ORIGINAL ARTICLE

An Investigation into the Mental Structure of Science Teacher Candidates towards the Concept of "Atom"

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***Abstract**: This study aimed to identify science teacher candidates' mental structures about the concept of the atom. This study included 120 science teacher candidates who were chosen using the convenience sampling method. This research is a phenomenological study. The data on students' mental models of the atom was collected using a metaphor form and an open-ended question form. Forms were utilized to collect written feedback from teaching candidates. The research data were subjected to content analysis. In addition, the MAXQDA application was utilized to assess and generate categorization. As a result of the research, science teacher candidates' mental structures about the concept of the atom were divided into six major categories. It has been discovered that atom models are most vividly represented in the mental structures of science teacher candidates while addressing the concept of the atom. Then, mental structures relating to the atom's structural properties, definition or conceptual explanation, historical process, subatomic particles, and functional function arose in that order. When the codes in these categories were reviewed in detail, it was discovered that the explanations provided were extremely cursory.*

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Introduction

CHEMISTRY is a science that examines the structure and behavior of matter, which is closely related to life (Samon & Levy, 2020; Seçen, 2013). In reality, traces of chemistry can be found in all activities performed at all stages of the day, beginning with waking up in the morning and washing our hands and faces with tap water and ending in the evening. This has prompted humans, who are also matter, to be obsessed with understanding matter and its structure from its inception (Sözbilir, Kutu, and Yaşar, 2013). Many scientists have worked hard to better comprehend the structure of matter, developing many models and theories. Models and theories are widely used to teach chemistry. In fact, science can be thought of as largely concerned with developing models for diverse aspects of the natural world (Adbo & Taber, 2009). The atom was central to these models and chemical activity (Tuvi and Nachmias, 2001). The concept of atoms dates back to before Christ and took centuries to completely understand (İnce, 2019). This is one of the most significant, popular, and central chemistry concepts and disciplines taught at all levels, from primary to university. It is clear that research into atoms and atomic structure, which we cannot directly observe and are difficult to visualize in our minds and imaginations, has a lengthy history, dating back to Democritus and continuing to the Modern Atomic Theory. Thus, various ideas, models, and explanations for the atom have been developed up to the present. An atom is a unit of matter that cannot be chemically divided. High-energy particle accelerators divide the atom into protons and neutrons, which are made up of quarks and antiquarks (Erdik & Sarıkaya, 2016). In this regard, the atom is one of the most fundamental notions that allow us to comprehend chemistry. To understand and experience the world around us, we must have a solid understanding of chemistry.

As a matter of fact, we make sense of the world by forming concepts and relationships between them. Concepts are also associated with mental structures (Atasoy, 2018). Scientific concepts represent the socially negotiated meanings of phrases or processes that people use to describe their interactions with the physical world (Hubber, 2006). Concepts can be defined as units of thought created by bringing together the common features of certain events, facts, and objects (Laçin-Şimşek, 2019). Concepts provide consistent meaning to events, processes, and objects across individuals (Özgür & Bostan, 2007). Teachers and teacher candidates in chemistry education and training must be knowledgeable about their field and subject. This field and subject knowledge mostly have an abstract structure. In the teaching of chemistry, such subject and field knowledge requires explanations that provide causal relationships between observed phenomena and abstract microscopic dimensions (Wheldon, 2012). Furthermore, students must develop mental models that are based on scientific knowledge of chemical ideas. Students' mental models of a concept provide valuable information about whether or not it is fully grasped. Mental models are shaped by individuals' cognitive systems and how they perceive concepts, and they might offer us information regarding misconceptions that people hold (Demirci, Yılmaz, & Şahin, 2016). Mental models are dynamic mental structures formed by individuals through cognitive processes (Atasoy, 2018). Individuals create mental models when interacting with their surroundings, which are then processed and comprehended in connection to pre-existing mental models (Hubber, 2006). Correct mental models are important guides for producing correct thoughts, and individuals who do not have mental models in accordance with scientific models cannot produce correct thoughts (Atasoy, 2018). Chemistry as a discipline is dominated by the use of models (Coll & Treagust, 2003). Students have difficulty developing mental models that are supported by scientific knowledge about the structure of the atom. Examining students' mental models, including university students, provides us with the required insights to measure their conceptual progress and detect their misconceptions. However, since the existing studies are few in number, studies on mental models related to the structure of the atom need to be expanded (Demirci, Yılmaz & Şahin, 2016). It seems that teachers' views on science-related concepts have been examined extensively in the last thirty years (Papageorgiou & Sakka, 2000). Research on students' mental models of atoms (Nakiboğlu, Karakoç, and Benlikaya, 2002; Özgür and Bostan, 2007) and content analysis of related papers (Demirci, Yılmaz, and Şahin, 2016) were undertaken. Additionally, students' mental models of other concepts in science, such as acid-base (McClary & Talanquer, 2011), ionic bonding (Coll & Treagust, 2003), diffusion (Stains & Sevian, 2015), optics (Hubber, 2006), environment (Shepardson, Wee, Priddy & Harbor, 2007), etc., have not been examined. When the literature is reviewed, it is clear that many studies have been undertaken to determine students' mental models, which include misconceptions about the structure of the atom. However, such research primarily focuses on determining conceptual learning and misunderstandings about the atom and its structure. These types of studies are really essential. It is equally crucial that additional such research be conducted. Conducting contemporary studies on the concept of the atom is critical to determining how the current situation will proceed. The current study seeks to identify which categories science teacher candidates' mental structures about the concept of an atom fall into. It was also investigated whether these mental structures are compatible with today's scientific reality. Thus, the concept of the atom, its structure, and evolution are addressed from a contemporary standpoint.

Purpose and Research Questions

This study sought to uncover the mental structures of science teacher candidates regarding the concept of the atom. The investigation aimed to answer the following questions:

1. What categories do science teacher candidates' mental structures about the concept of an atom fall under?
2. What are the perceptions of science teacher candidates towards the concept of the atom?
3. How do science teacher candidates visualize the concept of an atom in their minds?

Method

This research is a phenomenological study. The goal of phenomenology is to turn lived experience into a description of its "essence," allowing for reflection and analysis (McMillan & Schumacher, 2010). Phenomenological studies are suitable for studying affective, emotional, and often intense human experiences (Merriam, 2009). Phenomenological studies concentrate on phenomena such as events, experiences, perceptions, trends, conceptions, and circumstances that we are aware of but do not fully comprehend (Yıldırım & Şimşek, 2008). The concept of the atom is the phenomenon under investigation in this study. Although students are familiar with the concept of an atom, it is difficult to observe and comprehend because it is an abstract structure.

Participants

This research included 120 science teacher candidates who were selected through the convenience sampling method. A convenience sample is a group of participants chosen because they are easily available or convenient (McMillan & Schumacher, 2010). Participants in this research volunteered to take part and were chosen because they were convenient and easy to reach.

Data Collection Tools

Data on students' mental models of the atom were gathered through the administration of a metaphor form and one open-ended question form. Forms were used to elicit written opinions from teacher candidates. To uncover their metaphors for the concept of atom, teacher candidates were asked to complete the sentence "*Atom is like... because...*" Written opinions of teacher candidates were taken in the form of an open-ended question in order to determine their level of understanding and categories of the concept of atoms. The open-ended question in the form is, "*What do you understand from the concept of an atom? Explain.*"

Data Analysis

Content analysis was performed on the research data. A type of qualitative data analysis is content analysis. Patton (2014) defines content analysis as a qualitative data reduction effort aimed at the basic consistencies and meanings of the loaded and voluminous qualitative material or data received. It is the process of arranging and analyzing similar material within the framework of certain concepts, codes, categories, and themes (Yıldırım & Şimşek, 2008).

In this research, content analysis was conducted in two parts. In the first step, science teacher candidates' understanding of the concept of atom was subjected to content analysis. The data acquired from the form of open-ended questions was examined at this step. As a result of the content analysis, prospective teachers' explanations about atoms were divided into six main categories. These categories and the number of subcodes they contain are as follows: mental structure for the:

1. Atomic models: It contains 223 codes.
2. Structural properties of the atom: It contains 129 codes.
3. Definition/conceptual explanation of the atom: It contains 121 codes.
4. Historical process of the atom: It contains 78 codes.
5. Subatomic particles: It contains 51 codes.
6. Functional function of the atom: It contains 29 codes.

The second stage was to analyze the metaphors created by science teacher candidates on the concept of the atom. This concept's metaphors have been determined. At this point, it was checked to see if the metaphors were written completely and if the reasons behind them were clarified. Codes are used to express the recognized metaphors. The explanations and justifications supplied by teacher candidates for the metaphors were evaluated, and categories reflecting each code, that is, metaphor, were constructed.

Results

The findings of the research were presented in two stages. The results of the open-ended question are included in the first stage, followed by the results of the metaphorical form in the second.

Stage 1: Results Obtained through the Open-Ended Question

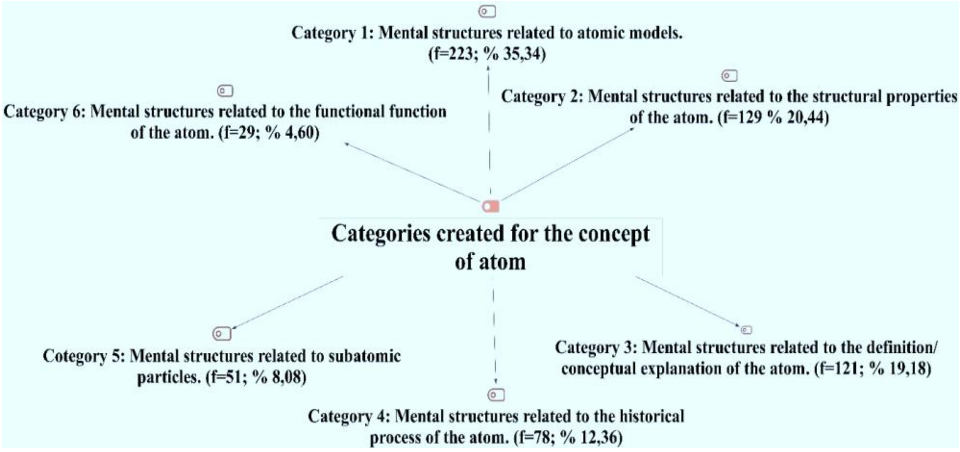

Figure 1. Categories Created for the Concept of Atom.

In the first stage, the categories of the science teacher candidates' mental structures regarding the concept of an atom were determined through open-ended questions.

Figure 1 includes categories related to the concept of atom, in line with the statements of science teacher candidates. As shown in the table, six categories have been defined for the concept of an atom. The six categories were mentioned 631 times in total. The reason for this is that science teacher candidates produced multiple explanations or propositions regarding the atom. It was determined that among these categories, the most common ones were "mental structures related to atomic models" (f = 223, 35.34%). The second category consisted of "mental structures related to the properties of the atom" (f = 129, 20.44%), followed by "mental structures related to the definition/conceptual explanation of the atom" (f = 129, 20.44%). Other categories can be seen in detail in **Figure 1** above. In addition, the codes in these six categories and the percentages and frequencies of these codes are presented in detail in **Tables 1-6**.

Table 1 depicts science teacher candidates' mental structures toward atomic models. As shown in the table, 28 distinct codes have been developed for the structure of the atom. These codes were used 223 times by 120 teacher candidates. The first two of these codes were identified as "There are numerous atomic models" (f = 30 and 13.45%) and "There is a Dalton model of the atom" (f = 29 and 13.01%). It has been observed that 7 of these codes—codes 14, 15, 16, 17, 19, 23, and 27—do not comply with scientific reality, and this rate is 5.40%. The remaining codes were found to match scientific reality at a rate of 94.60%.

Table 2 depicts science teacher candidates' mental constructs regarding the structural properties of the atom. The table shows that 26

Table 1. Science Teacher Candidates' Mental Structures Related to Atomic Models.

N	Codes	f	%
1	There are numerous atomic models.	30	13.45
2	There is a Dalton model of the atom.	29	13.01
3	There is the Thomson model of the atom.	26	11.66
4	There is the Rutherford model of the atom.	22	9.87
5	Thomson likened the atom to a raisin cake model.	20	8.97
6	There is the Bohr model of the atom.	19	8.52
7	There is a modern atomic model.	17	7.62
8	Today, modern atom theory is used as the final atomic theory.	13	5.83
9	In the raisin cake model, the batter or cake represents protons, and the grapes represent free-moving electrons.	8	3.59
10	Dalton stated that an atom is indivisible.	6	2.69
11	Dalton likened the atom to a solid, undivided sphere.	5	2.24
12	Rutherford tried to explain the concept of an atom with the "gold plate" experiment.	4	1.79
13	Democritus proposed the atomic shape.	4	1.79
14	Dalton defined the atom as "hollow globules.".	3	1.35
15	Bohr developed a solid-sphere model for the atom.	2	0.90
16	Rutherford used the concept of orbit for the first time in his atomic model.	2	0.90
17	The atom, according to Bohr, is an electron cloud.	2	0.90
18	Democritus likened the atom to an indivisible part.	1	0.45
19	Rutherford postulated that the atom is made up of a nucleus surrounded by electrons and protons.	1	0.45
20	Bohr postulated that the atom consists of a system of orbitals.	1	0.45
21	According to Dalton, the atoms of all elements are the same.	1	0.45
22	Dalton's atom model made no mention of subatomic particles like protons, neutrons, or electrons.	1	0.45
23	Thomson proposed that the atom is the smallest, indivisible building block of matter.	1	0.45
24	Rutherford employed alpha-rays in her atom model experiment.	1	0.45
25	In the atom, electrons are assumed to be in the electron cloud.	1	0.45
26	The atom has been compared to the world model.	1	0.45
27	The atom is like an empty balloon.	1	0.45
28	According to Bohr's atom theory, there are gaps in the structure we define as an atom.	1	0.45
	Total	223	100

N: Number of codes.

distinct codes have been developed for the structure of the atom. These codes were used 129 times by 120 teacher candidates. The first two of these codes were identified as "An atom consists of subatomic particles such as protons, neutrons, and electrons" (f = 49 and 37.98%) and "Protons and neutrons are present in the atom's nucleus, while electrons are in circles around it" (f = 24 and 18.60%). It has been observed that 9 of these codes—codes 2, 5, 10, 11, 19, 20, 23, 24, and 26—do not comply with scientific reality, and this rate is 29.48%. The remaining codes matched scientific reality at a rate of 70.52%.

Table 3 depicts science teacher candidates' mental structures considering the definition or conceptual explanation of the atom. As shown

Table 2. Science Teacher Candidates' Mental Structures Related to the Structural Properties of the Atom.

N	Codes	f	%
1	An atom consists of subatomic particles such as protons, neutrons, and electrons.	49	37.98
2	Protons and neutrons are present in the atom's nucleus, while electrons are in circles around it.	24	18.60
3	Atoms can be split and divided.	13	10.08
4	The majority of atoms are hollow.	6	4.65
5	Atoms cannot be divided, or disintegrated.	5	3.88
6	Matter cannot be split into atoms and analyzed under normal conditions.	3	2.33
7	In laboratory environment, atoms of matter can be investigated.	3	2.33
8	The majority of atomic mass is made up of nuclei.	2	1.55
9	Protons and neutrons are concentrated at the center of the atom, while electrons form an electron cloud surrounding it.	2	1.55
10	The atom is mobile.	2	1.55
11	An atom is shaped like a solid sphere.	2	1.55
12	There are isotope atoms.	2	1.55
13	There are isotone atoms.	2	1.55
14	There are isoelectronic atoms and ions.	2	1.55
15	Isotope atoms have the same number of protons but differ in the amount of neutrons.	1	0.78
16	Isotone atoms have the same number of neutrons but differ in the number of protons.	1	0.78
17	Isoelectronic atoms and ions have the same number and configuration of electrons.	1	0.78
18	There are isobar atoms.	1	0.78
19	Elements are in a cycle within the atom.	1	0.78
20	Atoms are the most basic structure of subatomic particles.	1	0.78
21	Each atom has its own mass number.	1	0.78
22	Electrons rotate both around themselves and the nucleus.	1	0.78
23	The orbit closest to the nucleus has the smallest energy.	1	0.78
24	The energy of the orbitals increases as they move away from the nucleus.	1	0.78
25	The atomic structure contains both positive and negative charges.	1	0.78
26	There are atoms in the molecular structure.	1	0.78
	Total	129	100

N: Number of codes.

in the table, 17 distinct codes were developed for the defining or conceptual explanation of the atom. These codes were used 121 times by some of the 120 teacher candidates. The first two of these codes were identified as "An atom is the smallest unit of matter" (f = 68 and 56.20%) and "An atom is the smallest particle of matter that can be divided" (f = 12 and 9.92%). It has been observed that 9 of these codes—codes 1, 2, 7, 8, 9, 10, 11, 14, and 17—do not comply with scientific reality, and this rate is 76.85%. The remaining codes were discovered to be compatible with scientific reality at a rate of 23.15%.

Table 3. Science Teacher Candidates' Mental Structures Related to the Definition/Conceptual Explanation of the Atom.

N	Codes	f	%
1	An atom is the smallest unit of matter.	68	56.20
2	An atom is the smallest particle of matter that can be divided.	12	9.92
3	An atom is a unit of matter made up of small structures and subatomic particles known as mesons and quarks.	9	7.44
4	The atom is the smallest unit of matter that possesses all of its properties.	6	4.96
5	The atom is the most fundamental particle of matter.	6	4.96
6	An atom is the smallest particle of matter that may be divided into smaller pieces and retains all of its properties.	5	4.13
7	An atom is a unit of matter that exhibits all of its qualities and cannot be divided into smaller parts.	3	2.45
8	An atom is the smallest particle of an element.	2	1.65
9	An atom is a model that has protons and neutrons in its nucleus and electrons moving in layers around it.	2	1.65
10	An atom is the concentrated form of the energy of matter.	1	0.83
11	An atom is matter's smallest energy state.	1	0.83
12	The atom is the smallest structural unit that describes the physical and chemical properties of matter.	1	0.83
13	An atom is a unit that exhibits the properties of matter.	1	0.83
14	An atom is defined as everything that occupies space and has mass.	1	0.83
15	The atom is the fundamental structural unit of the universe.	1	0.83
16	Atoms are models of atomic processes.	1	0.83
17	An atom is energy that can change into solid, liquid, gas, or plasma and is in a constant state of motion and vibration.	1	0.83
	Total	121	100

N: Number of codes.

Table 4. Science Teacher Candidates' Mental Structures Related to the Historical Process of the Atom.

N	Codes	f	%
1	When the first atom theories were proposed, the atom was thought to be indivisible.	21	26.92
2	Theories, models, and concepts that the atom is divisible have been proposed over time.	19	24.36
3	Many researches have been conducted on the atom up to the present day; it has gone through many processes, and many scientists have thought and produced ideas on the atom.	17	21.78
4	Democritus named it "atomus" originally, which means "indivisible" in Greek.	8	10.26
5	With modern atomic theory, it has been seen that the atom is divisible.	3	3.85
6	Chadwick discovered the neutron.	2	2.56
7	Rutherford discovered the proton.	2	2.56
8	Thomson discovered the electron.	2	2.56
9	Dalton made the first definition and study of the atom.	2	2.56
10	Following Democritus, Dalton conducted the first examination of the atom model.	1	1.28
11	Aristotle explained the atoms as fire, water, air, and earth.	1	1.28
	Total	78	100

N: Number of codes.

Table 5. Science Teacher Candidates' Mental Structures Related to Subatomic Particles.

N	Codes	f	%
1	Protons have a positive charge.	12	23.53
2	Electrons have a negative charge.	12	23.53
3	Neutrons have no charge.	10	19.61
4	Orbitals are the most likely locations for electrons to be discovered.	2	3.92
5	Electrons are being exchanged.	2	3.92
6	The number of protons represents the atomic number.	1	1.96
7	Subatomic particles such as electrons, neutrons, and protons are not the smallest particles of matter because they lack matter's characteristics.	1	1.96
8	When an atom acquires an electron, it becomes an anion.	1	1.96
9	When an electron is lost, the atom is transformed into a cation.	1	1.96
10	There is no proton exchange.	1	1.96
11	There is no neutron exchange.	1	1.96
12	Electrons make up the majority of the atom volume.	1	1.96
13	The mass of the electron is very small compared to other subatomic particles such as protons and neutrons.	1	1.96
14	When electrons move from the upper orbit/layer to the lower orbit/layer, they emit light.	1	1.96
15	Electrons become more stable as they move away from the nucleus.	1	1.96
16	Electron orbits/layers are formed when protons and electrons interact electrically.	1	1.96
17	Ionic bonding occurs through electron exchange.	1	1.96
18	Covalent bonding occurs as a result of electron sharing.	1	1.96
	Total	51	100

N: Number of codes.

Table 4 depicts the mental structures of science teacher candidates regarding the historical process of the atom. As shown in the table, 11 distinct codes have been created for the historical process of the atom. These codes were mentioned 78 times by some of the 120 teacher candidates. The first two of these codes were determined to be "When the first atom theories were proposed, the atom was thought to be indivisible." (f = 21; % 26, 92) and "Theories, models, and concepts that the atom is divisible have been proposed over time." (f = 19; % 24, 36). It was observed that three of these codes—codes 5, 9 and 11—did not comply with scientific reality, and this rate was 7.69%. The remaining codes were found to match scientific reality at a rate of 92.31%.

Table 5 depicts the mental structures of science teacher candidates regarding subatomic particles. As seen in the table, 18 different codes have been developed for subatomic particles. It was observed that these codes were expressed 51 times by some of the 120 teacher candidates. The first two of these codes were determined to be "protons have a positive charge." (f = 12; % 23.53) "Electrons have a negative charge." (f = 12; % 23.53). It

Table 6. Science Teacher Candidates' Mental Structures Related to the Functional Function of the Atom.

N	Codes	f	%
1	Atoms exhibit the properties of matter.	8	27.59
2	Atoms combine to produce compounds.	4	13.79
3	Atoms determine the character / properties of elements.	3	10.35
4	Atoms combine to form molecules.	3	10.35
5	The atom determines the chemical properties of matter.	2	6.90
6	The atom determines the physical properties of matter.	2	6.90
7	When atoms are divided, enormous amounts of energy are released.	2	6.90
8	When atoms unite, new substances are produced.	2	6.90
10	When different or the same atoms are joined, they generate atoms with various structures.	1	3.35
11	Atoms are responsible for the transmission of electricity.	1	3.35
	Total	29	100

N: Number of codes.

Table 7. Metaphors Created for the Concept of Atom.

Categories	Codes	f	%
Functional function of the atom	Cell (f=12), Water (f=3), Material / Cement (f=3), Human (f=2), World (f=2), Sun (f=2), Culture (f=2), Letter (f=2), Puzzle/Lego pieces (f=2), Fetus/Zygote (f=2), Backbone of chemistry, Memory substance (Chip), Soil, Essence, Gravity, Organ, Mother, Inside of an Onion, Brain, The tip of a pencil, A piece of wood, Bricks, Family, Nebula, Teacher, Stone, Breath, Bead, Core, Life, Heart, Tree, Seed, Complex fruit juice.	56	46.67
Atom models	Solar system (f=8), Earth (f=8), Round ball (f=3), Universe (f=2), Onion (f=2), Planet Saturn, School, House, Avocado, Human body, Lahmacun, Olives, Menthol candy, Dust cloud, Baklava, Peach.	34	28.33
Structural properties of the atom	Class (f=2), Human (f=2), One of the Pomegranates (f=2), Book (f=2), Magma, Universe, Seed, Building, Dot, Bacteria, Ant, Society, Cake, Water, Cone, Emotions, Soil, Hospital, Family, Cell, House, Hazelnut, Fruit cocktail, Education system, Matryoshka, Chemistry.	30	25.00
Total		120	100

was observed that four of these codes—codes 7, 14, 15, and 16—did not comply with scientific reality, and this rate was 7.84%. The remaining codes were found to match scientific reality at a rate of 92.16%.

Table 6 depicts the mental structures of science teacher candidates regarding the functional function of the atom. The table shows that 11 different codes were created for the atom's functional function. It was observed that these codes were stated 29 times by some of the 120 teacher candidates. The first two of these codes were determined to be "Atoms exhibit the properties of matter." (f = 8; % 27, 59) and "Atoms combine to produce compounds." (f = 4; % 13, 79). It was observed that two of these codes—codes 10 and 11—did not comply with scientific reality, and this rate was 6.7%. The remaining codes were found to match scientific reality at a rate of 93.3%.

Stage 2: Results Obtained through the Metaphor Form

Table 7 shows science teacher candidates' metaphorical perceptions of the concept of atoms. The table shows that their metaphorical views were divided into three categories. The categories are "functional function of the atom," "atomic models," and "structural properties of the atom".

Table 7 shows that science teacher candidates' metaphorical perceptions were primarily categorized as "functional functions of the atom" (f = 56, 46.67%). It was established that the code "Cell" (f = 12) was the most common in this category. In the second category, it was determined that there were "atomic models" (f = 34, 28.33%), and under this category, the codes "solar system" and "world" (f = 8) were mostly mentioned. In the third category, "Structural properties of the atom" (f = 30, 25.00%) was included, and it was determined that codes such as "Class," "Human," "One of the pomegranates," and "Book" (f = 2) were the most repeated. According to the statements of the teacher candidates, some codes, such as human, universe, water, and sun, although they are the same, is placed in different categories in terms of their meaning. **Table 7** contains detailed information on the three main categories and their sub-codes.

Conclusion and Discussion

As a result of the research, the mental structures of science teacher candidates regarding the concept of the atom were grouped into six main categories. It has been revealed that atom models are most vividly represented in the mental structures of science teacher candidates while discussing the concept of the atom. Then, respectively, mental structures related to the structural properties of the atom, the definition or conceptual explanation of the atom, the historical process of the atom, subatomic particles, and the functional function of the atom emerged. When the codes under these categories were examined in detail, it was seen that the explanations put forward were very superficial. In addition, it has been revealed that macroscopic explanations for the concept of atom are dominant, and the concept of atom cannot be detailed as we go to the microscopic dimension. It has also been discovered that some codes, or explanations in this category, contradict scientific knowledge. The codes in each category are addressed separately.

In the first category, the mental structures of science teacher candidates regarding atomic models were collected under 28 codes. These codes were most commonly expressed by teacher candidates. In other words, when teacher candidates hear the word "atom," they immediately think of atomic models. Teacher candidates mostly stated the names of models such as Dalton, Thomson, Rutherford, Bohr, and Modern atomic theories that were developed, respectively. However, some teacher candidates stated that the most recently developed atomic theory is the Modern Atom Theory. This has revealed that the atom and the atom model in the minds of the teacher candidates are not compatible with today's Modern Atom Theory. In addition, some of the statements of the teacher candidates in this category, although very few, such as "Dalton defined the atom as hollow globules," "Bohr developed a solid-sphere model for the atom," and "Rutherford used the concept of orbit for the first time in his atomic model," contradict scientific knowledge. Codes 14, 15, 16, 17, 19, 23, and 27 are also in opposition to scientific knowledge, with a relatively low rate (5.40%). The remaining codes have correct information (94.60%). Although these codes contain accurate information and are at a high rate, they only explain the features of atomic models developed before the Modern Atom Theory that are no longer valid today. In the second category, the mental structures of teacher candidates regarding the structural properties of the atom were revealed. Teacher candidates stated 26 different codes in this category 129 times. When the codes in this category are checked, most teacher candidates indicate that the atom is made up of subatomic particles like protons, neutrons, and electrons. This situation is similar to previous studies (Ekinci & Şen, 2020), where most of the students tend to explain and describe the classical structure of the atom. Furthermore, teacher candidates indicated that the atom is fissionable, has a hollow structure, and cannot be viewed or examined under normal circumstances. It has been noted that the statements made here are only superficial, and the microscopic structure of the atom cannot be fully explained. Additionally, some codes in this category do not match scientific knowledge. The second code in this category, "Protons and neutrons are present in the atom's nucleus, while electrons are in circles around it," contradicts scientific knowledge. Bohr Atom Theory defines the structure of an atom using this code. In addition, codes 5, 10, 11, 19, 20, 23, 24, and 26 do not comply with scientific reality, and this is 29.48%. This rate can be considered significantly high. The remaining codes agree with scientific reality by 70.52%. The high rate and compatibility with scientific knowledge should not deceive scientists or researchers. Because, despite the high rate, teacher candidates do not employ modern atom theory to explain the structure of the atom, instead merely superficially discussing the existence of subatomic particles. Also, it has been noticed that the Bohr atom model is more prevalent in the thoughts of teacher candidates. Similar to previous studies (Allred & Bretz, 2019; Ekinci and Şen, 2020; Harrison and Treagust, 1996; Harrison and Treagust, 2000; McKagan, Perkins, and

Wieman, 2008; Nakiboğlu, Karakoç, and Benlikaya, 2002; Özcan, 2013; Özgür and Bostan, 2007), this current study revealed that the structure of the atom is still mostly trying to be explained according to the Bohr atom model. The explanations focused on the concept of "orbit or layer" and made statements that are no longer valid today and do not comply with scientific reality. While students draw and visualize the structure of the atom, it seems that the modern atomic model is neglected (Derman, Koçak, and Eilks, 2019). On the other hand, although Modern Atom Theory is shown in lessons, this situation is reflected in the mental models of very few students (Demirci, Yılmaz, and Şahin, 2016). It should be evident that in modern atomic models, electrons do not "fly around" in the atoms, nor are they concretely "located" in or on any form of shell or circle. However, if teacher educators use the shell metaphor to explain quantum numbers and their accompanying energy levels, science teacher candidates may understand this as "forming shells (Derman, Koçak and Eilks, 2019). According to current modern atom theory, an atom consists of a nucleus in the center and a cloud of electrons surrounding it. Based on this, when explaining the structure of the atom, the electron cloud and orbitals, which are places where electrons are likely to be found, should be brought to the fore. It is important to develop analogies and metaphors for this purpose and use them in science lessons.

In the third category, the mental structures of teacher candidates regarding the definition or conceptualization of the atom were revealed. When the codes in this category were examined in detail, it was seen that the teacher candidates had serious deficiencies and had difficulties conceptualizing the atom. The first two codes in this category say, "An atom is the smallest unit of matter." and "An atom is the smallest particle of matter that can be divided" entirely contradicts modern definitions of the atom. In addition, codes 7, 8, 9, 10, 11, 14, and 17 do not comply with scientific reality, which is 76.85%. The atom is often explained as the smallest piece of matter, the smallest piece of matter that can be divided, the smallest piece of matter that shows all the properties of matter and cannot be divided into smaller pieces, etc. It may be argued that the phrase "smallest" is the one that misleads teacher candidates, students, and pupils. In other words, when discussing the concept of an atom, explanations center on the phrase "smallest," omitting or ignoring all other aspects. The teacher candidates and learners may not be inclined to consciously make such a statement. But what is vital is that the phrase "smallest" gets entrenched in the minds of the teacher candidates and sticks like a nail. This can be considered the foundation of explanations that contradict scientific knowledge. As a matter of fact, while students' mental structures regarding the structure of the atom are examined, concepts such as nucleus, atomic model, mass, particle, electron, and layer or shell come to the fore (Ekinci and Şen, 2020). As can be seen, “particle” is one of the concepts that students associate with. Gradually, this expression “particle” is being replaced by the expression “smallest particle”. The point to underline here is that it is felt that it would be more appropriate to use phrases such as a representative component or unit that explains a property of the matter rather than the smallest part. In this respect, it can be said that it would be more appropriate to define an atom as a part, unit, and structure that determines and characterizes the chemical properties of matter. In the fourth category, teacher candidates’ mental structures on the historical process of the atom were investigated. Teacher candidates explained that the atom has gone through a number of processes until now, that many scientists have thought about the atom and produced ideas, and that it has been the subject of many studies based on a long historical past. They emphasized that when the first atom theories were put forward, the idea that the atom was indivisible was dominant. But they said that over time, theories, models, and ideas were put forward that the atom was divisible. Explanations in this category contain some superficial information about the historical process and development of the atom. The majority of this information appears to agree with scientific knowledge. However, as stated in codes 5, 9, and 11, comments that contradict scientific reality were made, albeit in small numbers, with a rate of 7.69%, which is low. For example, some teacher candidates stated that the atom is divisible according to modern atomic theory. This information or explanation is erroneous, and it was proven that the atom is divisible and that there are subatomic particles long before the Modern Atomic Theory. In the fifth category, the mental structures of teacher candidates regarding subatomic particles were revealed. Teacher candidates mostly focused on the statements “protons are positively charged,” “electrons are negatively charged,” and “neutrons are uncharged.”. They mostly explained the charges of subatomic particles. They also stated that electrons exchange between atoms, but protons and neutrons do not interchange, and that ionic and covalent bonds are formed through electron transfer or sharing. However, they did not mention subatomic particles such as quarks, mesons, etc. other than protons, neutrons, and electrons. It has been recognized that explanations that are incompatible with modern atomic theory have been made, as well as deficiencies in understanding subatomic particles using modern atom theory. However, only two teacher candidates identified the locations where electrons are most likely to be found, as well as the phenomenon or concept of orbitals. It can be argued that there are major deficiencies in explaining teacher candidates’ mental structures relating to atomic particles in detail and that these are not at the microscopic level. However, some codes, albeit very few—codes 7, 14, 15, and 16—do not comply with scientific reality. The phrases used in the codes, such as “Subatomic particles such as electrons, neutrons, and protons are not the smallest particles of matter because they lack matter's characteristics," and "when electrons move from the upper orbit/layer to the lower orbit/layer, they emit light," are just a few examples. Here again, while subatomic particles are explained, the focus is on the Bohr atom model and the expression of the smallest particle of matter. This makes it difficult to perceive, understand, and remember subatomic particles. In the final category, teacher candidates' mental structures about the functional function of the atom were revealed. Teacher candidates explained the functional function of the atom using codes such as "Atoms exhibit the properties of matter," "Atoms combine to produce compounds," "Atoms determine the character and properties of elements,", "Atoms combine to form molecules," "The atom determines the chemical properties of matter," and "The atom determines the physical properties of matter". Although very few statements were made that contradict scientific knowledge, as can be seen from the codes, "When different or the same atoms are joined, they generate atoms with various structures." and "Atoms are responsible for the transmission of electricity."

In this research, teacher candidates' mental structures regarding the concept of the atom were examined. Students or learners have difficulty creating mental models for the concept of the atom (Çökelez, 2012). Students' misunderstanding of concepts causes them to create non-scientific mental structures and models regarding science concepts (Didiş-Körhasan and Wang 2016). In science classrooms and lessons, analogies like the solar system, the cell, and the shell metaphor are used to convey the notion of the atom. Before employing analogies and metaphors with students in scientific classrooms, teachers openly clarify their importance in both common language and science (Derman, Koçak and Eilks, 2019). Similar results were obtained in this study, and it was discovered that the solar system and the word model emerged as prominent metaphors in the teacher candidates' atom-related metaphors. As a conclusion, in this current study, while explaining the atom, teacher candidates focused on atomic models, structural properties of the atom, the definition or conceptualization of the atom, the historical process of the atom, subatomic particles, and the functional function of the atom. While teacher candidates explain the atom using these categories, they may have some deficiencies and mistakes. It is obvious that these explanations are very superficial. It has also been noticed that they cannot make sense of the atom by reducing it to a microscopic level. But it is also important that they focus on these six categories. Because when we say atom, these categories explain how the atom comes to life in the imaginations of teacher candidates in particular and learners in general. The most crucial aspect is that these six categories should be interpreted and supported by current atomic theories, theses, and scientific knowledge. This may take some time and prove tough in the short term. However, it should not be forgotten that the concept of the atom was developed more than 2,000 years ago. It is a well-known yet complex concept that takes a long time and involves several processes. It can also be argued that the concept and structure of the atom gained a fully scientific identity over the last two centuries, beginning with the Dalton atom theory and continuing with modern atom theory. Of course, it will be difficult for the concept of the atom, which takes a long time, is significant, and is the foundation of science and chemistry, to be fully grasped, precisely, and in harmony with scientific knowledge, as well as to be structured in the minds of the students or learners. However, realizing this makes it necessary to take precautions and make appropriate arrangements. There is no need to wait another 2000 thousand years for the atom to be comprehended and perceived. However, even if it will take a long time for the concept of the atom, which is compatible with scientific knowledge, to become embedded in the minds of the students, this risk must be taken.

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