.

McCollum *et al.*, (2014) found that touch-screen technology positively impacted how students' visual cognitive skills developed. Through 102 one-on-one interviews

with undergraduate students, the effect of touch-screen technology on spatial cognitive abilities as related to molecular geometries was evaluated. Moreover, the ability to convert a structural formula into a physical model of one's design was another indicator of the superior building abilities of molecules among those who used the iPad during previous activities, even though the iPad was not utilized during the construction exercise.

In summary, this study found that PhET computer simulations improved representational competence skills. There are research studies mentioned before (McCollum *et al.*, 2014; Patwardhan and Murthy, 2017; Stieff and DeSutter, 2021; Stieff, 2011), this study focused on the effects of computer simulations on pre-service science teachers' representational competence skills. This study contributed to the existing literature by adding new sample characteristics.

5.1.2. Combined Effects of Computer Simulations and Virtual Reality Applications on Representational Competence Skills

This study found that pre-service science teachers' representational competence skills were improved by using both computer simulations and virtual reality application named "Nanome" as can be seen in Table 4.9. Since the virtual reality application was implemented after the computer simulation, a combined effect of these two technological tools was detected. The findings of this study showed that the virtual reality application combined with the simulation improved two participants' representational competence skills to fifth-level skills which is describing how different representations might say the same thing in different ways. Additionally, although three participants showed forth-level skills which is explaining why a particular representation or set of representations was more appropriate before the virtual reality application, this number increased to four after the virtual reality treatment. Moreover, before the virtual reality application, nine participants showed second-level skills which were transforming one representation into another; however, this number also increased to 10.

When the literature was reviewed, no study was found on the effects of virtual reality applications on the representational competencies of pre-service science teachers, nor the combined effects of virtual reality and computer simulations. However, a similar study by (Echeverri Jimenez, 2022) was conducted to support students' ability to extract, represent, and predict stereochemical outcomes for the Diels-Alder reaction. This project focused on creating a Virtual Reality Learning Environment (VRLE) where students could practice their spatial skills while gaining representational competence. The sample of the study consisted of six North Carolina State University first-year graduate chemistry students and six second-year undergraduate chemistry students. The findings of this study showed that although evaluating how objects relate to one another and recognizing prominent characteristics were the most common visual-spatial skills in both groups, graduate students relied more on these two abilities than undergraduates did. With the exception of executing a series of mental processes and identifying dissimilar items as the same, which were favored by graduates and undergraduates, respectively, the majority of the remaining skills were used similarly across groups.

In summary, this study focused on the combined effects of virtual reality applications and computer simulations on pre-service science teachers' representational competence skills. The findings revealed that after using a virtual reality application named "Nanome", all participants improved their representational competence skills by reaching second-level skills in Post-Test 2. However, the improvement of representational competence skills was not at the same level for each participant.

5.1.3. Experiences in Using Computer Simulations

This study found that participants were willing to use computer simulations for learning and teaching. They claimed many reasons to use computer simulations in science lessons. The most common idea was that computer simulations enabled students to understand abstract subjects such as atoms and molecules. The study of (Yıldırım, 2021) supported this claim and found that virtual laboratory applications such as

computer simulations enhance students' academic success and meaningful learning by concretizing abstract subjects and boosting interest, excitement, and motivation in science courses.

Moreover, the pre-service science teachers claimed computer simulations can prevent students from being contaminated by harmful chemicals. The pre-service science teachers also thought that computer simulations enabled them to overcome the difficulty of finding necessary materials such as chemical substances and physical materials in science experiments. The study of Ben Ouahi *et al.* (2022) found that due to issues with a lack of experimental supplies, the delicate nature of some investigations, or their hazardous qualities, the majority of teachers (37.70%) preferred using interactive simulations in the classroom to the practical experiments planned in the textbook.

Additionally, the pre-service science teachers thought that computer simulation provides students with visualization of the concepts. The participants claimed that seeing the internal structure of the molecule enabled students to visualize them better in their minds. The research of (Correia *et al.*, 2019) lends weight to this conclusion. The study by (Correia *et al.*, 2019) found that the students favored the simulation elements that assisted visualization, guiding questions, blending different features and teaching techniques, and simple explanations of complex concepts. These techniques helped students overcome their preconceptions regarding the submicroscopic behavior of gases and accept alternate, scientifically-backed viewpoints.

Moreover, the participants claimed that computer simulations enabled them to change variables, and computer simulations like "Build an Atom" and "Build a Molecule" saved time and enabled experiments easily during the second interview of this study. This finding is supported by the study of (Khan, 2011), which explores teaching science through computer simulations, focusing on introductory chemistry classrooms in a North American public university. The study found that simulations improved critical thinking, clarified complex processes, and expanded textbook learning boundaries. Students found digital technology, such as computer simulations, intriguing due to their

ability to alter variables and track changes.

However, the participants of this study also claimed that there were also some weaknesses in computer simulations, including distracting, time-consuming, artificial appearance, confusion, and limited molecules. They found these weaknesses in "Build an Atom" and "Build a Molecule" simulations, affecting imagination, two-dimensional images, and the inability to see actual images or subatomic particles in the post-interview. This finding contradicts the study of (AlArabi *et al.*, 2022), which found that using visualization, computer simulations helped make connections and drew attention to the ideas and specifics of Newton's Second Law of Motion.

In summary, the pre-service science teachers' experiences with using computer simulations and their thoughts were revealed by this study. The existing literature supports the findings of this study that revealed the benefits of using computer simulations in science education (Ben Ouahi *et al.*, 2022; Correia *et al.*, 2019; Khan, 2011; Yıldırım, 2021). However, in this study, the pre-service science teachers found weaknesses in the computer simulations, which contradicted the study findings of (AlArabi *et al.*, 2022).

5.1.4. Experiences in Using Virtual Reality Applications

The pre-service science teachers thought that there were practical reasons to use virtual reality in science classes. These reasons were the ability to witness circumstances that cannot be observed in nature and the ability to protect themselves by avoiding hazardous substances. The study of (Aliyu and Talib, 2019) supports the findings of this research. In light of the need for a productive method for teaching chemical concepts to chemistry pre-service instructors in Nigeria, the study of (Aliyu and Talib, 2019) explored the recent use of Virtual Reality Technology (VRT) in educational settings and self-face learning of chemistry in particular. The results showed several advantages of VRT for chemistry pre-service instructors who need help teaching abstract chemistry concepts such as organic structure, molecular structure, and

chemical processes due to a need for more content understanding.

Virtual reality was enjoyable, drew students' attention, reduced potential chemical hazards, could help to eliminate impossibilities, facilitated subject understanding, and was a beautiful way to incorporate technology into a lesson while embodying an abstract concept, according to the participants. The study of (Reeves *et al.*, 2021) supports the findings of this study. They aimed to research how undergraduate chemistry students interact with virtual reality labs while studying. This case study showed six participants' learning experiences using virtual reality. The survey by (Reeves *et al.*, 2021) showed that the participants had the perception that Virtual labs were designed to eliminate obstacles that were thought to exist in a real laboratory to enhance the educational experience. Moreover, the findings of (Reeves *et al.*, 2021) showed that perceived affordances were recognized as advantageous for increasing the comprehension of the content and how it is understood. The contextual element of the VR Lab was viewed as a benefit that improved comprehension of what to accomplish and the importance of the step or procedure to the experiment's overall objective.

The pre-service science teachers thought that virtual reality applications helped them visualize the experiment. The participants claimed they would utilize virtual reality applications because they helped make abstract ideas like concrete particles and made them easier to remember when they are visualized. The study's results (Artun *et al.*, 2020) supported the findings of this study. The mixed-method research in Turkey of (Artun *et al.*, 2020) explored how virtual reality-enhanced laboratory activities affected pre-service science teachers' understanding of the scientific method. According to 54 3rd-grade pre-service science teachers' shared perspectives, the laboratory activities enhanced with virtual reality heavily utilized the observing skill.

Besides the benefits of virtual reality applications, this study found that the participants who used virtual reality before claimed virtual reality can be challenging to use in class, and excessive use might cause dizziness, as the study of (Di Lanzo *et al.*, 2020) suggested: there were drawbacks and problems with using virtual reality equipment,

including instances of cybersickness, motion sickness, nausea, pallor, perspiration, and headaches. The study by (Fransson *et al.*, 2020) also found that the possible issue of utilizing virtual reality for instructional purposes in schools was to need the separation of classes into smaller groups performing various tasks while some students use a small number of expensive virtual reality applications. This emphasized the necessity for flexibility regarding extra rooms, group size, timetables, and additional educators with virtual reality experience.

Moreover, the participants claimed that the "Nanome" virtual reality application offered unique features like observing atoms, having infinite options of elements, and a three-dimensional experience during the fourth interview of this study. The participants listed the advantages of using virtual reality for molecular building as being that it is more engaging because students can touch the molecular structure, create molecules by selecting bonds, prevent each bond from forming, have the ability to enlarge or shrink and have warning systems when a wrong step is taken. These findings are supported by the study of (Ferrell *et al.*, 2019), which found that the visualization component was thought to offer the most advantage. Most of the participants of this study said that "visualization" and "understanding 3D concepts" would benefit them. Additionally, (Fransson *et al.*, 2020) survey found that educators discovered numerous pedagogical applications for virtual reality. These featured more opportunities for complicated process visualization and teaching and learning activities that were engaging, varied, and experience-based. On the other hand, this study found that the participants identified the drawbacks of the virtual reality application named "Nanome" in terms of creating an atom, including not being based on any atomic models, being unable to detect subatomic particles, and being unable to observe the movement of atoms.

5.2. Conclusion

The most essential conclusion of this study is that virtual reality can be an assisted tool to improve the representational competence skills of pre-service science teachers.

In order to understand this improvement, the participants were asked to depict atoms and molecules. During the study, although some participants did not show any change in depicting atoms and molecules, some illustrated their atoms and molecules in different modeling. These drawings were analyzed by (Kozma and Russell's, 2005) list of representational competence skills. Since the participants used virtual reality applications after the computer simulations, the effects of virtual reality on representational competence skills cannot be mentioned solely. Therefore, the combined effects of computer simulations and virtual reality applications are discussed.

Moreover, another conclusion is that computer simulations help improve the representational competence skills of pre-service science teachers. The effects of computer simulations on representational competence skills have already been researched in the field of science and education. These research studies also supported this study's findings (McCollum *et al.*, 2014; Patwardhan and Murthy, 2017; Stieff and DeSutter, 2021; Stieff, 2011).

This study also revealed the pre-service science teachers' experiences using PhET computer simulations and "Nanome" virtual reality application about atoms and molecules. The pre-service science teachers found computer simulations and virtual reality applications helpful in imagining an abstract subject as atoms and molecules. Thus, visualization of these abstract concepts could be manageable with computer simulations and virtual reality applications. Moreover, the participants found technological tools to save time and sources such as laboratory materials. However, they also mentioned about negative aspects of experiencing PhET simulations and the "Nanome" virtual reality application. Even though the pre-service science teachers found these technological tools very beneficial in terms of teaching and learning in science, they mentioned that especially the features of virtual reality applications should be improved, such as adding sub-atomic particles and movement of the atoms and molecules.

5.3. Limitations and Recommendations for Further Research

This qualitative case study explored the combined effects of computer simulations and virtual reality applications on the representational competence skills of pre-service science teachers who study at Bogazici University in Turkey; hence it is not representative and generalizable to other university students. Further research can be done by replicating this study at several universities, including private universities, and comparing the results.

Another limitation of this study was the small sample; five third grade and five fourth-grade pre-service science teachers were the samples to understand the experiences of computer simulations, virtual reality applications, and their combined effects on representational competence skills. A mixed-method research design study can be used in the future to examine a more extensive study sample. Since this study revealed that there are combined effects of virtual reality and computer simulations on pre-service science teachers' representational competence skills, this study can be applied to chemistry and science teachers who work at a school for further research studies to understand if there is any effects of computer simulations and virtual reality applications on their representational competence skills. Additionally, a limitation of this study was the questions of the instruments; different questions can be asked in the future studies.

Moreover, the effects of virtual reality applications on representational competence skills should be explored solely to understand its effects deeper. Since this study was conducted after the computer simulation treatment, the impact of virtual reality should have been investigated in terms of representational competence. A research design can be implemented to achieve this goal.

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APPENDIX A: ETHICAL APPROVAL

Evrak Tarih ve Sayısı: 08.02.2023-112390

T.C.
BOĞAZİÇİ ÜNİVERSİTESİ REKTÖRLÜĞÜ
Fen Bilimleri ve Mühendislik Alanları İnsan Araştırmaları Etik Kurulu
(FMİNAREK)

Sayı : E-84391427-050.01.04-112390 08.02.2023
Konu : 2023/03 Kayıt no'lu başvurunuz hakkında

Sayın Doç. Dr. Sevil AKAYGÜN
Matematik ve Fen Bilimleri Eğitimi Bölüm Başkanlığı - Öğretim Üyesi

"The Effects of Using Simulation and Virtual Reality Application on Preservice Science Teachers' Representational Competence Skills" başlıklı projeniz ile Boğaziçi Üniversitesi Fen Bilimleri ve Mühendislik Alanları İnsan Araştırmaları Etik Kurulu (FMİNAREK)'e yaptığınız 2023/03 kayıt numaralı başvuru 06.02.2023 tarihli ve 2023/02 No.lu kurul toplantısında incelenerek etik onay verilmesi uygun bulunmuştur.

Bu karar tüm üyelerin toplantıya on-line olarak katılımıyla ve oybirliği ile alınmıştır. Onay mektubu tüm üyeler adına Komisyon Başkanı tarafından e-imzalanmıştır.

Saygılarımızla bilginize sunarız.

Prof. Dr. Tınaz EKİM AŞICI
Başkan

Bu belge, güvenli elektronik İmza ile imzalanmıştır.
Doğrulama Kodu :BSU4DK2UP2 Pin Kodu :27742 Belge Takip Adresi : https://turkiye.gov.tr/ebd?eK=4787&eD=BSU4DK2UP2&eS=112390
34342 Bebek-Istanbul
Telefon No:0212 287 17 53 Faks No:0212 265 70 06
İnternet Adresi:www.boun.edu.tr
Kep Adresi:bogaziciuniversitesi@hs01.kep.tr
Bilgi için: Nuşen MUNAR
Unvan: Mühendis

Bu belge, güvenli elektronik imza ile imzalanmıştır.

Figure A.1. Ethical approval.

APPENDIX B: PARTICIPANT INFORMED CONSENT FORM T.R. BOGAZICI UNIVERSITY FIELD OF SCIENCE AND ENGINEERING HUMAN RESEARCH ETHICS COMMITTEE PARTICIPANT INFORMATION AND CONSENT FORM

Institution supporting the research: Boğaziçi University

Name of the Study: The Effects of Using Simulation and Virtual Reality Application on Preservice Science Teachers' Representational Competence Skills

Name of Project Coordinator/Researcher: Assoc. Prof. Sevil Akaygun, Oznur Erkoca

Address: Boğaziçi University 34342 Bebek/Istanbul Turkey

E-mail address: erkocaoznur@gmail.com

Phone: +905543883312

Dear Participant,

Öznur Erkoca, a graduate student at Boğaziçi University Institute of Science and Engineering and Department of Science Education, is conducting an educational project titled "The Effect of Using Simulation and Virtual Reality Application on Pre-Service Science Teachers' Representational Competence Skills" as her master's thesis. The aim of this study is to examine the effects of using simulation and virtual reality applications on pre-service science teachers' display proficiency skills. Approval for the research was obtained from the Human Research Ethics Committee of Boğaziçi University, Sciences and Engineering (FMINAREK).

We invite you to participate in our scientific research project. If you decide to participate in this research, we will conduct a workshop with you where we will use computer simulations and virtual reality tools. This workshop is planned as three sessions and is planned to be in an office or laboratory suitable for work in Boğaziçi University North Campus.

The first session of the workshop consists of a pre-test and an interview. The pre-test

which includes 2 open-ended questions is planned to take 20 minutes. Face-to-face semi-structured interview about computer simulations will be held with you. The interview is planned to last approximately 20-30 minutes. With your permission, a voice recording will be taken during the interview. In case you do not want your voice recording to be recorded, the researcher will keep interview notes. Before proceeding to the second session of the workshop, appointments will be requested from you for group workshop that will take place in the second session.

In the second session of the workshop, which is planned to take 60 minutes, you will be asked to use a computer simulation. After using the computer simulation, you will be asked to fill in the Post-Test 1 consisting of eight open-ended questions.

In the third session of the workshop, which will last 120 minutes, there will be a face-to-face semi-structured interview about your representations in Pre-Test 1 and Post Test 1. The interview is planned to last approximately 20-30 minutes. With your permission, a voice recording will be taken during the interview. In case you do not want your voice recording to be recorded, the researcher will keep interview notes. Then, you will be asked to fill Pre-Test 2. Face-to-face semi-structured interviews about your representations of in Pre-Test 2 will be conducted. The interview is planned to last approximately 20-30 minutes. With your permission, a voice recording will be taken during the interview. In case you do not want your voice recording to be recorded, the researcher will keep interview notes. Then you will be asked to use a demo application via using virtual reality equipment. After the demo application, you will be asked to use a virtual reality application. After using virtual reality application, Post-Test 2 will be distributed.

At the end of the workshop, you will be interviewed about their experience on virtual reality and their representations in Post Test 2. Interviews were planned to last approximately 20-30 minutes and will be conducted face to face. With your permission, a voice recording will be taken during the interview. In case you do not want your voice recording to be recorded, the researcher will keep interview notes. After interviews completed, the participants will be asked to design a classroom activity which involves virtual reality application.

Participation in this research is completely voluntary. You will not be paid or

charged any fees. The study is not expected to pose a risk to you, but if you feel uncomfortable at any stage of the workshop process, you may withdraw from the study. You can skip any question during the workshop and withdraw from the research at any stage of the study without giving any reason. In this case, the data we have received from you will be destroyed. In this workshop, you will be taught new educational tools that you can use in the teaching profession. It is expected that the new programs you will learn will contribute to your professional development.
This research is carried out for a scientific purpose and the confidentiality of participant information is kept as a basis. Research data will only be used for scientific purposes and will be destroyed after the research is finished. Your personal information will not be included in the publications and presentations where the research results are shared.
If you would like additional information about the study you can contact, the project coordinator, Boğaziçi University Department of Mathematics and Science Education faculty member Assoc. Prof. Sevil Akaygün (Phone: (212) 359-4409 e-mail: sevil.akaygun@boun.edu.tr) and researcher Öznur Erkoca (Phone: +905543883312, e-mail: erkocaoznur@gmail.com). You can consult Boğaziçi University Science and Engineering Human Research Ethics Committee (FMINAREK) regarding your rights regarding research.

☐ I have read the text above, I have understood the scope and purpose of the study and my responsibilities as a participant. I agree to participate in the research.

☐ I approve the recording of my voice during the interview process.

☐ I do not have epilepsy.

Participant's Name-Surname: ….....

Signature: ….....

Address (Phone Number, Fax Number, if any): ….....

Date (day/month/year):…../……../.....

Researcher's Name-Surname: Öznur Erkoca

Signature: ....

Date (day/month/year):...../...../.....

Figure B.1. Boğaziçi University Science and Engineering Human Research Ethics Committee (FMINAREK).

APPENDIX C: BROCHURE



Figure C.1. Brochure.

APPENDIX D: PARTICIPANT INVITATION FORM

ORTAOKUL FEN BİLGİSİ KONULARINA YÖNELIK SİMÜLASYON VE SANAL GERÇEKLİK UYGULAMALARI ATÖLYE ÇALIŞMASI

Sayın katılımcı,

Ben Öznur Erkoca, Boğaziçi Üniversitesi Fen Bilimleri ve Mühendislik Alanları Enstitüsü, Matematik ve Fen Bilimleri Eğitimi Bölümü yüksek lisans öğrencisiyim. Yüksek lisans tezi kapsamında Doç. Dr. Sevil Akaygün danışmanlığında "Simülasyon ve Sanal Gerçeklik Uygulaması Kullanmanın Fen Bilgisi Öğretmen Adaylarının Gösterim Yeterlik Becerilerine Etkisi" adı altında bilimsel bir araştırma projesi yürütmekteyim. Bu çalışmanın amacı simülasyon ve sanal gerçeklik uygulaması kullanmanın fen bilgisi öğretmen adaylarının gösterim yeterlik becerileri üzerindeki etkilerini incelemektir. Araştırma ile ilgili Boğaziçi Üniversitesi Fen Bilimleri ve Mühendislik Alanları İnsan Araştırmaları Etik Kurulu'ndan (FMINAREK) onay alınmıştır. Sizi bilimsel araştırma projemize katılmaya davet ediyoruz. Bu araştırmaya katılmaya karar verirseniz, sizinle bilgisayar simülasyonları ve sanal gerçeklik araçları kullanacağımız bir atölye yapacağız. Bu atölye çalışmasının Boğaziçi Üniversitesi Kuzey Kampüsü'nde 3 oturum sürmesi planlanmaktadır. Atölye çalışmasının birinci oturumu yaklaşık 1 saat sürecek olup bireysel olacak şekilde, ikinci oturumu yaklaşık 1 saat sürecek olup grup çalışması halinde ve üçüncü oturumu ise katılımcının uygun zamanı saptanarak bireysel yapılacaktır.

Bu araştırmaya katılım tamamen isteğe bağlıdır. Çalışmanın sizin için bir risk oluşturması beklenmemektedir ancak atölye sürecinin herhangi bir aşamasında rahatsızlık hissederseniz çalışmadan çekilebilirsiniz. Bu atölye çalışması sizlere öğretmenlik mesleğinde ve kendi derslerinizde de kullanabileceğiniz simülasyon ve sanal gerçeklik araçlarını deneyimlemeniz için fırsatlar sunacaktır. Deneyimleyeceğiniz yeni programların mesleki gelişiminizde size katkı sağlanması beklenmektedir.

Araştırmacı: Öznur Erkoca

Bu çalışmaya katılmak isterseniz lütfen aşağıdaki soruları cevaplayınız.

DEMOGRAFIK BILGILER

Adınız- Soyadınız:

Telefon:

E-mail:

Doğum Tarihi:

Boğaziçi Üniversitesi'nde kaçıncı döneminizi okumaktasınız?

- 4
- 5
- 6
- 7
- Diğer:

Aşağıda listelenen derslerden şu ana kadar aldığınız dersleri seçiniz (F notu aldığınız dersler hariç):

- ED 101
- SCED 120
- PHYS 101
- PHYS 102
- PHYS 201
- BIO 101
- BIO 102
- CHEM 103
- CHEM 104

Tamamladığınız kredi sayısını yazınız.

.....

Figure D.1. Demografik bilgiler.

KATILIMCI DENEYİM ANKETİ

Aşağıdaki teknolojik cihazları ne sıklıkta kullandığınızı belirtiniz. *

	Hiçbir zaman	Nadiren	Bazen	Sık sık	Her zaman
Bilgisayar	○	○	○	○	○
Tablet (IPad vs.)	○	○	○	○	○
Akıllı Telefon	○	○	○	○	○
Sanal Gerçeklik	○	○	○	○	○

Öğretmen adayı olarak derslerinizde bilgisayar simülasyonlarına ne kadar yer vermek ister misiniz? Lütfen aşağıdaki kutucuklardan birini seçiniz (1: hiçbir zaman, 2: nadiren, 3: bazen, 4:sık sık, 5: her zaman) *

	1	2	3	4	5	
Hiçbir zaman	○	○	○	○	○	Her zaman

Öğretmen adayı olarak derslerinize bilgisayar simülasyonlarını dahil etmek isterseniz, bunları ne sıklıkla uygulamayı düşünürdünüz? Lütfen aşağıdaki seçeneklerden birini seçin. *

- ○ yılda 1 ders saati
- ○ dönemde 1 ders saati
- ○ ayda 1 ders saati
- ○ haftada bir ders saati

Daha önce öğrenci olarak bilgisayar simülasyonu kullandınız mı? Eğer kullandıysanız kısaca hangi simülasyonları kullandığınızı yazınız.

.....

.....

.....

Figure D.2. Deneyim Anketi.

Daha önce öğretmen adayı olarak derslerinizde bilgisayar simülasyonlarına yer verdiniz mi?

.....

.....

.....

Eğer yer verdiyseniz kısaca hangi simülasyonları (PhET, WISE, vb.) kullandınız?

.....

.....

.....

Hangi konularda simülasyon kullandınız?

.....

.....

.....

Fen eğitiminde bilgisayar simülasyonlarının hangi konu/konular için daha uygun olduğunu düşünüyorsunuz? Lütfen konu(lar)ın adını yazınız.

.....

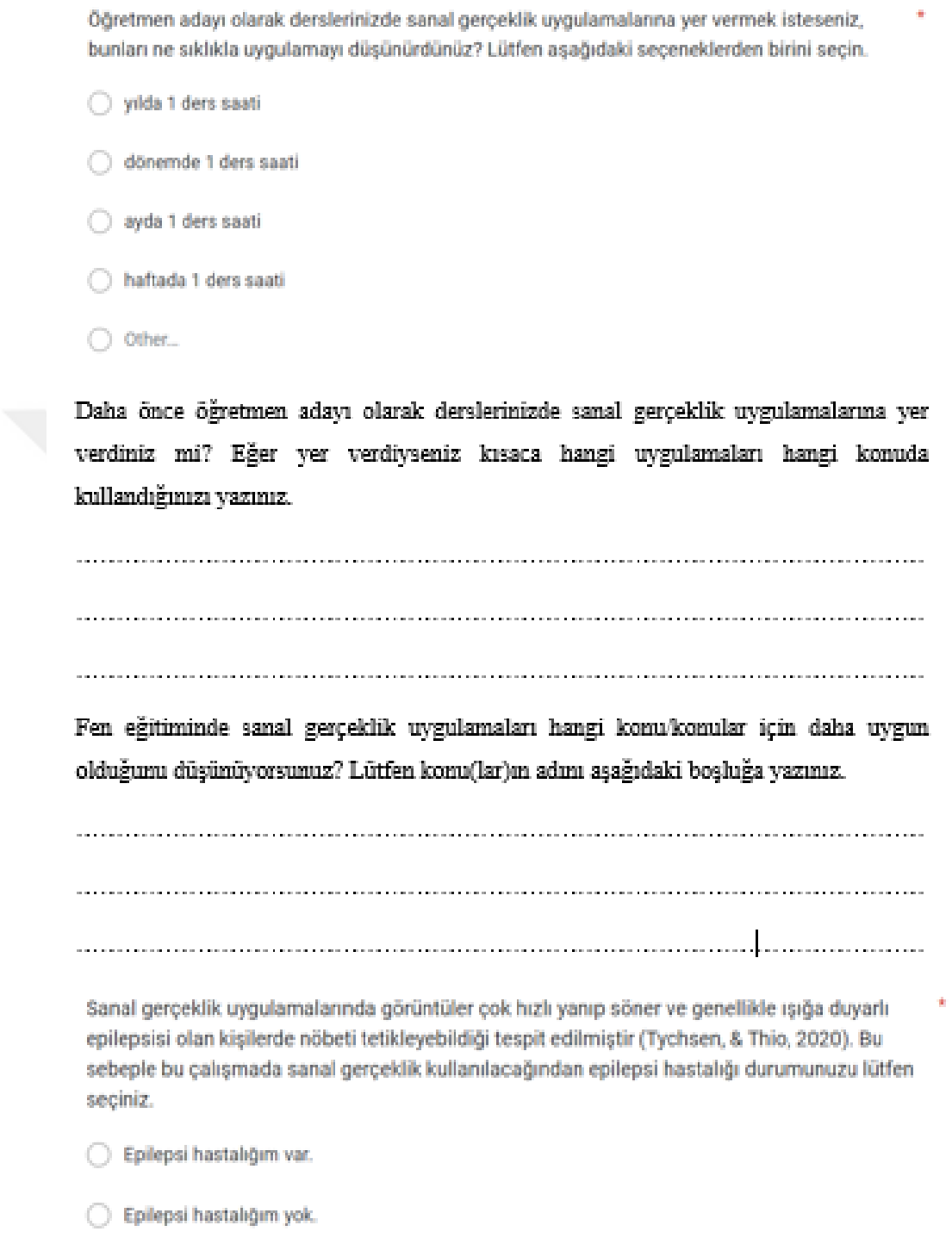
.....

.....

Öğretmen adayı olarak derslerinizde sanal gerçeklik uygulamalarına yer vermek ister misiniz? * Lütfen aşağıdaki kutucuklardan birini seçiniz (1: hiçbir zaman, 2: nadiren, 3: bazen, 4:sık sık, 5: her zaman)

	1	2	3	4	5	
hiçbir zaman	○	○	○	○	○	her zaman

Figure D.3. Deneyim Anketi 1.


Öğretmen adayı olarak derslerinizde sanal gerçeklik uygulamalarına yer vermek isteseniz, bunları ne sıklıkla uygulamayı düşünürdünüz? Lütfen aşağıdaki seçeneklerden birini seçin. *

- yılda 1 ders saati
- dönemde 1 ders saati
- ayda 1 ders saati
- haftada 1 ders saati
- Other...

Daha önce öğretmen adayı olarak derslerinizde sanal gerçeklik uygulamalarına yer verdiniz mi? Eğer yer verdiyseniz kısaca hangi uygulamaları hangi konuda kullandığınızı yazınız.

.....

.....

.....

Fen eğitiminde sanal gerçeklik uygulamaları hangi konu/konular için daha uygun olduğunu düşünüyorsunuz? Lütfen konu(lar)ın adını aşağıdaki boşluğa yazınız.

.....

.....

.....

Sanal gerçeklik uygulamalarında görüntüler çok hızlı yanıp söner ve genellikle ışığa duyarlı epilepsisi olan kişilerde nöbeti tetikleyebildiği tespit edilmiştir (Tychsen, & Thio, 2020). Bu sebeple bu çalışmada sanal gerçeklik kullanılacağından epilepsi hastalığı durumunuzu lütfen seçiniz. *

- Epilepsi hastalığım var.
- Epilepsi hastalığım yok.

Figure D.4. Deneyim Anketi 2.

APPENDIX E: PRE-TEST 1

Name-Surname:

REPRESENTATIONAL COMPETENCE PRE-TEST - 1:

Please answer the following questions before attending the computer simulation application part of the workshop:

1. 1. Imagine that you can observe a single Helium (He) atom at room temperature for 3 milliseconds. Draw in the boxes below what you can observe in each millisecond and briefly explain your drawing. (₂He).

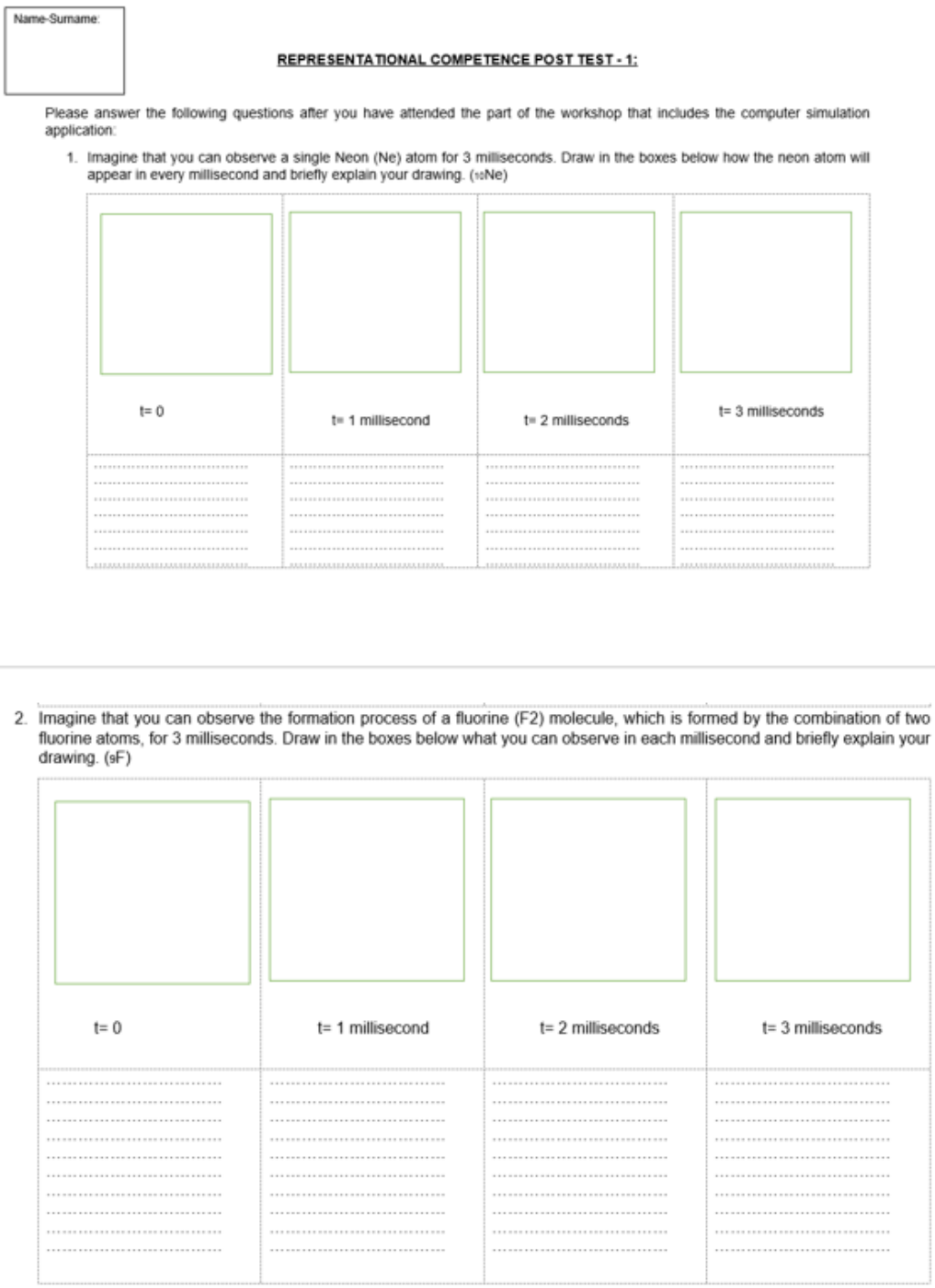
t= 0	t= 1 millisecond	t= 2 milliseconds	t= 3 milliseconds
.....	.....	.....	.....

2. Imagine that you can observe the formation process of one oxygen (O2) molecule, which is formed by the combination of two oxygen atoms, for 3 milliseconds. Draw in the boxes below how the oxygen molecule will appear in each millisecond and briefly explain our drawing. (₈O)

t= 0	t= 1 millisecond	t= 2 milliseconds	t= 3 milliseconds
.....	.....	.....	.....

Figure E.1. Pre-test 1.

APPENDIX F: POST-TEST 1



Name-Surname:

REPRESENTATIONAL COMPETENCE POST TEST - 1:

Please answer the following questions after you have attended the part of the workshop that includes the computer simulation application:

1. Imagine that you can observe a single Neon (Ne) atom for 3 milliseconds. Draw in the boxes below how the neon atom will appear in every millisecond and briefly explain your drawing. ($_{10}$Ne)

t= 0	t= 1 millisecond	t= 2 milliseconds	t= 3 milliseconds
.....	.....	.....	.....

2. Imagine that you can observe the formation process of a fluorine (F2) molecule, which is formed by the combination of two fluorine atoms, for 3 milliseconds. Draw in the boxes below what you can observe in each millisecond and briefly explain your drawing. ($_{9}$F)

t= 0	t= 1 millisecond	t= 2 milliseconds	t= 3 milliseconds
.....	.....	.....	.....

Figure F.1. Post-test 1-1.

3. Are there any changes in your representation of the atomic model you created before and after the workshop? If yes, please explain the changes you have made with justifications.

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4. Are there any changes in your representation of the molecule model you created before and after the workshop? If yes, please explain the changes you have made with justifications.

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5. What information did you use and what did you take into account in the representation of your atomic model that you created before and after the workshop?

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Figure F.2. Post-test 1-2.

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6. What information did you use and what did you take into account in the representation of your molecule model that you created before and after the workshop?

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7. What are your thoughts and experience in building atom/molecule model using PhET Simulation? Please explain.

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8. What are your thoughts on PhET Simulation that you used in the workshop? Please explain

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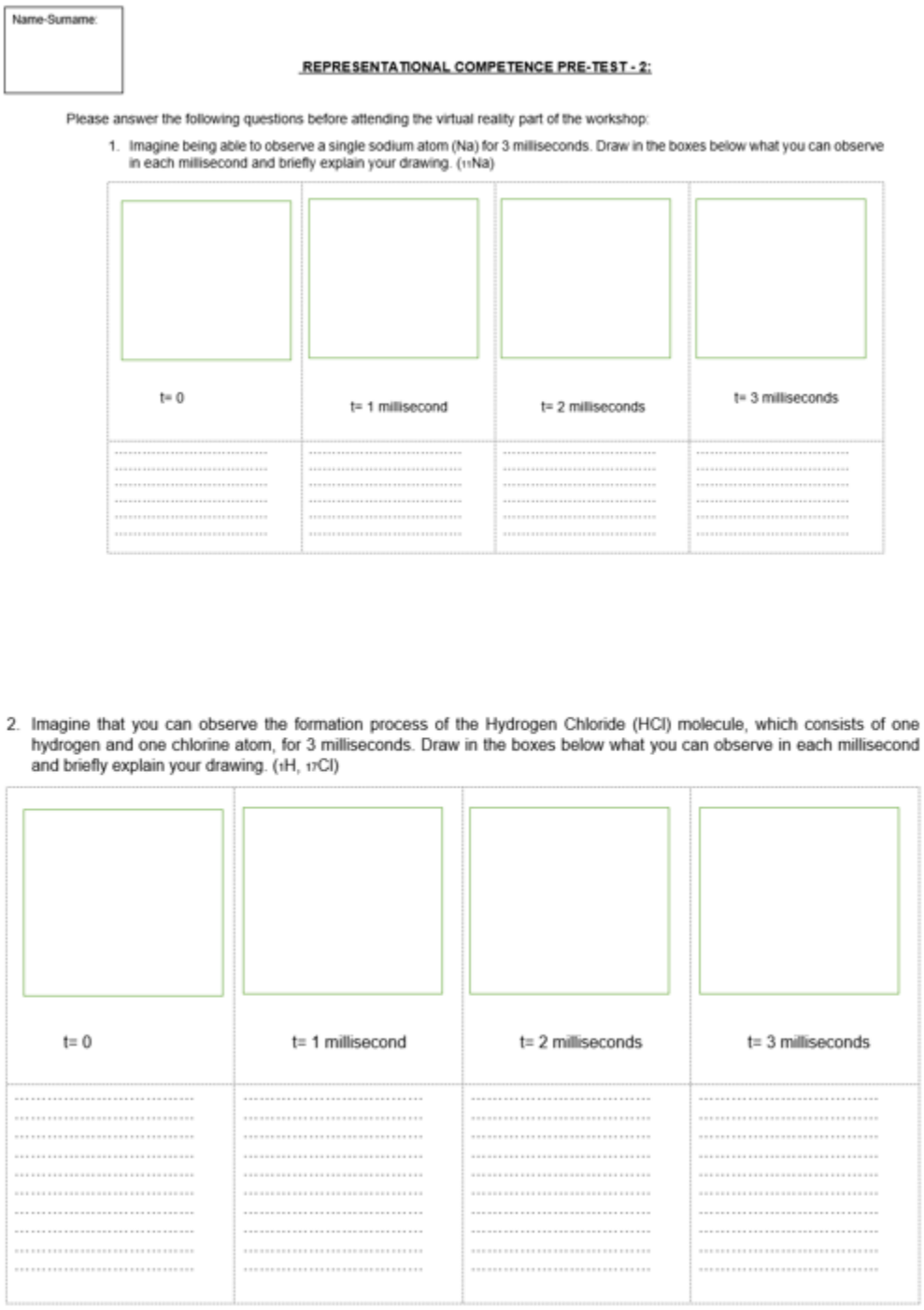
Figure F.3. Post-test 1-3.

APPENDIX G: PRE-TEST 2



Name-Surname:

REPRESENTATIONAL COMPETENCE PRE-TEST - 2:

Please answer the following questions before attending the virtual reality part of the workshop:

1. Imagine being able to observe a single sodium atom (Na) for 3 milliseconds. Draw in the boxes below what you can observe in each millisecond and briefly explain your drawing. ($_{11}$Na)

t= 0	t= 1 millisecond	t= 2 milliseconds	t= 3 milliseconds

2. Imagine that you can observe the formation process of the Hydrogen Chloride (HCl) molecule, which consists of one hydrogen and one chlorine atom, for 3 milliseconds. Draw in the boxes below what you can observe in each millisecond and briefly explain your drawing. ($_{1}$H, $_{17}$Cl)

t= 0	t= 1 millisecond	t= 2 milliseconds	t= 3 milliseconds

Figure G.1. Pre-test 2.

APPENDIX H: POST-TEST 2



Name-Surname:

REPRESENTATIONAL COMPETENCE POST TEST - 2:

Please answer the following questions after you have attended the virtual reality application part of the workshop:

1. Imagine being able to observe a single Magnesium (Mg) atom for 3 milliseconds. Draw in the boxes below what you can observe in each millisecond and briefly explain your drawing. (₁₂Mg)

t= 0	t= 1 millisecond	t= 2 milliseconds	t= 3 milliseconds

2. Imagine that you can observe the formation process of the Hydrogen Fluoride (HF) molecule, which consists of one hydrogen and one fluorine atom, for 3 milliseconds. Draw in the boxes below what you can observe in each millisecond and briefly explain your drawing. (₁H, ₉F)

t= 0	t= 1 millisecond	t= 2 milliseconds	t= 3 milliseconds

Figure H.1. Post-test 2-1.

3. Are there any changes in your representation of the atomic model you created before and after the workshop? If yes, please explain the changes you have made with justifications.

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4. Are there any changes in your representation of the molecule model you created before and after the workshop? If yes, please explain the changes you have made with justifications.

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5. What information did you use and what did you take into account in the representation of your atomic model that you created before and after the workshop?

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Figure H.2. Post-test 2-2.

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6. What information did you use and what did you take into account in the representation of your molecule model that you created before and after the workshop?

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7. What are your thoughts on your experience of creating atom/molecule model using Virtual Reality application? Please explain.

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8. What are your thoughts on the Virtual Reality application you used in the workshop? Please explain.

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Figure H.3. Post-test 2-3.

APPENDIX I: PRE-SERVICE TEACHERS REPRESENTATIONAL COMPETENCE INTERVIEW QUESTIONS-1: (ING)

I. Simulations

1. First of all, can you talk about your experience with simulations in general?
    a. Have you used simulation on an extracurricular subject? (Ex: flight, class, earthquake, game etc.)
        a. If yes, what simulations did you use? What did you feel?

2. When you were a student, did you ever use simulation to learn a subject?
    a. What subject did you use it for?
    b. Which simulation did you use?

3. As a teacher (in internship or private lesson), have you ever used simulation to teach a subject? Have you ever included simulation in your course?
    a. What subject did you use it for?
    b. Which simulation did you use?
    c. Why did you choose this simulation?
    d. How did you use it?

II. PhET Simulations

4. Have you ever used PhET simulations before?
    a. What subject did you use it for?
    b. Which simulation was it? If you have used more than one, you can only mention one.
    c. Why did you choose this simulation?
    d. Have you used it as a teacher/student,
    e. Can you explain how you used the simulation?

Figure I.1. Pre-service teachers representational competence interview questions-1: (ing).

f. Could you tell us about your views on the use of this simulation for teaching purposes? What are their strengths and weaknesses?

5. Do you plan to use simulation in your lessons when you become a teacher? Why is that?

a. What subjects do you use it for?

b. Why these subjects?

c. How do you use it? Can you describe your application method?

III. Atom and Molecule Model Drawing and Simulation

Ok, so let's take a look at your first drawing and explanation of the atom (Pretest-1).

6. Can you explain how you represented the helium atom?

a. Which atomic model did you use in your representation?

b. What features did you pay attention to when drawing your representation of the atomic model?

c. Is there anything in your drawing that you wanted to represent but couldn't? What did you have trouble representing?

d. What did you do to overcome this challenge?

7. Now let's take a look at your first drawing and explanation of the oxygen molecule (Pretest-1).

a. Can you explain how you represented the formation process of the oxygen molecule with a drawing?

b. What features did you pay attention to when drawing your molecular model representation?

c. Is there anything in your drawing that you wanted to represent but couldn't? What did you have trouble representing?

i. What did you do to overcome this challenge?

Figure I.2. Pre-service teachers representational competence interview questions-1: (ing) 1.

APPENDIX J: PRE-SERVICE TEACHERS REPRESENTATIONAL COMPETENCE INTERVIEW QUESTIONS-2: (ING)

IV. Atomic Model Simulation

1. Now let's talk about the first simulation you used in the workshop:

a. Can you explain step by step what you did in the simulation? How did you create the atomic model?

b. How do you compare the atomic model you created in the PhET simulation with the atomic model you drew?

i. What are the similarities?

ii. What are the differences?

c. What are the advantages of using PhET simulation to generate an atomic model representation?

d. What are the limitations of using PhET simulation to generate an atomic model representation?

V. Molecule Model Simulation

2. Now let's talk about the second simulation you used in the workshop:

a. Can you explain step by step what you do when you use simulation to create your molecular model representation?

b. How do you compare the molecule model you created in the PhET simulation with the Oxygen (O2) molecule model you drew in PreTest1?

i. What are the similarities?

ii. What are the differences?

c. What are the advantages of using PhET simulation to build your representation of a molecule model?

Figure J.1. Pre-service teachers representational competence interview questions-2: (ing).

d. What are the limitations of using PhET simulation to build your representation of a molecule model?

VI. Atom and Molecule Model Drawing (After completing Part I of the Workshop)

Let's take a look at your second drawing and explanation of the atom (Post Test-1).

3. Can you explain how you represented the Neon (Ne) atom?

a. What type of atomic model did you use in your representation?

b. Where did you start your drawing?

c. In what order did you add the subatomic particles?

d. Is there anything in your drawing that you wanted to represent but couldn't? What did you have trouble representing?

i. What did you do to overcome this challenge?

e. Have you made any changes to your Neon atom (What) model representation relative to your initial atomic model? If your answer is yes, how did you change it?

f. Did the PhET simulation give you an idea when building your atom and molecule model a second time? How?

4. Now let's take a look at your second drawing and explanation of the Fluorine (F2) molecule (Post Test-1).

a. Can you explain how you represented the formation process of the fluorine molecule?

b. Where did you start your drawing?

c. Which parts did you add in order?

d. What features did you pay attention to while drawing the molecule?

e. Is there anything in your drawing that you wanted to represent but couldn't? What did you have trouble representing?

i. What did you do to overcome this challenge?

f. Have you made any changes in your representation of the Fluorine (F2) molecule relative to your previous molecule model? If your answer is yes, how did you change it?

g. Did the PhET simulation application give you an idea when building your molecule model once again? How?

Figure J.2. Pre-service teachers representational competence interview questions-2: (ing) 1.

APPENDIX K: PRE-SERVICE TEACHERS REPRESENTATIONAL COMPETENCE INTERVIEW QUESTIONS-3: (ING)

Hello, thank you again for participating in my study. Today, I would like to ask a few questions about his experiences and views on virtual reality.

I. Virtual Reality Applications

1. First of all, can you talk about your experiences with virtual reality in general?
    a. Have you ever used a virtual reality application in an extracurricular subject? (Ex: game, climbing wall, roller coaster, etc.)
2. Have you used virtual reality applications for learning / teaching purposes?
    a. When you were a student, did you ever use simulation to learn a subject?
        i. What subject did you use it for?
        ii. Which simulation did you use?

    b. As a teacher (in internship or private lesson), have you ever used a virtual reality application to teach a subject? Have you ever included it in your lesson?
        i. What subject did you use it for?
        ii. Which app did you use?

3. What do you think about virtual reality applications in general?

4. Do you plan to use virtual reality application in your lessons when you become a teacher? Why is that?
    a. What subject did you use it for?
    b. Why these subjects?
    c. How do you use it? Can you describe your application method?

II. Atom and Molecule Model Drawing

Okay, so let's look at your third drawing and explanation of the atom (Pre-Test-2).

5. Can you explain how you illustrated the sodium atom? (Pre-Test - 2).

Figure K.1. Pre-service teachers representational competence interview questions-3: (ing).

a. What type of atomic model did you use in your representation?

b. Where did you start your drawing?

c. In what order did you add the subatomic particles?

d. Is there anything in your drawing that you wanted to represent but couldn't? What did you have trouble representing?

i. What did you do to overcome this challenge?

6. Now let's look at your drawing and explanation of the Hydrogen Chloride (HCl) molecule.

a. Could you explain how you represented the formation process of the Hydrogen Chloride molecule?

b. Where did you start your drawing?

c. Which parts did you add in order?

d. What features did you pay attention to while drawing the molecule?

f. Is there anything in your drawing that you wanted to represent but couldn't? What did you have trouble representing?

i. What did you do to overcome this challenge?

Figure K.2. Pre-service teachers representational competence interview questions-3: (ing) 1.

APPENDIX L: PRE-SERVICE TEACHERS REPRESENTATIONAL COMPETENCE INTERVIEW QUESTIONS-4: (ING)

III. Virtual Reality Experience in the Workshop

Now let's talk about the virtual reality application you use in the workshop:

1. What are you doing in the virtual reality application? Which atomic model, molecular model did you create?

    a. How did you build your atom model representation, can explain step by step are you?

    b. How did you create your molecular model representation, can you explain step by step?

2. How do you compare the atomic model you created in the virtual reality application with the atomic model you drew?

    a. What are the similarities?

    b. What are their differences?

3. How do you compare the molecular model you created in the virtual reality application with the atomic model you drew?

    a. What are the similarities?

    b. What are the differences?

4. Can you compare the PhET simulation with the virtual reality application?

    a. What are the similarities?

    b. What are the differences?

5. What are the advantages of using virtual reality applications to create an atomic model representation?

Figure L.1. Pre-service teachers representational competence interview questions-4: (ing).

III. Virtual Reality Experience in the Workshop

Now let's talk about the virtual reality application you use in the workshop:

1. What are you doing in the virtual reality application? Which atomic model, molecular model did you create?

    a. How did you build your atom model representation, can explain step by step are you?

    b. How did you create your molecular model representation, can you explain step by step?

2. How do you compare the atomic model you created in the virtual reality application with the atomic model you drew?

    a. What are the similarities?

    b. What are their differences?

3. How do you compare the molecular model you created in the virtual reality application with the atomic model you drew?

    a. What are the similarities?

    b. What are the differences?

4. Can you compare the PhET simulation with the virtual reality application?

    a. What are the similarities?

    b. What are the differences?

5. What are the advantages of using virtual reality applications to create an atomic model representation?

Figure L.2. Pre-service teachers representational competence interview questions-4: (ing) 1.

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Figure M.1. PhET copyright policy.