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Research Article

Addressing student misconceptions about atoms and examining instructor strategies for overcoming them

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This paper is twofold. First, it examines the misconceptions held by students about atoms. Second, it determines the suggestions of the instructors (academics and teachers) to overcome these misconceptions. The study adopted a case study research method. A questionnaire was administered to 288 students and a semi-structured interview was conducted with 20 educators, including 10 teachers and 10 academics from the fields of physics and chemistry. A number of students were observed to have misconceptions about atoms, and they were unable to grasp the concept. This situation may have resulted from teaching students the theories of the atoms in a historically chronological order and ineffective methods of teaching. It was recommended that atomic models not be taught in primary school education, and that three new methods could be used in teaching this subject.

Keywords: Atoms; Atomic models; Misconceptions; Suggestions of academics and teachers

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1. Introduction

Teaching the concept of the atom, which greatly contributes to economic and technological development, opens up new horizons for humanity. Identifying deficiencies in this area and finding solutions is therefore important. In recent years, physical facts about atom structure have emerged and their inclusion in course books and curricula has been delayed. In addition, the fact that there are many theories about atoms has caused confusion about its teaching (Kilic, 2010). In spite of the fact that models (pictures and representations) of atoms are commonly used, they can fail to accurately represent an atom and may even contain errors (Yaseen & Akangul, 2016). In particular, due to its microscopic and abstract structure, it is difficult to understand for students of all ages (Cokelez & Duman, 2005; Griffiths & Preston, 1992). Hejnová and Králík (2019) argue that in addition to their own beliefs, students also hold misconceptions caused by poorly designed education. The abstract nature of atoms and their size smaller than the microscopic dimension are causes for difficulty when teaching the concept of atoms.

To determine students' level of understanding of the concept of the atom and their misconceptions, the status of the concept of the atom in course-books, mental models of the atom, and the effect of different methods of teaching the concept of the atom, various studies have been conducted. It has

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been stated in almost all studies that it is difficult to understand the concept of atoms, and that students have many misconceptions about it (Akyol, 2009; Alkan, 2022; Ayaz, 2020; Aygen 2019; Basaran & Gozutok, 2022; Bilir et al., 2018; Cardoso et al., 2020; Cokelez & Duman, 2005; Demirci et al., 2016; Ekinci & Sen, 2020; Hejnová, & Králík, 2019; Kilici, 2019; Kiriktaş, 2023; Ozkan, 2019; Yaseen & Akangul, 2016; Zarkadis et al., 2020). In all grade levels, there was a significant difference between students' mental models and atomic model representations in textbooks (Yaseen & Akangul, 2016). In a study by Akyol (2009), most physical sciences and chemistry teacher candidates created atomic models in their minds that resembled the Rutherford and Bohr models. Additionally, students had difficulty developing a mental model of the concept of atoms (Cokelez & Duman, 2005; Demirci et al., 2016; Hejnová, & Králík, 2019). Cokelez and Yalcin (2012) found that students had a lack of knowledge and experience about atomic models. Griffiths and Preston (1992) determined that course-books generally included conflicting atomic models, leading to student confusion. As reported in Kilic (2010), teachers had difficulties understanding the concepts related to the theories of the atoms included in the textbooks. As Park and Light (2009) discovered in their study conducted in the USA, students need to use their own experiences to understand the concept of atomic structure from their perspective. Concept maps were used by Ekinci and Sen (2020) to teach the concept of atoms. It was determined, however, that the students were not successfully able to link the concepts in a meaningful way to produce new meanings or propositions related to the quantum nature of the atom. A study by Demircioglu et al. (2012) examined the effect of concept change text and three-dimensional models on 7th graders' understanding of the atom's structure. Researchers found that using three-dimensional models and concept change texts together in teaching improved students' understanding of the structure of the atom and corrected alternative concepts. A study conducted by Niaz et al. (2002) found that students' conceptual understanding could be enhanced through class discussions based on Piaget's principle of learning through discovery.

Several methods were studied in these studies to overcome difficulties experienced during the teaching of atoms in order to overcome the difficulties. Most of these methods failed, while others required a long time to be implemented.

In terms of physical science teaching in schools, understanding the atom is very important. Many chemistry subjects such as chemical bonds and molecular structure, as well as biology subjects such as the main components of living things and physics subjects such as electricity, magnetism, and metallic conductivity, are based on the concept of atoms (Aygen, 2019). Due to misconceptions and knowledge deficiencies related to the concept of atoms, students will have difficulty understanding physics, chemistry, and biology starting in primary school, which in turn will affect their academic lives, lead to misconceptions, and decrease their interest in physical sciences courses in the future.

The misconceptions encountered in the teaching of the concept of the atom and the problem of not comprehending this concept adequately continue to exist, as noted above.

1.1. The Aim

This study examines teaching difficulties, misconceptions, and causes related to atom concepts and suggests ways of resolving them. Answers to the following research questions were sought:

RQ 1) What are the misconceptions of elementary (6-14 years), high school (14-18) and university (18+) students related to atoms?

RQ 2) What is the student understanding in terms of the concept of atoms (its definition, structure, and shape)?

RQ 3) What are the opinions of field experts on what can be done in order to correct misconceptions and improve comprehension levels regarding the concept of atoms?

2. Method

To identify the difficulties, misconceptions and causes associated with teaching the concept of the atom, and to offer solutions to these problems, a case study method was utilized. Case studies offer the opportunity to examine a group of people, issues, problems, or programs in depth (Marrais & Lapan, 2004). In some very complex cases, case studies can be used to explain cause-effect relationships or inform decision-making mechanisms (Yin, 1994). Moreover, case studies allow for detailed analysis of a situation within certain boundaries (Merriam, 2015).

2.1. Participants

Two groups were included in the study. In the first group, students were assessed on their understanding of the atom and misconceptions about it. The first group consisted of 357 students in total, 40 of whom were 8th grade students, 152 of whom were Science and Anatolian high school 12th grade students, and 165 of which graduated from a department in high school that included courses on the atom and atomic models. However, some of these selected students did not respond to most of the questions on the questionnaire and chose the same answers for all questions; therefore, they were not included in the analysis. Consequently, the first group of students consisted of 288 in total, including 28 eighth-graders, 124 students from 12th-grade Science and Anatolian high schools, and 136 university freshmen. In the second group, 20 educators were interviewed in order to find out their opinions on the difficulties encountered in understanding the concept of atoms, and to eliminate misconceptions regarding it. Table 1 below shows the fields and careers of educators.

Table 1
Academics and teachers in the study sample

	Title				
Expertise Field	Prof. Dr.	Assoc. Dr.	Dr. Instructor Member	Teacher	Total
Physical	1	3	1	5	10
Chemical	2	2	1	5	10
Total	3	4	2	10	20

2.2. Instruments

The study data was collected using a questionnaire and a semistructured interview form. Students in elementary school, high school, and university were asked to complete the questionnaire in order to identify their understanding of the concept of atoms and their similarities in the literature-based misconceptions. The questionnaire consists of two sections. In the first section of the questionnaire, two open-ended questions and one multiple-choice question are included. These questions were derived from the literature (Ehab et al., 2018; Kaya, 2010). As part of the first question, students were supposed to define atoms and explain their structure, while part of the second question was asked to draw the shape of the atoms they imagined. For the third question, the students were provided with four visuals related to the atomic models in the course-books, and were asked to select the option that represented the atom best. In the second section of the questionnaire, students were provided with 34 concepts consisting of true or false statements related to the misconceptions in the literature and the structure of the atom, and they were asked to respond to these statements by choosing "True", "False", or "No idea".

For the purposes of ensuring the validity of the questionnaire, five academic experts (4 of physics and 1 of chemistry) reviewed the questions on the basis of content, coverage, and appearance; a few questions were revised, three concepts that were perceived to repeat the same subject were removed, and the questionnaire was finalized after adding five concepts. In order to test the reliability of the questionnaire, it was administered two times with a two-week interval to 20 students in a science high school. The Cronbach's alpha consistency coefficient of the questionnaire was .82, which indicates high reliability.

Four questions were asked of the teachers in the interviews about the difficulties encountered when teaching the atoms and what could be done to overcome them. In the interviews held with the academics, they were informed about the problems determined in the literature and their opinions on how to overcome these problems were asked. Two teachers were interviewed as part of a pilot study to ensure the validity of the interview form, and their responses were analyzed. One question that caused misunderstanding was then removed, and other questions were revised as recommended. In order to provide the reliability of the interview form, three field experts examined the answers provided by academics and teachers. Experts reported that the responses were consistent. As a result, the study provided reliable, credible, transferable, and verifiable data.

Data were collected from the students in the study through the administration of a questionnaire at the beginning of the academic year. Therefore, the students' knowledge of atoms was derived from their previous education. This means that they gained their knowledge through elementary school education (between the ages of 6-14 years) and high school education (between the ages of 14-18 years).

2.3. Data Collection Process

The study was conducted during the fourth week of fall semester of 2022-2023. Upon permission of the school administrations and teachers, the questionnaires were administered by the teachers under the researcher's supervision in 35 minutes.

Interviews lasted between 30 and 45 minutes. Interviews were conducted without a time limit. As the interviewees did not permit recording audio files, important points during the interview and information remembered by the researcher after the interview were noted.

2.4. Data Analysis

Qualitative and quantitative techniques were used to analyze the data. The responses to the open-ended questions in the first section of the questionnaire were categorized according to their similarity, and the students' opinions for each situation were presented as numbers. In the second part of the questionnaire, the frequency and percentage of answers given to the multiple choice questions as "True", "False", and "No idea" were presented. Percentage values were used as a basis for evaluation.

Qualitative data analysis techniques were used to categorize the interview data as primary data or irrelevant data. Primary data were classified based on similarity, and common opinions were calculated based on their frequency. One professor, two associate professors, and one doctoral faculty member discussed the applicability of these in a group.

3. Findings

Results from the questionnaires and interviews are presented under separate headings.

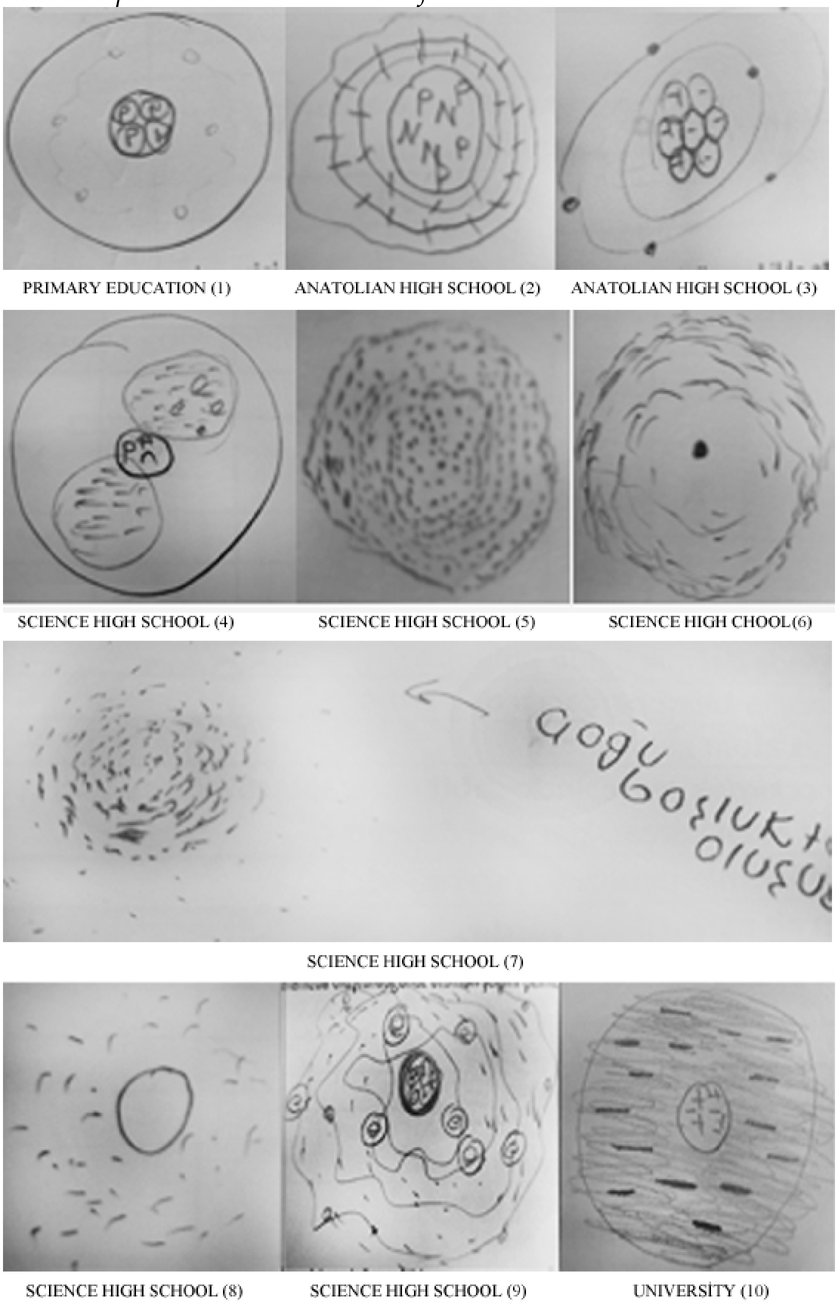
3.1. Findings from the Questionnaire

"What is an atom?" was correctly answered by only 11 of the 288 students. The majority of students (f = 209) answered the question as "it is the smallest building block of matter." Other responses included "it is the smallest indivisible building block of matter" (f = 2), "it is the smallest building block of a cell" (f = 15), "it is the primary matter" (1), and "atoms cannot be divided" (f = 15). Among the students, 36 did not answer this question.

Regarding the structure of an atom, more than half of the students (f = 166) responded that an atom is made up of protons, neutrons, and electrons, and protons and neutrons are in the nucleus, while electrons are around the nucleus. There were different opinions expressed by some of the students (f = 73) about where electrons move. There are three related answers: "electrons are at the orbitals" (f = 23), "electrons are at the orbits" (f = 30), and "electrons look like clouds" (f = 20). Other students used expressions about the structure of the atom, such as "an atom is made up of protons, neutrons, electrons, and quarks" and "an atom is made up of protons, neutrons, electrons, orbit, and nucleus" (f = 5). Other than quarks, the students did not mention any other subatomic particles. Only 29 students expressed an opinion on the shape of the atom. A number of students expressed "it has a sphere-like shape" (f = 17), "it is round" (f = 3), and "most parts of it are void" (f = 6). One student described it as having an elliptical shape, one student described it as being like an empty sphere within.

Students were asked to draw the shape of the atom they defined in the first question. Most of the shapes of the atom (f = 254) drawn by the students were similar to the shapes they saw in the course books. Models of the Bohr atomic (f = 102), the modern atomix (f = 91) and the Rutherford atomic (f = 61) were drawn. Furthermore, 24 students did not draw any shapes, while 10 students drew the shapes they imagined (Figure 1).

Figure 1
Atom shapes created in the minds of the students



Students who created atomic model shapes in their minds were mainly science high school students, and the shapes they drew resembled the shape of the atom in the modern atomic theory adopted by the world.

According to the students, the most correct shape of the atom was drawn by students using the modern atomic theory ($f = 110$), the Bohr atomic model ($f = 105$), and the Rutherford atomic model (69). The Thomson atomic model was not drawn by any student. There were four students who did not respond to this question. Also, the students were asked why they preferred the atom shape they drew. There were only 26 students who answered this question. There were three answers: "Electrons surround the nucleus like a gas cloud" (6), "You cannot find electrons" ($f = 4$), and "Electrons are in orbitals" ($f = 3$). Based on the Rutherford atomic model, the answers were "electrons are on certain orbits" ($f = 3$), "the orbits don't have a circular shape" ($f = 2$), and "it's the shape I saw most closely related to an atom" ($f = 1$), and "this is what we've been taught" ($f = 19$). When it comes to the Bohr atomic model, the responses were "electrons move on orbits" ($f = 4$), "protons are in the middle and electrons are orbiting around them" ($f = 1$), and "the nucleus is in the middle and orbits surround it" ($f = 2$).

Table 2 shows the frequency and percentage values of students' responses to statements including misconceptions about atoms, facts, and incorrect judgments. According to Table 2, %72 of the students believe that the statements "The atom is the most essential and basic structure of a cell" and "The nucleus of the atom has a spherical shape" are true, even though these are two common misconceptions. By far the lowest percentage of "True" responses were in the misconceptions "An atom does not have any sub-particles" by 9% and "Atoms that make up the basis of each matter have the same properties" by 10%. In addition, 13% of students responded as "True" to the misconception that "The atom is indivisible".

Based on the table, certain percentages of students answered "False" to the true statements about the atom. These percentages, however, were quite high in regards to some statements. Some of these high ratios were related to the concept that "An atom cannot be observed in any way (stimulation, etc.)" (95%), "Each particle in an atom has a counter particle" (41%), "Some atoms can go into fission on their own" (33%), "In an atom, electrons behave like particles moving around the nucleus" (27%), and "The nucleus covers a small part of the volume of the atom (25%).

3.1. Findings from the Interviews

3.1. Findings from the interviews held with the teachers

When teachers were asked to reflect on their difficulties during the instruction of atoms, the majority of them ($f = 7$) emphasized that the inclusion of the concept of atoms in the curriculum and its teaching according to the historical chronology led to confusion in the minds of students, since what is read first stays in their minds. Additionally, these teachers emphasized that because the atom is smaller than microscopic dimensions and an abstract concept, they found it difficult to give examples from their environment and present the subject. They also stated that when students prepared for the lesson with the information they gleaned from various sources such as books, encyclopedias, the Internet, etc., they had difficulty understanding the concept of the atom. A teacher stated that the emergence of some physical facts regarding the concept of the atom in recent years, and the inclusion of these facts in the curriculum and course-books in a delayed manner, have made the teaching of the concept more challenging. In four cases, teachers reported that the variety of atomic models caused confusion and made teaching the subject difficult. According to four teachers, students were not interested in the course, which made it difficult to teach it.

Another question asked teachers to explain why students have difficulty understanding the concept of an atom. It was reported by seven teachers that students are not interested in learning because they are not interested in learning in general. Six teachers stated that students had difficulty learning due to the large number of atomic models and their teaching according to historical chronology. There were three teachers who stated that although the first models were simpler, students were able to understand them, but the later models were harder to grasp. Five of the teachers expressed that students had difficulty comprehending the subject due to the atom's size being smaller than the microscopic dimension and its abstract nature.

Table 2
Students' opinions on misconceptions, facts, and incorrect judgments related to the concept of atom

Row	Statements	True*		False**		No idea	
		f	%	*f*	%	*f*	%
1	The atom is indivisible.[1] (F)	38	13	249	87	1	0
2	Most of an atom is empty space. (T)	200	70	59	20	29	10
3	Atoms that make up the basis of each matter have the same properties.[2] (F)	28	10	246	85	14	5
4	In an atom, electrons are like chickpeas mixed into a soup with a positive charge. (F)	93	32	161	56	34	12
5	An atom can be seen through a microscope.[3] (F)	143	50	92	32	53	18
6	An atom has subatomic particles. (T)	254	88	17	6	17	6
7	Electrons revolve on fixed layers. [4] (F)	90	31	171	59	27	10
8	An atom is alive.[5] (F)	104	36	106	37	78	27
9	Electrons can pass from one layer to another. (T)	258	90	21	7	9	3
10	Each particle in an atom has a counter particle. (T)	94	33	118	41	76	26
11	Electrons are scattered in an atom. [6] (F)	139	48	130	45	19	7
12	Electrons are not limited to the layers and they are possibly found in any place in an atom. (T)	174	60	71	25	43	15
13	An atom cannot be observed in any way (stimulation, etc.). (F)	7	2	273	95	8	3
14	When matter is heated, the atom expands.[7] (T)	147	51	50	17	91	32
15	Electrons do not have sub-particles. (T)	89	30	114	40	85	30
16	Electrons move in certain orbits.[8] (F)	83	29	175	61	30	10
17	Electrons behave both like a particle and a wave. (T)	169	58	39	14	80	28
18	The atom has a spherical shape.[9] (F)	146	51	102	35	40	14
19	In an atom, there are electrons, protons, and neutrons. (T)	264	93	10	3	14	5
20	Neutrons are in the nucleus of an atom. (T)	244	84	22	8	22	8
21	Some atoms can go into fission on their own. (T)	93	32	96	33	99	35
22	Atoms include neutrons. (T)	260	90	13	5	15	5
23	An atom does not have any sub-particles.[10] (F)	26	9	236	82	26	9
24	Protons are found in the nucleus of the atom. (T)	264	92	17	6	7	2
25	Physical properties of the matter can also be observed in the atom.[11] (F)	122	43	82	28	84	29
26	The nucleus covers a small part of the volume of the atom. (T)	171	60	73	25	44	15
27	An atom is like a circle.[12] (F)	145	51	96	33	47	16
28	The nucleus is in the center of the atom. (T)	265	92	13	5	10	3
29	The nucleus of the atom has a spherical shape.[13] (F)	207	72	45	16	36	12
30	An atom consists of protons, electrons, neutrons, an orbit, and the nucleus.[14] (F)	202	70	64	22	22	8
31	In an atom, electrons behave like particles moving around the nucleus. (T)	175	61	77	27	36	13
32	The atom is the most essential and basic structure of a cell.[15] (F)	207	72	63	22	18	6
33	Protons and neutrons have sub-particles. (T)	141	49	63	22	84	29
34	Physical effects (striking, smashing, heating, etc.) change the structure of the atoms in the matter.[16] (F)	60	21	192	66	36	13

Note. (T): The statement is true; (F): The statement is false; *: Students think the statement is true; **: Students think the statement is false. False statements represents common misconceptions. These can be found at: [1.] Kaya, 2018; Kılıcı, 2019. [2.] Demirci et al., 2016; Kılıcı, 2019. [3.] Gökulu, 2013; Kılıcı 2019. [4.] Çökelez & Yalçın, 2012; Demirci et al., 2016. [5.] Meşeci et al., 2013; Hejnova & Hejya, 2018. [6.] Demirci et al., 2016; Kılıcı, 2019. [7.] Tunç et al., 2011; Kılıcı, 2019. [8.] Kaya 2018; Kılıcı, 2019. [9.] Hejnova & Hejya, 2018; Kılıcı 2019. [10.] Kaya, 2018; Kılıcı, 2019. [11.] Sarıkaya & Ergün, 2014; Kılıcı 2019. [12.] Harrison & Treagust, 1996; Demirci et al., 2016. [13.] Kaya 2018; Hejnova & Hejya 2018. [14.] Griffiths & Preston, 1992; Kaya, 2018. [15.] Kaya 2018; Zarkadis et al., 2020; [16.] Harrison & Treagust, 1996; Sarıkaya & Ergün 2014.

When teachers were asked to express the false statements that the students use the most in relation to the concept of atoms, they said in this regard that the false statements about the concept of atoms were the atom is indivisible, the atom is the smallest indivisible building block of matter, and the atom is the smallest indivisible particle.

Finally, teachers were asked for their suggestions on how to improve student understanding of this concept. Teachers stated that elementary school should not teach theories of the atoms; instead, they should introduce the concept of atoms while studying the structure of matter. Moreover, teachers stressed that the first theories of the atom should be presented briefly in one class hour in high school and that the modern theories of the atom should be taught in greater detail later on. According to four teachers, simulations regarding atomic models should be prepared by experts, and three-dimensional models related to the atomic models should be created as course material and sent to schools. A total of seven teachers emphasized the importance of increasing students' interest in learning and improving their attitude towards education.

3.1. Findings from the interviews held with the academics

The academics were informed of the difficulties encountered when teaching the concept of the atom, and they were asked how these difficulties can be overcome.

In the majority of cases ($f = 8$), academics said that experts could concretize the concept of atoms with simulations and applications. Five academics expressed their opinion as only the definition of the concept of the atom should be taught in elementary education, and the first theories of the atom should be briefly taught in high school in a short period of time (one or two class hours), and then the modern atomic theory should be taught in detail. One of the academics has highlighted that the atom's structure is mysterious, so attempting to describe it from everyday life would not be helpful.

Three academics expressed that during the presentation of the atomic models, they should be written on the blackboard in chronological order, the deficiencies of each model should be emphasized, and the solutions offered by the modern atomic theory to these deficiencies should be emphasized. Providing atomic models on a table with their properties might prevent misconceptions, according to two academics. In order to prepare this table, they wrote atomic models in rows and properties of the atom in columns, and when an atomic model overlapped with the properties it explained, they marked that box with a tick. One academics stated that theories of the atoms can be classified according to their development stages, and added that this classification can be in the form of 1) Primary theories of the atoms: Dalton and Thomson, 2) Experimental theories of the atoms: Rutherford and Bohr, and 3) Modern atomic theories.

4. Discussion and Conclusion

A majority of students incorrectly defined the atom as the smallest building block of matter. Many studies have shown that students define the atom the same way (Akyol, 2009; Cokelez & Yalcin 2012; Kaya, 2018; 2010; Kilici, 2019; Meşeci et al., 2013). These misconceptions might have been developed due to the Dalton and Thomson theories of the atom, which contain similar statements as the students' definitions, in classes and course materials. Furthermore, students marked statements 10, 12, 21, 26, 30, and 33 (see Table 2), which explain facts, as "wrong" at a considerable rate. Teachers' methods when presenting atom concepts in class may have contributed to this situation. In primary school, high school, and university, the students were unable to fully understand the concept of atom.

Furthermore, it was determined that 8% to 72% of students had misconceptions (see Table 2). Considering the course curricula in Türkiye, it is seen that the concept of atoms is included in the elementary school curriculum of the physical sciences course in the seventh grade under the heading “Physical Structure of Matter” under the heading “The Concept of Atoms in the Historical Process, what is a Molecule?”” (Ministry of National Education [MoNE], 2018). As what is learned first becomes permanent in the mind, these misconceptions may have developed as a result of the teaching of atom in elementary school. Many countries around the world include the concept of atoms and atomic models in their primary and secondary school curricula (Hejnová & Hejya, 2018). Starting from elementary school ages, students are taught about the structure of the atom, which is a prerequisite for many subjects in chemistry, such as chemical bonds, molecular structure, and periodic table (Aygen, 2019). Hejnová and Králík (2019) allege that students' misconceptions are the result of classical physics presentations about the atom in primary and secondary schools, as well as sub-level presentations. Numerous studies have found that students have difficulty understanding and learning this abstract and complicated concept (Bilir et al., 2018; Cokelez & Duman, 2005; Cokelez & Yalçın, 2012; Griffiths & Preston, 1992). According to various studies, misconceptions in the minds of students are caused by ideas that do not reflect the facts in the historical development of scientific concepts taught in elementary schools (Griffiths & Preston, 1992; Hejnová & Králík, 2019). Also, physicists are divided over what atomic models should be included in the curricula in what age range (Ehab et al., 2018). According to the discussions above, including an abstract concept such as atom in the curriculum of primary school education, which forms the first step of education, makes it difficult for students to understand the concept and leads to misconceptions. This led to the conclusion that atoms should not be taught in primary schools.

There were 35% of the students who drew atoms as defined in the modern atomic theory, 32% drew Bohr-type atoms, and 21% drew Rutherford-style atoms (see Figure 1). Students were also asked to explain why they chose the atomic model they drew. Few students (9%) provided explanations, and these explanations were not satisfactory. Students may have not understood the subject well due to the different shapes drawn for different theories related to the concept of the atom due to a variety of theories associated with it. According to Kilic (2010), teachers had difficulty teaching the concepts related to the theories of the atoms in course-books. In their study, Podolefsky and Finkelstein (2006) noted that there are more than one theory explaining the structure of the atom, which resulted in students becoming confused by models associated with these theories. It has been stated that there may be some inadequacies in terms of representing the atom while creating the models related to the theories of the atom, and these may include some mistakes (Yaseen & Akangul, 2016). According to Yaseen and Akangul, (2016), students' mental models may be influenced by their course books. A study by Çökelez and Yalçin (2012) found that most students couldn't answer a question about the shape of an atom. The present study also found that very few students (10%) made expressions about explaining the atom's shape. A majority of those who responded that the atom has a spherical shape. There may have been a lack of attention in the sources to the controversy about the shape of the atom. Similar views were also reported by Cokelez, (2012), and Hejnová and Králík, (2019). Dalton and Thomson also included this disagreement in their theories of the atoms. This have affected the students' expressions. As far as drawing the shape of the atom was concerned, the students were unable to form a definite structure.

As a result of the interviews conducted with academics and teachers, opinions will be provided on methods and applications that can be used to improve the teaching of the concept of atoms. In particular, elementary school should not introduce atomic models but rather teach the definition of the atom as part of the structure of matter subject. A brief summary of the theories of the atoms should be taught (in one or two class hours), followed by a detailed presentation of the modern atomic theory. Similar suggestions were made by Bilir et al. (2018). With aging, humans' mental perceptions also improve, and their abilities to acquire cognitive, emotional, and psychomotor behaviors increase (Sahin et al., 2022). Therefore, it is obvious that students who have had a certain level of education at the high school level will be able to comprehend and learn the concept of atoms.

Furthermore, the academics in the present study stated that the atomic theories could be presented through three different methods. The first is presenting the theories according to their development stages as 1) Primary theories: Dalton, Thomson, 2) Experimental theories:

Rutherford, Bohr, and 3) Modern atomic theory. Second, atomic theories are written on the blackboard in chronological order along with their shortcomings. The third method involves creating a table and showing what properties the theories explain about the atom. It was also stated by several researchers that teaching based on these methods could be beneficial (Kılıcı, 2019). According to these researchers, the subject of theories of the atom should be presented holistically without any loose points between the subjects, and the limitations and deficiencies of each theory should be emphasized when teaching them. According to Bilir et al. (2018), the theories of the atom should be taught separately in one class hour to prevent gaps between them. In this way, theories of the atoms will be presented holistically. Lastly, academics and teachers emphasized that simulations prepared by experts on atom structure should be used in classrooms.

5. Recommendations

Based on the findings of the study, the following recommendations were made:

In primary and secondary schools, atomic theories and models should not be taught. At this level, only the definition of an atom should be considered.

At the high school level, atomic theories and models should be introduced. Using the methods recommended by the academicians and teachers in our study, these subjects can be presented and approved by five experts in the field: Classifying theories of the atoms according to their development stages, presenting theories of the atoms in a table to be created, or arranging the theories of the atoms chronologically. Therefore, the theories of the atoms will have been presented holistically, and learning difficulties in this area will have been determined in the student questionnaires without causing confusion.

Researchers can use these methods in this area and compare their results with traditional methods.

The authors of coursebooks should be very sensitive when selecting atomic models that they will include in their course-books to ensure that students won't have any problems representing atomic models and the shape of an atom. Additionally, educators should emphasize the relationship between the most recent information on the subject and the information being presented while explaining the shapes of each model in order to avoid misunderstandings.

For students to visualize the structure of atoms mentally, teachers should use three-dimensional simulations prepared by experts in their classes.

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References

Akyol, D. (2009). *Investigation of the science education undergraduate students' mental models of atoms* [Unpublished doctoral dissertation]. Dokuz Eylül University, İzmir.

Alkan, M. (2022). *Determination of the perceptions of 7th class middle school students on the atom by using metaphors* [Unpublished master's thesis]. Aksaray University, Aksaray.

Ayaz M. E. (2020). Subatomic particles and technological developments in this field. *MTA Bulletin of Natural Resources and Economy, 30*, 1-16.

Aygen, A. (2019). *Chemistry teachers' and prospective chemistry teachers' conceptual understanding about atomic models* [Unpublished master's thesis]. Gazi University, Ankara.

Başaran, V., & Gözütok, T. T. (2022). Can atomic theories be evaluated in terms of paradigm shift? Anxiety. *Bursa Uludağ University Faculty of Arts and Sciences Journal of Philosophy*, *21*(2), 779-805. https://doi.org/10.20981/kaygi.1156777

Bilir V., Digilli Baran, A. & Karaçam, S. (2018). Atomic theories that preservice science teachers confuse and underlyıig reasons. *Inonu University Journal of the Faculty of Education*, *19*(1), 212-220. https://doi.org/10.17679/inuefd.331368

Cardoso, P. S. S., Nunes, M. C. S., Silva, G. P. S., Braghittoni, L. S. & Trindade, N. M. (2020). Atomic models of high school students, radiation and radioactivity concepts. *Physics Education, 55*(3), 035030. https://doi.org/10.1088/1361-6552/ab7fc6

Cokelez, A. (2012). Junior high school students' ideas about the shape and size of the atom. *Research in Science Education, 42*, 673-686. https://doi.org/10.1007/s11165-011-9223-8

Çökelez, A. & Duman, A. (2005). Atom and molecule: upper secondary school french students' representations in long-term memory. *Chemistry Education Research and Practice, 6*(3), 119-135. https://doi.org/10.1039/B4RP90005G

Cokelez, A. & Yalçın, S. (2012). Investigation of mental models of elementary 7th grade students about atom concept. *Elementeary Education Online*, *11*(2) 452-471.

Demirci, S., Yılmaz, A. & Şahin, E. (2016). An overview of high school and university students' mental models of atomic structure. *Journal of the Turkish Chemical Society, 1*(1), 87-106,

Demircioğlu, G., Aydın, M. A. & Demircioğlu, H. (2012). The effect of conceptual change text and three-dimensional model on 7th grade students' understanding of atomic structure. *Journal of Bayburt Education Faculty, 7*(2), 70-96.

Ehab O. M., Safwan M. O., Nathir A.F. Al-R. , Nacir T. & Ihab M. O. (2018). Misconceptions about atomic models amongst the chemistry students. *International Journal for Innovation Education and Research*, *6*(2), 256-263. https://doi.org/10.31686/ijier.vol6.iss2.958

Ekinci S. & Şen A. İ. (2020). Investigating grade-12 students' cognitive structures about the atomic structure: a content analysis of student concept maps. *International Journal of Science Education*, *42*(6), 977-996. https://doi.org/10.1080/09500693.2020.1744045

Gökulu, A. (2013). Investigating the effects of computer based learning and to determine students' misconceptions on nature of the matter concept. *The Journal of Academic Social Science Studies, 6*(5), 571-585. https://doi.org/10.9761/JASSS1078

Griffiths, A. K., & Preston, A. K. (1992). Grade-12 students' misconceptions relating to fundamental characteristics of atoms and molecules, journal of research in science teaching. *Journal of Research in Science Education, 29*(6), 611-628. https://doi.org/10.1002/tea.3660290609

Harrison A. G., & Treagust, D.F. (1996). Secondary students' mental models of atoms and molecules: implications for teaching chemistry. *Science Education*, *80*(5), 509-534. https://doi.org/10.1002/(SICI)1098-237X(199609)80:5%3C509::AID-SCE2%3E3.0.CO;2-F

Hejnová E. & Hejya D. (2018). Pupils' misconceptions about atoms juxtaposedto the structure of matter as imagined byancient thinkers. *Scientia in Educatione*, *9*(2), 22–43. https://doi.org/10.14712/18047106.1176

Hejnová, E. & Králík, J. (2019). Images of atoms in physics textbooks for lower secondary schools vs. misconceptions of pupils about atoms. *AIP Conference Proceedings, 2152,* 030006. https://doi.org/10.1063/1.5124750

Kaya, A. (2010). Determination of science teacher candidates' levels of understanding the concepts of light and atom. *Erzincan University Journal of Education Faculty, 10*(1), 15–37.

Kaya, A. (2018). Determination of secondary school students' levels of understanding the concept of atom. *MSKU Journal of Education, 5*(1), 1-9. https://doi.org/10.21666/muefd.309222

Kılıç, F. (2010). *Searching of atomic theories presented in high school chemstry textbooks in the point of history and philosopy of science and the ideas of teachers* [Unpublished master's thesis]. Gazi University, Ankara.

Kilici, A. T. (2019). *The misconceptions about the concept of atom in 7th grade students* [Unpublished master's thesis]. Necmettin Erbakan University, Konya.

Kiriktaş H. (2023). The Evolution of Students' Mental Models and Metaphors towards the Atomic Concept. *European Scientific Journal, 15,* 136.

Ministry of National Education [MoNE]. (2018). *Fen bilimleri dersi öğretim programı: İlkokul ve ortaokul 3, 4, 5, 6, 7 ve 8. sınıflar* [Science curriculum: Primary and secondary school 3, 4, 5, 6, 7 and 8]. Author.

Marrais, K. B. & Lapan, S. D. (2004). *Foundations for research: methods of ınquiry in education and the social services.* Lawrence Erlbaum Associates.

Meşeci, B., Tekin, S., & Karamustafaoğlu, S. (2013). Detection of misconceptions regarding the particulate structure of matter. *Dicle University Social Sciences Institute Journal*, *5*(9), 20-40.

Merriam, S. B. (2015). *Qualitative research: a guide to design and ımplementation*. Jossey-Bass.

Niaz, M., Aguilera, D., Maza, A. & Liendo, G. (2002). Arguments, contradictions, resistances and conceptual change in students' understanding of atomic structure. *Science Education*, *86,* 505-525, https://doi.org/10.1002/sce.10035

Özkan E. B. (2019). *Determining the perceptions of the science teacher candidates' on the issues of 'atom and atomic structure* [Unpublished master's thesis]. Aksaray University, Aksaray.

Park, E. J. & Light G. (2009) Identifying atomic structure as a threshold concept: Student mental models and troublesomeness. *International Journal of Science Education*, *31(*2), 233-258. https://doi.org/10.1080/09500690701675880

Podolefsky, N. S. & Finkelstein, N. D. (2006). The use of analogy in learning physics: the role of representations. *Physical Review Physics Education Research, 2,* 020101. https://doi.org/10.1103/PhysRevSTPER.2.020101

Sarıkaya, M. & Ergün, A. (2014). Investigation of primary and secondary school students' understanding of the effect of some physical factors on the shape of atoms and molecules. *Turkish Journal of Education*, *3*(3), 56-73. https://doi.org/10.19128/turje.181087

Şahin A. E., İşler N. K. & Zoraloğlu S. (2022). Analysis of academic performance of students starting primary school at different ages with the 4+4+4 arrangement based on LGS data. *Ankara University Journal of Faculty of Educational Scieences*, *55*(2), 387-420. https://doi.org/10.30964/auebfd.1089906

Tunç, T., Akçam, H. & Dökme, İ. (2011). Misconceptions about some basic science concepts by pre-primary teachers with three-stage questions. *Gazi Journal of Faculty of Education*, *31*(2), 817-842,

Yaseen Z., & Akangül S. (2016). Comparison of high school students' mental models about atom with the visuals in textbooks. *Mehmet Akif Ersoy University Journal of Education Faculty, 40,* 469-490.

Yin, R. K. (2003). *Case study research: Design and methods.* Sage.

Zarkadis N., Stamovlasis D. & Papageorgiou G. (2020). Student ideas and misconceptions for the atom: A latent class analysis with covariates. *International Journal of Physics and Chemistry Education*, *12*(3), 41-47.