The Evolution of Students' Mental Models and Metaphors towards the Atomic Concept*

Halit Kiriktaş
Siirt University, Türkiye

Doi: 10.19044/ejes.v10no1a55 URL:http://dx.doi.org/10.19044/ejes.v10no1a55

Submitted: 17 February 2023
Accepted: 14 March 2023
Published: 31 March 2023

Abstract:

It could be argued that the main goal of the teaching process is to create accurate projections of scientific models in the minds of individuals. In this context, it could be argued that it is important to determine the change and development of the mental models that individuals create for events/phenomena and related metaphors in this process.

This paper seeks to reveal how the mental models and metaphors of students with similar sociodemographic characteristics have evolved throughout the teaching process from secondary school to the undergraduate level. In the present study, the cross-sectional survey model, which is one of the descriptive research methods, was used. While the population of the study consists of students and pre-service teachers who receive formal education in public schools located in the South East Anatolia region in the 2019-2020 academic year, the sample consists of 720 students in total selected in equal numbers from every grade level with similar socio-demographic characteristics (60 students selected from the 5th-grade to the 4th-year students of the undergraduate degree). The data collection tool used in the study was a four-tier conceptual understanding test created by the researcher, who also tested its validity and reliability. The data were subjected to descriptive statistics, content analysis, and the Chi-square test.

The results reveal that the students have highly different definitions and metaphors for the concept of the atom with their mental models generally evolving up to the Rutherford atomic model and failing to reach a higher model.

It is recommended in future studies that researchers follow the process longitudinally and investigate the reasons why students' mental models fail to evolve into higher atomic models.

Keywords: Science Education, Atom, Mental Model, Metaphor

* This study was conducted on a different sample, independent of the previous study conducted by the researcher, and presented as an oral presentation at the *International Conference on Education in Mathematics, Science & Technology* (ICEMST 2017).

1. Introduction

From a modelling perspective, Science Education can be defined as a process aimed at creating accurate projections of scientific models formed in basic disciplines such as physics, chemistry, biology, and astronomy in students' minds (Norman et al. 1983). In simpler terms, science education can be defined as the process of transforming scientific models in related disciplines into mental models (Teller, 1994). In this respect, it can be argued that effective and efficient science teaching requires the definitions of not only the scientific models in the related disciplines and the mental models corresponding to the students but also the monitoring of their development and that success can only be achieved if the harmony between the two models is identified (Norman at al. 1983; Schwarz & White, 2005).

Considering the scientific models taught as part of science teaching, it is suggested that such models generally describe abstract phenomena/events, but can be presented to students through representations (Coll & Treagust, 2001; Gilbert, 2004), and in this respect, they are more challenging compared to the models in other disciplines in creating accurate mental projections (Harrison & Treagust, 1998). On the other hand, bearing in mind that mental models are subjective cognitive constructs that can differ from scientific models in constructing mental models not only because of the individual characteristics of those who construct but also because of external factors such as social environment, instructor, and teaching materials (Harrison & Treagust, 1998), the importance of monitoring the compatibility of mental models with the scientific model becomes more evident throughout the science teaching process.

In addition, it could be argued that mental models, which refer to the meaningful and coordinated whole of the information constructed in the mind, exist not only cognitively but also emotionally and in terms of psychomotor. In this respect, to fully understand the mental models that students have for any phenomenon/event, the data for these three dimensions should be collected and handled holistically. In this context, metaphors can be drawn upon to understand how mental models of individuals are created emotionally. It is reported in various studies that metaphors can be used to determine individual thoughts and feelings toward a certain concept (Fainsilber & Ortony, 1987; Lubart & Getz, 1997; Lakoff, & Johnson, 1980).

The literature review reveals that studies have long been carried out to identify mental models and the level of models. It is understood that current studies are generally aimed at identifying mental models and model levels, provided that they are limited to the cognitive dimension of the target group at a certain age level for basic concepts such as "*atom, cell, reaction, planet*" (Ayvacı et al, 2016; Coll & Treagust, 2001; Vosniadou & Brewer, 1992).

Studies specific to *the concept of the atom* have shown that the age groups from primary school to the undergraduate level are handled separately, and remarkable results are achieved in terms of the cognitive dimension and depending on the developmental characteristics and knowledge levels of the age groups (Adbo & Taber, 2009; Allred & Bretz, 2019; Akyol, 2009; Alkan, 2022; Baji & Haeusler, 2021; Bilir & Karaçam, 2021; Çökelez & Yalçın, 2012; Derman, at al, 2019; Kaya, 2018; Muştu & Ucer, 2018; Muştu, 2021: Özgür, 2007; Sarıdaş & Ünsal, 2020;). On the other hand, the literature does not include a comprehensive study that holistically scrutinizes the mental models of such age groups related to the concept of the atom and compares such models in terms of various dimensions apart from the cognitive dimension. In this context, this study is expected to make a significant contribution to the literature as it is aimed at determining the mental models of students from secondary school to undergraduate level, the metaphors they created for the concept of the atom, and the progress in such phenomena throughout education.

In this context, the present study seeks to determine how the mental models and metaphors of students with similar sociodemographic characteristics have evolved throughout education from secondary school to the undergraduate level.

In parallel with the relevant purpose, the following research questions were addressed:

1) What are the definitions and visual representations of the concept of the atom according to the grade and school level of the student groups?
2) What types of *metaphors* are created by the student groups for the concept of the atom according to grade level and school level?
3) To which scientific model do the mental models of the student groups for the concept of the atom correspond?
4) Is there a significant difference between the mental models of the student groups for the concept of the atom according to the education level?

2. Method

2.1 Design

Seeking to determine the evolution of the mental models and metaphors for the concept of the atom created by students with similar sociodemographic characteristics throughout the teaching process from secondary school to the undergraduate level, the present study quintessentially is based on the "cross-sectional survey model", which is listed among descriptive research method. It can be claimed that the relevant research model is suitable for measurements made at once on samples with different characteristics and large numbers (Büyüköztürk et al., 2010).
The sample of the study was shaped as follows appropriately and in compliance with the relevant selected method.

2.2 Sample

The researcher drew upon the selective sampling method in the study. The population consists of students and pre-service teachers receiving formal education in public schools located in the South East Anatolia region in the 2019-2020 academic year, and the sample consists of 720 students in total selected in equal numbers from every grade level with similar socio-demographic characteristics (60 students selected from the 5^{th}-grade to the 4^{th}-year students of the undergraduate degree). The students and pre-service teachers included in the sample were picked from among students with similar sociodemographic characteristics with the following selection criteria: Parents' educational status, economic income, and no history of receiving supportive education outside of school. In this direction, the sample included students who grew up in a family with secondary and high school education and without any supportive academic education outside of school (private lessons, private tutoring education, etc.). Secondary school students were picked from the 5^{th}, 6^{th}, 7^{th}, and 8^{th} grades of a public school while high school students were picked from the 9^{th}, 10^{th}, 11^{th}, and 12th-grades of the numerical sciences department of an Anatolian high school and pre-service teachers from the 1^{st}, 2^{nd}, 3r, and 4^{th} grades studying in the science teaching program of 3 different state universities. Pre-service science teachers were included in the sample as they are the first educators to guide students in constructing the concept of the atom.

The goal of using the relevant sampling method is to bring the research closer to the longitudinal research model. This helped determine how the mental models and metaphors of the students for the concept of the atom evolve throughout the teaching process and statistically compare the relevant phenomena in terms of education levels. Similarly, this sampling method helped perform an effective and efficient longitudinal study, which could only be carried out with a 12-year follow-up period, in a short time.

The research process for the relevant sample proceeded as follows.

2.3 Research Process

At the onset of the research process, a theoretical framework was drawn through a literature review along with a four-tier conceptual understanding test developed by the researcher based on the framework and a sample determined in parallel with the purpose of the research. Once the necessary permissions were obtained, the authorized administrators and advisor teachers in public schools were interviewed and given information about the purpose and process and which characteristics are needed for students to be included in the sample. Thus, in consultation with the advisor teachers, the researcher determined the intended characteristics and number of students for each grade level among the students studying in branches different from the relevant grade levels on a voluntary basis. To avoid any disruption in the teaching process, students selected from different branches were taken to the same advisory class, and the application process was performed on different days for each grade level under the supervision of the advisor teacher and the researcher. The researcher informed the students about the content of the study, distributed the measurement tools, and asked them to answer the relevant questions in a sufficient time (35 minutes). The students were not interrupted throughout the application. And finally, the measurement tools were retaken to terminate the application.

The characteristics of the measurement tool used in the research are detailed below.

2.3 Measurement Tool and Its Characteristics

A four-tier conceptual understanding test was developed by the researcher in line with the theoretical framework and the measurement tool development process. In the first stage, 4 questions were formed in line with the theoretical framework along with necessary instructions. Then, 4 faculty members working in the related field were consulted for their opinions on field, language, structure, and face validity. Once positive expert opinions were obtained, a pilot scheme was performed with the participation of 1 teacher and 3 students from each grade level and the validity of the measurement tool for each grade level was ensured. Thus, the tool took its final form. The items in the measurement tool created at the end of the process are respectively as follows:

- How would you describe *the concept of the atom* in your own sentences*?*
- Considering the *atomic* structure, can you write its properties?
- Can you draw the shape that occurs in your mind when you hear *the concept of the atom?*
- I think the atom looks like …………………. because ………………………………… .

The analysis process of the data obtained via the relevant measurement tool is as follows.

2.3 Data Analysis Process

Descriptive statistics, qualitative-quantitative content analysis, and Chi-square test were applied to the data obtained via the measurement tool. While analysing the data, first, two science educators specialized in their fields performed a qualitative content analysis simultaneously and independently of each other. As part of the analysis process, the experts examined the statements written for each item (1^{st}, 2^{nd}, and 4^{th}) and created codes and themes. Then, they analysed the responses to the 1st and 2nd questions and the images in the 3^{rd} question to identify which scientific model is compatible with the mental model of the student (Dalton, Thomson, Rutherford, Bohr, Modern Theory and Quantum Atom Models, as cited in Şahin and Founder 2005, were taken as a reference).

The evolution of atomic models can be summarized as follows.Dalton atomic model can be considered as the simplest model. It forms the basis of today's models. According to this model, the atom is defined as a filled sphere. Thomson atomic model; In addition to the dalton model, the charges (+,-) showing an even distribution in the filled sphere are revealed. Rutherford introduced the concept of nucleus and stated that negative charges are around this nucleus. The Bohr Atom model took the atom out of the classical understanding and brought it into a modern framework. Bohr stated that electrons are in certain orbits (circular) and move with opposite spin. Modern Theory put forward the concept of Orbital and put forward the concept that electrons are located in different orbitals according to their energy level and orbitals are not orbitals. According to this theory, orbitals are defined as regions where electrons are most likely to be found (Şahin ve Kurucu,2005).

At the end of the process, the Kappa value, which indicates the agreement between experts, was calculated as 0.75 (good level). The scientific model determined by experts for each student was numbered from 1 to 6 (Dalton Atom model: 1, Thomson Atom model: 2, Rutherford Atom model: 3, Bohr Atom model: 4, Modern Theory Atomic model: 5, and Quantum Atom model: 6) and converted into categorical data. The Chi-square test was applied to the obtained data via the SPSS 23.0 package program to identify the levels of differentiation between the groups.

The findings obtained from the analysis are detailed below.

3. Findings

The findings that emerged as a result of the analysis process are given in line with the problem statements and the order of the students' education level. In this way, it is aimed to organize the data according to the education level of the students and to interpret the differentiation patterns according to the education level more effectively.

In this context, the findings regarding the definitions of the concept of the atom and the shapes drawn by the student groups according to the level of education are presented below.

Table 1. Findings regarding the definitions of secondary school students for the concept of the atom

Definitions/Grade Level	5th-grade		6th-grade		7th-grade		8th-grade		Total	
	f	%	f	%	f	%	f	%	f	%
The smallest unit of a matter	11	18	20	33	33	55	44	73	108	45
Indivisible smallest matter	13	22	10	16	15	25	9	16	47	11
Matter too small to be observed	2	3	10	16	6	10	4	6	22	9
Sphere with stored energy	15	25	5	8	6	10	3	5	29	12
Bomb-making material	13	22	11	18	-	-	-	-	24	10
Very small fireball made of gases	6	10	4	7	-	-	-	-	10	4
Total	60	100	60	100	60	100	60	100	240	100

Table 1 reveals that 45% of secondary school students make use of the scientific definition in the books while 55% make wrong definitions using their own sentences. It is understood that as the grade level increases, the tendency to make scientific definitions increases, but the students tend to avoid using their own sentences and resort to the definition in the books. On the other hand, it can be suggested that the vast majority of 5th and 6th-grade students define the atom as a bomb or a sphere carrying energy.

Table 2. Findings regarding the shapes drawn by secondary school students for the concept of the atom

Shapes/Grade Level	5th-grade		6th-grade		7th-grade		8th-grade		Total	
	f	%	f	%	f	%	f	%	f	%
The atomic model with S-P orbitals	9	15	3	5	8	14	4	7	24	10
The atomic model with S orbitals	-	-	-	-	20	33	6	10	26	11

Interconnected spheres	-	-	4	8	5	8	15	25	24	10
Hollow sphere	9	15	16	25	12	20	13	21	50	21
Solid sphere	8	15	12	20	10	17	10	17	40	17
Solid cube	11	18	3	5	-	-	-	-	14	6
Fireball	16	25	15	25	2	3	3	5	36	15
Amorphous structures	7	12	7	12	3	5	9	15	26	11
Total	60	100	60	100	60	100	60	100	240	100

Table 2 reveals that 31% of secondary school students draw scientific shapes, 38% draw hollow or solid spherical structures, 15% draw fireballs, 11% draw amorphous structures, and 6% draw cubic structures. It is understood that as the grade level increases, they tend to draw scientific figures. On the other hand, it can be suggested that this tendency decreases as there is an increase in the grade level in which 25% of the 5th and 6th-grade students draw the atom as a fireball. Finally, 10% of the students in all grade levels describe the atom using amorphous (meaningless) drawings. The definitions of high school students about the concept of the atom and the findings regarding the shapes they draw are presented in Table 3 and Table 4.

Table 3. Findings regarding the definitions of high school students for the concept of the atom

Definitions/Grade Level	**9th-grade**		**10t-grade**		**11th-grade**		**12th-grade**		**Total**	
	f	**%**	**f**	**%**	**f**	**%**	**f**	**%**	**f**	**%**
The smallest unit of matter	34	57	23	38	17	29	19	31	93	39
The particle that chemically has all the properties of an element	18	30	5	8	23	38	13	21	59	24
Sphere with a nucleus made up of protons and neutrons around which electrons revolve	-	-	3	5	7	12	14	24	24	10
The round shape inside a matter			8	13	3	5	6	10	17	7
The smallest indivisible matter with energy at its centre	5	8	14	24	5	8	4	7	28	12
Matter used in making weapons that are too small to be seen	3	5	7	12	5	8	4	7	19	8
Total	60	100	60	100	60	100	60	100	240	100

Table 3 reveals that 39% of high school students make a scientific definition based on books, 24% make a scientific definition in their own words, and 47% make a wrong definition. It can be suggested that some students make definitions by using subatomic particles at a rate that varies in direct proportion to the grade level, although the students are wrong in this sense. On the other hand, it is understood that 20% of the students at this level of education tend to make definitions related to energy or weapons. Finally, it is observed that the students' use of subatomic particles in their own words to make correct scientific definitions and use of subatomic particles for a definition first occurs at this level of education.

Table 4. Findings regarding the shapes drawn by high school students for the concept of the atom

Shapes/Grade Level	**9th-grade**		**10th-grade**		**11th-grade**		**12th-grade**		**Total**	
	f	**%**	**f**	**%**	**f**	**%**	**f**	**%**	**f**	**%**
The atomic model with S Orbitals	9	15	7	12	12	20	21	36	49	21
The atomic model with S-P Orbitals	9	15	6	10	9	15	6	10	30	12
Interconnected spheres	-	-	5	8	-	-	6	10	11	4
Sphere full of charge	5	8	3	5	5	8	4	7	17	8
Sphere with dots inside	15	25	5	8	7	12	5	8	32	13
Hollow sphere	10	16	8	14	9	15	3	5	30	12

Solid sphere	4	7	9	15	8	13	3	5	24	10
Fireball	4	7	10	16	6	10	10	16	30	12
Amorphous structures	4	7	7	12	4	7	2	3	17	8
Total	60	100	60	100	60	100	60	100	240	100

Table 4 reveals that 25% of high school students draw the atom with scientific models, 43% with hollow, solid spheres, or spheres full of charge, 12% with a fireball, and 8% with amorphous structures. It can be suggested that the number of students who draw scientific models increases in direct proportion to the grade level, the number of students who draw spherical structures decreases inversely with the grade level, albeit at a low rate, and the number of students who draw fireballs and amorphous structures does not change with the grade level. Finally, it can be observed that the tendency to draw shapes by using charges (plus+, minus-) first occurred at this level of education. The definitions of the pre-service teachers regarding the concept of the atom and the findings about the shapes they drew are presented in Table 5 and Table 6.

Table 5. Findings regarding the definitions of pre-service teachers for the concept of the atom

Definitions/Grade Level	**Undergraduate 1**		**Undergraduate 2**		**Undergraduate 3**		**Undergraduate 4**		**Total**	
	f	**%**	**f**	**%**	**f**	**%**	**f**	**%**	**f**	**%**
The smallest unit of matter	35	58	40	67	26	44	28	47	129	54
The smallest unit of matter that has physical and chemical properties	1	2	2	3	8	13	2	3	13	6
A system with a nucleus made up of protons and neutrons, in which electrons revolve in their orbits	5	8	12	20	2	3	20	33	39	16
A system that operates with a centre (core) focus	3	5	-	-	3	5	-	-	6	2
The beginning of the formation phase of a matter	4	7	3	5	5	8	3	5	15	7
The core of the indivisible matter	7	12	-	-	16	27	7	12	30	12
Hard sphere with charges inside	5	8	3	5	-	-	-	-	8	3
Total	60	100	60	100	60	100	60	100	240	100

Table 5 reveals that 54% of the pre-service teachers make a scientific definition based on books, 24% of them make a scientific definition in their own words, and 22% of them make a wrong definition. On the other hand, for the first time in this teaching level, the students use the existence of neutrons to define the atom and tend to define the atom as a dynamic system. Considering the differences at the grade level, it is understood that the tendency to make scientific and accurate definitions increases in direct proportion to the grade level.

Table 6. Findings regarding the shapes drawn by the pre-service teachers for the concept of the atom

Shapes/Grade Level	**Undergraduate 1**		**Undergraduate 2**		**Undergraduate 3**		**Undergraduate 4**		**Total**	
	f	**%**	**f**	**%**	**f**	**%**	**f**	**%**	**f**	**%**
The atomic model	10	17	6	10	11	18	12	20	39	16

with S-P Orbitals										
The atomic model with S Orbitals	19	32	30	50	25	41	9	28	91	37
Interconnected spheres	3	5	3	5	-	-	3	5	9	4
Solid sphere	16	26	13	22	9	16	11	18	49	21
Hollow sphere	11	18	8	13	4	7	7	12	30	12
Sphere full of charge	1	2	-	-	11	18	10	17	22	10
Total	60	100	60	100	60	100	60	100	240	100

Table 6 reveals that 47% of the pre-service teachers use scientific models and 43% use solid/hollow spheres or spheres with positive/negative charges to represent the atom. It is striking that as the grade level increases, the use of scientific models decreases and the tendency to represent the atom using a charged spherical structure increases. On the other hand, it is understood that unusual representations such as amorphous structures and fireballs are not observed at this level of education.

The findings regarding the metaphors created by the students for the concept of the atom according to the level of education are as follows.

Table 7. Findings regarding the secondary school students' metaphors for the concept of the atom

Metaphors/Grade Level	**5th-grade**		**6th-grade**		**7th-grade**		**8th-grade**		**Total**	
	f	**%**	**f**	**%**	**f**	**%**	**f**	**%**	**f**	**%**
Planet (Sun, Earth)	2	3	4	7	5	8	5	8	16	6
Solar system					6	10	8	13	14	5
Cell	11	18	3	5	4	7	2	3	20	8
Black Spot	6	10	6	10	10	17	7	12	29	13
Soccer ball or marble	7	12	16	27	16	27	11	19	50	21
Daisy	3	5	3	5	2	3	2	3	10	5
Watermelon			3	5	8	13	10	17	21	9
Bomb	20	34	11	18			4	7	35	15
Meteor	6	10	5	8	3	5	5	8	19	7
Volcano			5	8	3	5	2	3	10	5
Stone or rock	5	8	4	7	3	5	4	7	16	6
Total	60	100	60	100	60	100	60	100	240	100

Table 7 reveals that considering this level of education, students make use of 11 different metaphorical concepts in total. It is understood that 11% of secondary school students liken the atom to the planet or solar system, 8% to the cell, 47% to soccer ball, marble, and black spot, 5% to daisy, 9% to watermelon, 27% to a dangerous structure such as a bomb, meteor, and volcano, and 6% to a stone or rock. As the grade level of the students increases, the planet model analogy for the atom increases, the soccer ball or black spot analogy is used by a significant portion of the students at every grade level, the analogy of a dangerous structure such as a bomb, meteor, and volcano and a cell is quite high in the low-level grades, and this figure decreases as the grade level increases. On the other hand, it is also understood that the analogy of daisy and watermelon increases in direct proportion to the grade level, and some of the students at each grade level liken the atom to structures such as stone and rock.

Table 8. Findings regarding high school students' metaphors for the "concept of atom”

Metaphors/Grade Level	**9th-grade**		**10th-grade**		**11th-grade**		**12th-grade**		**Total**	
	f	%	**f**	%	**f**	%	**f**	%	**f**	%
Solar System	7	12	7	12	6	10	6	10	26	11

Saturn	6	10	-	-	10	17	7	12	23	10
Grape cake	5	8	7	12	5	8	4	7	21	9
Fruit (apple, watermelon)	6	10	5	8	3	5	5	8	19	7
Grit	11	18	10	16	9	15	12	20	42	18
Soccer ball or marble	14	23	17	29	10	17	16	27	57	24
Bomb	4	7	9	15	5	8	2	3	20	8
Meteor	7	12	5	8	12	20	8	13	32	13
Total	60	100	60	100	60	100	60	100	240	100

Table 8 reveals that the high school students make use of a total of 8 different metaphorical concepts for the atom. Accordingly, 11% of the students liken the atom to the solar system, 10% to Saturn, 7% to fruit, 9% to grape cake, 24% to soccer ball or marble, 8% to bomb, and 13% to meteor. In total, the students used metaphors associated with scientific models such as the solar system, Saturn, fruit, and grape cake by 37% without any increase or decrease based on the grade level. They also made use of metaphorical concepts that could not be associated with scientific models such as grit, soccer ball, bomb, and meteor by 63%. On the other hand, it is observed that at this level of education, 21% of the students liken the atom to structures that may pose a danger such as meteors or bombs.

Table 9. Findings regarding pre-service teachers' metaphors for the "concept of atom"

Metaphors/Grade Level	Undergraduate 1		Undergraduate 2		Undergraduate 3		Undergraduate 4		Total	
	f	%	f	%	f	%	f	%	f	%
Solar System	9	15	8	13	7	12	13	22	37	16
Universe	7	12	6	10	5	8	8	13	26	10
Saturn	4	7	2	3	4	7	3	5	13	5
Earth	9	15	6	10	5	8	-	-	20	8
Cell	5	8	9	15	7	12	7	12	28	12
Fruit (apple, pomegranate, watermelon, etc.)	3	5	10	17	6	10	10	17	29	13
Grape cake	4	7	2	3	11	18	-	-	17	7
Soccer ball or marble	11	18	10	17	11	18	11	18	43	18
Grit	8	13	7	12	4	7	8	13	27	11
Total	60	100	60	100	60	100	60	100	240	100

Table 9 reveals that the pre-service teachers use 9 different metaphorical concepts in total. Accordingly, 16% of them liken the atom to the solar system, 10% to the universe, 5% to Saturn, 8% to the earth, 12% to the cell, 13% to the fruit, 7% to grape cake, 18% to a soccer ball or marble, and 11% to grit. It is understood that the metaphors created by the pre-service teachers are mostly concepts that could be associated with scientific atomic models while concepts that may pose a danger such as meteors or bombs are not preferred.

Table 10 includes the findings regarding the scientific models in which the students' mental models for the concept of the atom are compatible based on the level of education. Since the mental model compatible with the quantum atom model could not be achieved, the relevant model was not included in the findings section.

Table 10. Findings on scientific models that are compatible with secondary school students' mental models for the concept of the atom

Scientific Atomic Models/Grade Level	5th-grade		6th-grade		7th-grade		8t-grade		Total	
	f	%	f	%	f	%	f	%	f	%

Dalton Atomic Model	53	88	51	85	43	72	46	77	193	81
Thomson Atomic Model	3	5	6	10	6	10	5	8	20	8
Rutherford Atomic Model	3	5	-		6	10	5	8	14	6
Bohr Atomic Model	1	2	3	5	5	8	4	7	13	5
Modern Atomic Theory	-		-		-	-	-	-	-	-
Total	60	100	60	100	60	100	60	100	240	100

Table 10 reveals that the mental models of the secondary school students included in the sample for the concept of the atom are compatible with the Dalton Atom Model (81%), Thomson Atomic Model (8%), Rutherford Atomic Model (6%), and Bohr Atomic Model (5%) and that at this level of education, no mental models compatible with the Modern Atomic Theory are created. The findings for the grade level also reveal that 75% of the students in all grade levels have a mental model compatible with the Dalton Atomic Model, and as the grade level increases, so does the rate of students' atomic models that are compatible with more advanced scientific models. In this context, considering the historical development process of atomic models, it is observed that students' mental models are compatible with more advanced scientific models in direct proportion to their grade level and show a positive change.

Table 11. Findings on scientific models that are compatible with high school students' mental models for the concept of the atom

Scientific Atomic Models/Grade Level	**9th-grade**		**10th-grade**		**11th-grade**		**12th-grade**		**Total**	
	f	**%**	**f**	**%**	**f**	**%**	**f**	**%**	**f**	**%**
Dalton Atomic Model	27	45	36	60	23	38	27	45	113	**47**
Thomson Atomic Model	11	18	12	20	19	32	10	16	52	**21**
Rutherford Atomic Model	16	27	8	13	11	18	13	22	48	**20**
Bohr Atomic Model	6	10	4	7	7	12	9	15	26	**10**
Modern Atomic Theory	-		-		-	-	1	2	1	1
Total	60	100	60	100	60	100	60	100	240	100

Table 11 reveals that the mental models of high school students for the concept of the atom are compatible with Dalton (47%), Thomson (21%), Rutherford (20%), Bohr (10%), and Modern Atomic Theory (1%). Grade-level-based findings also reveal that most of the mental models of 9th and 10th-grade students are compatible with the Dalton atomic model and that this rate decreases as the grade level increases while the rate of compatibility with more advanced atomic models increases. In addition, it is understood that mental models compatible with the modern atomic model are created among 12th-grade students, albeit at a low rate.

Table 12. Findings on scientific models that are compatible with pre-service teachers' mental models for the concept of the atom

Scientific Atomic Models/Grade Level	**Undergraduate 1**		**Undergraduate 2**		**Undergraduate 3**		**Undergraduate 4**		**Total**	
	f	**%**	**f**	**%**	**f**	**%**	**f**	**%**	**f**	**%**
Dalton Atomic Model	20	33	20	33	9	15	14	23	63	26
Thomson Atomic Model	12	20	7	12	21	35	18	30	58	25
Rutherford Atomic Model	16	27	27	45	15	25	13	22	71	29
Bohr Atomic Model	11	18	5	8	15	25	15	25	46	19
Modern Atomic Theory	1	2	1	2	-	-	-	-	2	1
Total	60	100	60	100	60	100	60	100	240	100

Table 12 reveals that 26% of the pre-service teachers' mental models for the concept of the atom are compatible with Dalton, 25% with Thomson, 29% with Rutherford, 19% with Bohr, and 1% with the Modern Atomic Model. Grade-level –based findings also reveal that the mental models of the pre-service teachers increase in direct proportion to the grade level, and the compatibility with the modern atomic theory is at a very low rate only in the 1st and 2nd years of undergraduate education. Finally, it is understood that compatibility intensifies in decreasing proportions from the Dalton and Thomson models to the Rutherford and Bohr models.

Table 13 includes the findings of the Chi-square test performed to determine the statistical differentiation level of the scientific models that are compatible with scientific atomic models based on the level of education.

Table 13. Findings of the Chi-square test performed to determine the relationship between the student groups' levels of education and the compatibility of their mental models with scientific models

Type of School	Scientific Atomic Models						X^2	sd	p
	Dalton	Thomson	Rutherford	Bohr	Modern	Total			
Secondary School	%59,5	%11,7	%12,9	%16	0	%100	247,46	8	0.000
High School	%24,1	%22,2	%31,3	%21,3	%1,1	%100			
University	%11,9	%22,4	%38,4	%25,6	%1,8	%100			

p<.05

Table 13 reveals that 59.5% of secondary school students' mental models are compatible with Dalton, 11.7% with Thomson, 12.9% with Rutherford, and 16% with Bohr Atomic Model. Similarly, the mental models of high school students are observed to be compatible with Dalton (24.1%), Thomson (22.2%), Rutherford (31.3%), Bohr (21.3%), and the Modern Atomic Model (1.1%). Finally, the mental models of the pre-service teachers are observed to be compatible with Dalton (11.9%), Thomson (22.4%), Rutherford (38.4%), Bohr (25.6%), and the Modern Atomic Model (1.8%). Considering the level of significance [($X^2(8)$=0,393)], it can be argued that a significant difference emerges in terms of the compatibility of the students' mental models with the scientific models based on the level of education. In other words, a significant relationship emerges between students' levels of education and the compatibility of their mental models with scientific models.

The comparison of the findings with previous studies in the literature is presented below.

4. Discussion

Designed to unearth how the mental models and metaphors for the concept of the atoms created by students with similar sociodemographic characteristics have evolved throughout the teaching process from secondary school to the undergraduate level, this study reveals some significant findings.

The findings reveal that the majority of secondary school students misidentify the concept of the atom using their own sentences at the beginning of their education, and as the grade level increases, the rate of correct and book-based definitions increases. Similarly, a majority of the students initially define the atom as a dangerous object that carries energy, which is a tendency that declines in further stages of education (Table 1). Approximately 1/3 of the students make use of scientific shapes to describe the atom and the tendency to use scientific shapes increases depending on the grade level. While students initially liken an atom to a fireball, such tendency declines in further stages of education (Table 2). Some studies also reveal similar findings showing that the majority of students misidentify the atom, compare it to a bomb, and make epistemologically similar definitions to historical processes (Baji, & Haeusler, 2021; Muştu & Ucer, 2018; Özgür, 2007). The findings regarding the metaphorical approach of secondary school students to the concept of the atom indicate that they make use of 11 different metaphorical concepts including spherical structures such as soccer balls or marbles, black spots, planets or solar systems, dangerous structures such as bombs, meteors or volcanoes, and stones or rocks (Table 7). Alkan reports that the students of the level of education mainly draw upon the solar system as a metaphorical concept for the concept of the atom. Finally, most of the mental models created by the students for the concept of the atom are observed to be compatible with the Dalton Model and change partially toward Thomson, Rutherford, and Bohr Models, respectively, depending on the increase in the grade level while such models fail to be compatible with the Modern Atomic Theory (Table 10). Along the same lines, Çökelez & Yalçın reported some findings in this respect in a study conducted in 2012.

In this context, it could be argued that at the onset of the secondary education level, a mental model for the concept of the atom is not developed by some of the students, while the model developed by other students is compatible with the Dalton Atom Model contrary to expectations. Similarly, a vast majority of the students emotionally perceive the atom as a dangerous phenomenon that carries energy at the beginning and gradually experience a decline in such tendency.

The definitions made by high school students for the concept of the atom reveal that the rate of correct definitions increases considerably in direct proportion to the grade level and the students can make correct definitions using their own sentences and use subatomic particles for the first time at the secondary education level. On the other hand, a majority of the students wrongly define the atom with some of them defining it as a dangerous matter (Table 3).

The shapes drawn at this level of education demonstrate that although the rate of drawing scientific shapes increases at the secondary school level, a significant part of them draw non-scientific shapes with some of them drawing amorphous structures and shapes described as dangerous. As in the definition, it is striking that subatomic particles are used in the drawings for the first time at this level (Table 4).

Another finding is that high school students make use of 8 different metaphorical concepts for the concept of the atom, most of which could not be associated with scientific models, and that the use of metaphors such as bombs and meteors continues. On the other hand, more sympathetic concepts such as daisies are also preferred (Table 8). High school students are observed to develop mental models that are compatible with the Dalton Atomic Model at the beginning and compatibility with the Thomson and Rutherford Atomic Models increases as the grade level increases. Although compatibility with the Bohr Atomic Model increases at a limited level in direct proportion to the grade level, the development of a mental model compatible with the Modern Atomic Theory is quite limited (Table 11). Some studies report that high school students generally have a mental model compatible with the Bohr Atomic Model (Adbo & Taber, 2009; Kaya, 2018; Sarıdaş & Ünsal, 2020).

It could be argued that the atomic models of high school students are still at the level of the Dalton Model at the beginning with some students still perceiving the atom as a dangerous phenomenon emotionally. This tendency is observed to change positively in direct proportion to the grade level with mental models evolving into more advanced scientific models and mainly continues to be concentrated in Thomson and Rutherford Models while there is no evolution into modern and higher atomic models.

The findings regarding pre-service teachers reveal that a majority of them define the atom scientifically, based on books, and as a mobile system for the first time with misconceptions continuing at this level as well (Table 5). Derman et al (2019) reported that pre-service teachers make a great number of individual definitions. The shapes drawn indicate that a majority of the pre-service teachers draw shapes in harmony with scientific models and avoid extraordinary drawings such as amorphous structures and fireballs. On the other hand, highly charged spherical shapes are also drawn (Table 6). Bilir and Karaçam (2021) reported that pre-service teachers have a mental model compatible with the particle model. The findings indicate that the pre-service teachers used 9 different metaphorical concepts that are largely compatible with scientific models and unassociated with dangerous structures. Although the mental models of pre-service teachers for the concept of the atom are at a lower rate than high school students at the beginning of their undergraduate education, they are significantly compatible with the Dalton Model and evolve into the Bohr Atomic Model while a low-level evolution emerges for the Modern Atomic Model (Table 12). Allred & Bretz (2019) report similar findings while Akyol (2009) reports that the mental models of pre-service teachers are mostly compatible with the Rutherford Model. Along the same lines, Muştu (2021) reports that pre-service teachers are highly open to developing concept maps for the atom.

A majority of undergraduate students still have simple mental models at the beginning of education and continue to do so, albeit at a lower rate, however; the mental models could evolve to the Bohr Atom Model with negative affective approaches disappearing subsequently.

Finally, a significant relationship emerged between the level of education and the compatibility of students' mental models with scientific models (Table 13). Accordingly, it could be argued that the level of education significantly affects the mental models for the concept of the atom.

5. Conclusion

In summary, secondary school students develop mental models compatible with the Dalton Atomic Model, which is contrary to expectations and such tendency generally evolves to a construct compatible with the Bohr Atomic Model in further stages. Similarly, students generally begin to develop mental models for the concept with a structure such as a solid sphere or black spot by evolving into spheres containing spaces and charges at the high school level, while undergraduate students make use of mobile systems and charges moving in orbits independent of the nucleus. On the other hand, students perceive the atom as a dangerous phenomenon emotionally at the secondary school level and continue to do so, albeit at a diminishing pace, even until the end of high school level and such tendency ends at the undergraduate level. One may also notice that students have important misconceptions in their mental models of the atom at almost every level during their education in terms of conceptual and visual structures, and such misconceptions continue at the undergraduate level.

Finally, based on the findings the following recommendations are given for a huge contribution to the literature:

- Although the concept of the atom is taught to the students in accordance with the Modern Atomic Theory, an explanation should be provided for the reasons why their mental models begin to form in accordance with the Dalton Atomic Model.
- Researchers are recommended to unearth the reasons why students do not reach Modern and Quantum Atomic Theories during the teaching process.

- Researchers are recommended to reveal the reasons why students perceive atoms as dangerous emotionally at the beginning of the teaching process.
- Researchers are recommended to eliminate the misconceptions of pre-service teachers in undergraduate education and to design sample applications for the correct construction of the atomic concept and test the effects.

References:

Adbo, K., & Taber, K. S. (2009). Learners' mental models of the particle nature of matter: A study of 16-year-old Swedish science students. International Journal of Science Education, 31(6), 757-786.

Allred, Z. D. R., & Bretz, S. L. (2019). University chemistry students' interpretations of multiple representations of the helium atom. Chemistry Education Research and Practice, 20(2), 358-368.

Akyol, D. (2009). Fen alanlarında öğrenim gören üniversite öğrencilerinin zihinlerindeki atom modellerinin incelenmesi [Examination of the atomic models in the minds of university students studying science.]. Yayımlanmamış Yüksek Lisans Tezi, Dokuz Eylül Üniversitesi Eğitim Bilimleri Enstitüsü, İzmir.

Alkan, M. (2022). Ortaokul 7. sınıf öğrencilerinin atom kavramına ilişkin algılarının metafor aracılığıyla belirlenmesi [Determination of secondary school 7th-grade students' perceptions of the concept of the atom through metaphor]: Aksaray,(Master's thesis, Aksaray Üniversitesi Fen Bilimleri Enstitüsü). Aksaray.

Ayvacı, H. Ş., Bebek, G., Alper, A. T. İ. K., Keleş, C. B. & Özdemir, N. (2016). Öğrencilerin sahip oldukları zihinsel modellerin modelleme süreci içerisinde incelenmesi: Hücre konusu örneği [Examination of the mental models that students have in the modeling process: A case study of cell topic]. Dicle Üniversitesi Ziya Gökalp Eğitim Fakültesi Dergisi, (28), 175-188.

Baji, F., & Haeusler, C. (2021). Introducing Iranian primary children to atoms and molecules. Research in Science Education, 1-32.

Bilir, V., & Karaçam, S. (2021). Evaluation of mental models of prospective science teachers on chemical reactions. Journal of Pedagogical Research, 5(1), 258-274.

Büyüköztürk, Ş., Çakmak, E. K., Akgün, Ö. E., Karadeniz, Ş., & Demirel, F. (2010). Bilimsel araştırma yöntemleri [Scientific Research Methods](5. bs.). Ankara: Pegem Akademi, 109.

Coll, R. K., & Treagust, D. F. (2001). Learners' mental models of chemical bonding. Research in science education, 31(3), 357-382.

ÇÖKELEZ, A., & YALÇIN, S. (2012). İlköğretim 7. sınıf öğrencilerinin atom kavramı ile ilgili zihinsel modellerinin incelenmesi [Examination of the mental models of primary school 7th-grade students for the concept of atom.]. İlköğretim Online, 11(2), 452-471.

Derman, A., Koçak, N., & Eilks, I. (2019). Insights into components of prospective science teachers' mental models and their preferred visual representations of atoms. Education Sciences, 9(2), 154.

Fainsilber, L., & Ortony, A. (1987). Metaphorical uses of language in the expression of emotions. Metaphor and Symbol, 2(4), 239-250.

Gilbert, J. K. (2004). Models and modelling: Routes to more authentic science education. International Journal of Science and Mathematics Education, 2, 115-130.

Harrison, A. G., & Treagust, D. F. (1998). Modelling in science lessons: Are there better ways to learn with models?. School Science and Mathematics, 98(8), 420-429.

Kaya, A. (2018). Ortaöğretim öğrencilerinin atom kavramını anlama seviyelerinin tespiti

[Determination of the level of understanding of the atomic concept of secondary school students]. Muğla Sıtkı Koçman Üniversitesi Eğitim Fakültesi Dergisi, 5(1), 1-9.
Lubart, T. I., & Getz, I. (1997). Emotion, metaphor, and the creative process. Creativity research journal, 10(4), 285-301.
Lakoff, G., & Johnson, M. (1980). The metaphorical structure of the human conceptual system. Cognitive science, 4(2), 195-208.
Mustu, Ö. E. (2021). Qualitative Evaluation of Prospective Science Teachers' Concept Maps about the Atom. International Journal of Progressive Education, 17(1), 158-171.
Muştu, Ö. E., & Ucer, S. (2018). Investigation of secondary school students' cognitive structure about the concept of the atom through the drawing technique [Ortaokul öğrencilerinin atom kavramına ilişikin bilişsel yapılarının çizim tekniği ile incelenmesi]. Journal of Human Sciences, 15(2), 984-995.
Norman, D. A., Gentner, D., & Stevens, A. L. (1983). Mental models. Human-computer Interaction, chap. Some Observations on Mental Models, 7-14.
Özgür, S. (2007). Atom Kavramının Epistemolojik Analizi ve Öğrencilerin Konu İle İlgili Kavram Yanılgılarının Karşılaştırılması [Epistemological Analysis of the Concept of the Atom and Comparison of Students' Misconceptions about the Subject]. Physical Sciences, 2(3), 214-231.
Sarıdaş, N., & Ünsal, Y. (2020, September). Ortaöğretim 12. Sınıf Öğrencilerinin Atom Kavramına Yönelik Zihinsel Modellerinin İncelenmesi [Investigation of Secondary School 12th-grade Students' Mental Models for the Concept of Atom]. In 5. International EMI Entrepreneurship and Social Sciences Congress Proceedıngs E-Book (p. 462).
Schwarz, C. V., & White, B. Y. (2005). Metamodeling knowledge: Developing students' understanding of scientific modeling. Cognition and instruction, 23(2), 165-205.
Şahin, Y., & Kurucu, Y. (2005). Atom fiziği [Atomic physics]. Pegem A Yayıncılık. Ankara.
Teller, A. (1994). The evolution of mental models. Advances in genetic programming, 199-219.
Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. Cognitive psychology, 24(4), 535-585.